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Evaluation of Cowpea Genotypes for Drought Tolerance Using the Pot Screening Approach

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Background: Tolerance to drought is crucial for cowpea producers in Northern Ghana, where the bulk of the crop is produced

Aims: To assess Five cowpea genotypes for their tolerance to drought at various stages of development.

Study Design: Randomized complete block design was used for the study.

Place and Duration of Study: The study was carried out in pots over a three-month period at the Savanna Agricultural Research Institute, Tamale-Northern Ghana.

Methodology: The study made use of factorial experiment in randomized complete block design using two factors (genotypes and water stress regimes). Treatment combinations were replicated three times. Genotypes were subjected to moisture stress at either the vegetative, flowering or pod filling stages. A well-watered control was included.

Results: Though the analysis of variance indicated significant main effects for genotype and moisture stress for a number of traits studied, no significant interactions between the two factors were evident for the traits studied. Moisture stress significantly reduced the number of pods per plant and grain yield. Moisture stress imposed during the vegetative phase has the most significant reduction in grain yield and number of pods per plant compared to the irrigated control. In general, the correlation coefficients were weak and not statistically significant. All the significant correlation

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coefficients were positive and were found between grain yield and its components. Also, the relationship between susceptibility to moisture stress and yield potential was investigated by correlation and regression analysis. This study indicated a significant positive relationship between susceptibility to moisture stress and yield potential.

Conclusions: No single genotype was found to be most tolerant to drought for all the three growth stages in which drought was imposed. The study, therefore, emphasised the difficulty in combining high yield potential and drought tolerance in development cowpea genotypes.

Keywords: Cowpea; moisture stress; susceptibility index; trait correlations.

1. INTRODUCTION

Cowpea (*Vigna unguiculate*) (L) (Walp) is one of the earliest grain leguminous crops grown in semiarid West Africa where rainfall is typically low (300 – 600), erratic in time and space and unreliable [1]. Cowpea is an annual crop that is adapted to warm conditions and sensitive to chilling. Consequently, it is cultivated in the tropics and subtropics during the warm season.

Cowpea is also a source of employment to the majority of people in developing countries in the tropics. The grain has a high protein content of about 20-30% and 20-35% starch [2]. The young leaves, juvenile pods and peas are used as vegetables, whilst various snacks and meals are prepared from the grain. The above ground parts are harvested and used as to feed animals. The haulms too are used to feed livestock mostly during the dry season and can also be incorporated into the soil to enhance fertility [3].

Worldwide production of cowpea is estimated at three million tonnes [4], from 12.5 million hectares with 64% of this in Central and West Africa [5].

The major areas of production in Ghana comprise the Guinea and Sudan Savanna ecologies.

Cowpea is the second most important grain legume after peanut in Ghana and plays an important role in the economy and diet of urban and rural poor [6].

Cowpea production is constrained by a range of biotic and abiotic factors. In particular, insect pests damage the crop from seedling emergence to storage [7]. In addition, diseases caused by viruses, fungi and bacteria cause substantial yield losses. Bacterial blight (*Zanthomonas compestris* pv *vignicola* (Burkholder) Dye), Fusarium wilts (*Fusarium oxysporium* Schlechtend) and *Cercospora* leaf spots *(Cercospora canescents* Ellis and G. Martin) are particularly important in the wetter and rain fed areas of production. The parasitic weed, *Striga gesnerioides* (Wild) Vatke is also an important constraint to production and can also reduce grain yields of up to 80% for susceptible cultivars [8]. The timing and intensity of drought relative to the crop's life-cycle to high night temperatures, are important limitations to sustainable cowpea production.

In Ghana research on cowpea is conducted by two major research institutes, Savannah Agricultural Research Institute (SARI) which has its mandate for the Northern Sector and the Crop Research Institute (CRI) which has its mandate for the Southern Sector.

The recommended practices given to farmers by research stations in the northern regions of Ghana are that, farmers are advised to use clean seeds with no insect damage to obtain good plant stand. Planting should be planned in such a way that maturity will coincide with the dry season. In northern regions, if the variety is early maturing, planting should be done from April to May or July to August. For the medium maturing varieties, planting should be done from April to May or July to mid-August. In the transitional zone, early maturity type should be planted in March to April in the major season and from August to September for the minor season. In the coastal savannah, the early maturing types can be planted from April to September. For erect/semi erect types a spacing of 60 cm x 20 cm is recommended whereas 80 cm x 20 cm should be used for the prostrated types. As a general rule cowpea is normally planted at a time that will allow the maturity of the pods to coincide with the dry weather. The optimum planting date depends on the agro-ecology [9]. Substantial variability exists among genotypes of cowpea thus making it adaptable to a wide range of cropping systems in their areas of production. Genotypic differences have been acknowledged for all stages of phenological development of the crop, form emergence to pod maturity, in pigmentation and yield attributes [10,11]. In the production systems, the spreading indeterminate bushy growth of cowpea provides ground cover, hence overpowering weeds and prevent soil erosion. It also fixes atmospheric nitrogen into the soil thereby improving soil fertility. Significant differences in drought tolerance between cowpea varieties have been suggested but the evaluation of this draught tolerance of cowpea in the field is very slow, arduous and could provide inconsistent results. Identification of varieties that can endure unfavorable environments such as drought would be integral for farmers in the Northern Ghana.

The present study, therefore, seeks to evaluate five genotypes of cowpea for tolerance to vegetative and reproductive stage drought stress in pots.

2. MATERIALS AND METHODS

Five cowpea genotypes were assessed for their tolerance to drought at various stages of growth. The study was carried out in pots over a three-month period.

2.1 Characteristics of Genotypes Used in the Study

Five genotypes of cowpea were received from the Savanna Agricultural Research Institute (SARI). One genotype Apagbaala is a cultivar recommended for Northern Ghana and was developed by the SARI, whereas the International Institute of Tropical Agriculture (IITA) developed the other four varieties. These include IT 87D-885, IT 94K-440-3, IT 96D-610 and IT 98K-128-4. All the genotypes are photo insensitive.

2.2 Site Description and Geographical Location of Study Site

The study was carried out at SARI, Nyankpala. Nyankpala is located in the Northern Guinea Savanna Zone with a mean annual rainfall of about 1000 mm. it is located on latitude 9º25'N and longitude 0º, 58'W at an altitude of 183 m above sea level. The mean annual surrounding temperature is 28.3ºC and an annual relative humidity of 54%. The relative humidity is variable, falling during the dry season and rising during the rainy season.

2.3 Sowing and Crop Management

The soil used for the study was brown, moderately drained and sandy loam. It was free of concretions. Soil samples collected from the field, were air-dried and sieved by passing soil through a 2 mm sieve. The sieved samples were weighed and kept in pots. Five genotypes of cowpea were planted in the pots of dimension 21mm by 16.5mm.

Each pot contained approximately 6.5kg of soil. The soil in each pot was watered to field capacity before planting was done. The plants were watered daily until the drought regime began with the exception of the control which was continuously watered throughout the experiment. Spraying was done with The insecticide lambda cyhalothrin (Product Karate, Zeneca Agricultural Products, Wilmington, DE, USA) at the rate of 20 g active ingredient to control pre and post flowering insect pests.

2.4 Experimental Design

The study made use of a factorial experiment in a randomized complete block design using two factors. The factors were five genotypes of cowpea and four drought regimes. The treatment combinations were replicated three times. There were six pots per genotype per replication for each drought stress level. Four seeds were planted in each pot and thinned to two plants per pot two weeks after planting. The distances in nursery pots were 30cm within rows and 40cm between rows.

2.5 Drought Stress Treatment

Genotypes were subjected to three drought regimes (vegetative, flowering and pod filling stages) and a well-watered control. The soil in each pot was watered to field capacity before planting. Vegetative stage drought began at three weeks after planting and lasted for ten days. Flowering stage drought was imposed from the day of the first flower appearance and lasted for 10 days. Four days after the flowering stage drought was terminated for a genotype, the pod filling stage drought was imposed and lasted for 10 days.

2.6 Data Collection

Various data sets were obtained from measurements done for a number of traits.

2.6.1 Plant height

At flowering plant, height was measured on three plants per treatment, taken at the base of the youngest expanding leaf to the soil surface on the main stem. Plant height was taken using a rope and a meter rule. Averages were computed to get the plant height.

3.6.2 Number of Nodules per plant and nodule weight per plant

Two plants were selected per treatment at flowering. The plants were carefully removed from the ports with minimal disturbance to the rooting system and immersed in water to wash off the soil. The nodules removed during flowering stage were oven dried at 60^0C for 72 hours in a hot air oven and weighed.

2.6.3 Shoot weight and root weight

Two plants were randomly sampled in each row and uprooted carefully. The shoot system was separated from the root system and place in labelled envelopes. They were oven dried at 60^0C for 72 hours and weighed.

2.6.4 Shoot weight to root weight ratio

This was determined by the ratio of the shoot weight to the root dry weight.

2.6.5 Number of pods per plant

Pods per plant were taken at maturity. Five plants were sampled for each treatment. The pods from the plants were removed, counted and divided by five to obtain the average number of pods per plant.

2.6.6 Number of seeds per pod

Five plants were randomly selected per treatment. Four pods were removed from each plant, and twenty pods were obtained per treatment. The pods were threshed and the total number of seeds was divided by twenty to obtain an average number of seeds per pod.

2.6.7 Hundred seed weight

The weight of a hundred seeds for each treatment was determined by the use of an electronic scale.

2.6.8 Grain weight

At harvest, the pods were dried in a hot air oven at 60^0C for 72 hours. The pods were threshed and the total yield per genotype was measured the grammes (g) using an electronic scale.

2.6.9 Harvest index

This was determined by the relation:

$$\frac{Grain\ weight}{Pod\ weight + shoot\ weight + root\ weight} \times 100\%$$

2.6.10 Stress susceptibility Index

This was determined by the relation:

$$\frac{1-\frac{Ys}{Yws}}{1-\frac{\bar{Y}s}{\bar{Y}ws}} (Fisher\ and\ Maurer, 1978)$$

Where;

$1-\frac{\bar{Y}s}{\bar{Y}ws}$ = Stress intensity
Ys = Yield under stress
Yws = Yield without stress
$\bar{Y}s$ = Mean yield of all genotypes under stress
$\bar{Y}ws$ = Mean yield of all genotypes without stress

2.7 Data Analysis

The data collected were subjected to analysis of variance (ANOVA) using Genstat discovery Edition version 12. Treatment means were separated by the least significant difference (LSD) method. Association between traits studied was examined by calculating the simple correlation coefficient. The relationship between stress susceptibility and yield potential was determined by regressing stress susceptibility index of genotypes on the genotypic yield obtained under well-watered conditions.

3. RESULTS

Soil moisture stress effect on cowpea growth and yield was investigated in a pot experiment that involved five cowpea genotypes and four moisture stress regimes. The moisture stress treatments include 10 days of moisture stress at either the vegetative, flowering or pod filling phases, and a well-watered control. Though the analysis of variance indicated significant main effects for genotype and moisture stress for a number of the traits studied, no significant interaction between the two factors was evident for any of the traits studied.

3.1 Genotype and Moisture Stress Effects on Vegetative Growth Components

The growth components studied include plant height at flowering, root weight and shoot weight taken at pod maturity. Significant differences among the moisture stress treatments were evident for all three traits, whereas the genotype effect was significant for plant height only (Table 1).

The significant effect of genotype for plant height was due mainly to the shorter height for Apagbaala (16.1cm) that was significantly lower than the other four varieties (20.4-22.8) between which no significant differences were observed. Moisture stress significantly increased plant height with the most significant increase observed for stress imposed during the vegetative phase (Table 2). Similarly, moisture stress reduced total biomass production (root and shoot weight) and the effect was most severe with vegetative stage stress compared to moisture stress at the flowering and pod filling phases. Moisture stress imposed during the flowering and pod filling stages had no apparent effect on root biomass.

3.2 Genotype and Moisture Stress Effects on Reproductive Growth Components

Six components of reproductive growth were assessed and include length of matured pods number of pods per plant, number of seeds per pod, hundred seed weight, harvest index and grain yield. Genotype main effects were significant for all traits except grain yield and harvest index. Harvest index ranged from 76.9% in IT 87D-885 to 79.9% in IT96D-610, whereas grain yield was in the range of 27.6g/plant in IT 87D-885 to 33.4g/plant in IT 98K-128-4. Apagbaala had the shortest pods that were significantly different from those of IT 98K-128-4 (Table 3). The other three varieties had similar pod lengths. The number of seeds per pod was also lowest in Apagbaala and highest in IT 94K-440-3. Except for IT 87D-885 that had fewer pods per plant of 16. The number of pods per plant was not different between the other genotypes. Seed size estimated by the weight of hundred seeds was largest in IT 8 7D-885 and least in IT 94K-440-3.

The influence of moisture stress treatments on reproductive growth components was evident on only the number of pods per plant and grain yield. No significant differences were recorded between stress treatments for the other four reproductive stage traits. Moisture stress imposed during the vegetative phase had the most significant reduction in grain yield and number of pods per plant compared to the irrigated control (Table 4). Drought imposed during the flowering and pod filling stages had similar grain yields and number of pods and were only marginally lower (statistically) compared to the control.

3.3 Genotype and Moisture Stress Effects on Nodulation

Nodulation was assessed in terms of number of nodules per plant and dry weight of nodules per plant. No significant genotype or moisture stress effect was observed for the number of nodules per plant. This was so in spite of the wide range of 10 nodules per plant for IT 94K-440-3 to 16 nodules per plant observed for IT 87D-885, due to the large coefficient of variation observed for nodulation traits (Table 1). Significant moisture stress effects were evident for the dry weight of nodules per plant with an almost two-fold variation between vegetative stage moisture stress (54mg/plant) and flowering stage stress (104mg/plant). Surprisingly, nodule weight was similar for the control and moisture stress at the pod filling stage (58mg/plant).

3.4 Trait Relationships

Relationship between recorded traits was studied using simple correlation coefficients. In general, the correlation coefficient was weak and not statistically significant. All the significant correlation coefficients were positive and were mainly between grain yield, pods per plant, shoot weight and seeds per pod (Table 5). Nodule dry weight also showed significant positive correlation with root weight and shoot weight.

Table 1. Mean squares and levels of significance for various plant traits obtained from analysis of variance

	Vegetative growth components				Reproductive growth components						Nodulation trains	
Factors	**Plant height**	**Shoot weight**	**Root weight**	**Pod length**	**Pods/plant**	**Seeds/pods**	**100 seed weight**	**Harvest index**	**Grain yield**	**Nodules/ plant**	**Nodule dry weight**
Genotype	82.42*	0.49	0.11	16.85**	235.62*	9.51*	26.79**	18.83	70.32	71.93	0.16x10-2
Moisture stress	117.26**	47.67**	0.41*	2.38	500.05*	7.12	2.12	23.31	905.50**	63.78	0.83x10-2
CV%	10.65	37.00	35.90	9.20	25.74	4.10	3.10	6.76	27.60	40.56	40.35

** = P<0.05; ** = P<0.01; ns= not significant*

Table 2. Effect of moisture stress imposed at various growth phases on plant height, shoot and root weight in cowpea

Growth stage	Plant height (cm)	Shoot weight (g)	Root weight (g)
Vegetative	19.7	4.5	0.6
Flowering	24.2	8.0	0.9
Pod filling	20.3	6.8	0.9
Control	17.5	8.5	0.9
Mean	20.4	7.0	0.8
LSD (0.5)	3.12	2.44	0.27

Table 3. Genotype and main effects for some reproductive stage traits of five cowpea genotypes evaluated under moisture stress at various stages of growth

Genotype	Hundred seed weight (g)	Pod length (cm)	Pods per plant	Seeds per pod
Apagbaala	14.0	14.1	23.0	11.9
IT 87D-885	17.2	16.9	16.1	13.3
IT 94K-440-3	13.4	16.6	23.4	14.3
IT 96D-610	15.5	16.7	24.5	12.6
IT 98K-128-4	14.4	18.3	29.3	13.1
Mean	14.9	16.7	23.1	13.0
LSD (0.05)	0.89	1.26	6.8	1.41

Table 4. Influence of water stress regime on different growth stages on grain yield and pods per plant

Growth stage	Grain yield (g/plant)	Pods per plant
Vegetative	20.1	15.4
Flowering	31.9	24
Pod filling	30.1	22
Control	38.9	29.3
Mean	30.2	23.1
LSD (0.5)	8.35	6.08

Table 5. Pearson correlation coefficients between traits assessed on five cowpea genotypes evaluated under four moisture regimes

	Grain weight	Hundred seed weight	Plant height	Nodule weight	Pod length	Pod per plant	Root weight	Shoot weight	Seeds per pod
Grain weight	1.000								
Hundred seed weight	-0.082	1.000							
Plant height	-0.175	0.064	1.000						
Nodule weight	0.147	0.064	0.364	1.000					
Pod length	0.341	0.253	0.171	-0.172	1.000				
Pods per plant	0.921**	-0.348	-0.247	0.095	0.272	1.000			
Root weight	0.633**	0.055	0.045	0.505*	0.341	0.533*	1.000		
Shoot weight	0.553**	-0.132	0.168	0.463*	0.075	0.411	0.661**	1.000	
Seeds pod	0.574**	-0.079	0.434	0.044	0.347	0.394	0.259	0.521	1.000

** = P<0.05; ** = P<0.01; ns= not significant*

3.5 Moisture Stress Susceptibility among Genotypes

Susceptibility of a genotype to moisture stress for each drought treatment was estimated using formula described by Fischer and Maurer (1978) and based on grain yield. The stress intensity was highest for stress imposed during the vegetative phase and least for the flowering stage stress. The stress susceptibility index for a genotype indicates the relative susceptibility to moisture stress for a particular moisture stress treatment. Between genotypes, the larger the index, the more susceptible the genotype to moisture stress. For moisture stress imposed at the vegetative and pod filling stages, Apagbaala was the most tolerant to stress followed by IT 87D-855 (Table 6). IT 87D-885 was however the most drought tolerant when stress was imposed during the flowering stage. Averaged across drought stress treatments, IT 87D-885 was the most tolerant to moisture stress followed by Apagbaala and with IT 94K-440-3 being the least drought tolerant.

Table 6. Stress susceptibility index for five cowpea genotypes evaluated under three drought regimes

Genotype	Stress susceptibility index			
	Vegetative stage stress	Flowering stage stress	Pod filling stress	Average over life cycle
Apagbaala	0.402	1.030	0.011	0.481
IT 87D-885	0.721	0.027	0.149	0.299
IT 94K-440-3	1.110	1.389	2.126	1.542
IT 96D-610	1.284	0.7622	1.605	1.217
IT 98K-128-4	1.225	1.483	0.541	1.083
Mean	0.948	0.938	0.886	0.924
LSD (0.05)	0.168	0.262	0.417	0.232

Table 7. Pearson correlation coefficient between stress susceptibility index and genotype yield potential

Growth stage	Correlation coefficient	Probability
Vegetative	0.90	0.034
Flowering	0.69	0.194
Pod filling	0.80	0.103

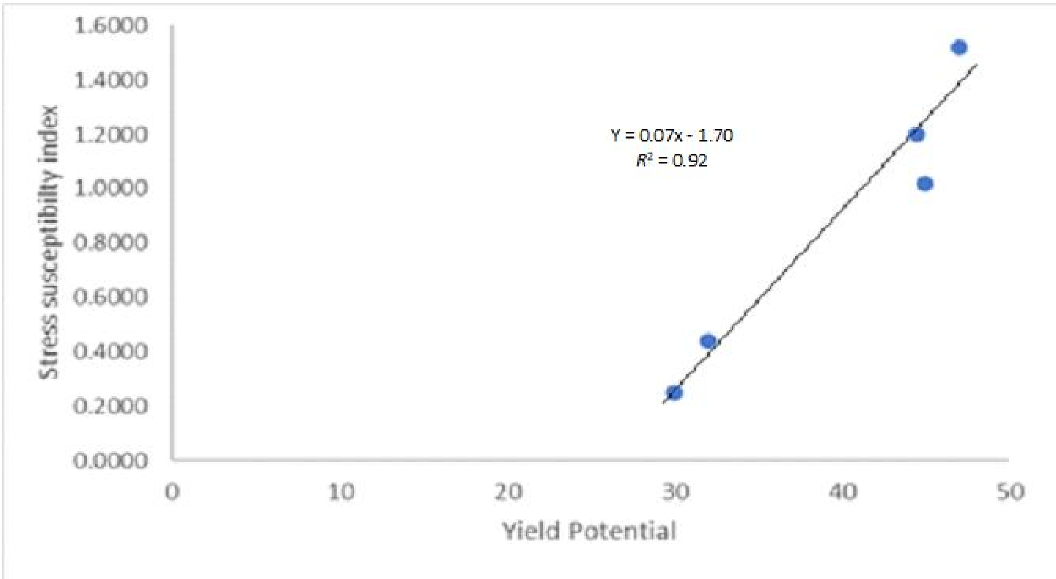

Fig. 1. Relationship between genotype moisture and stress susceptibility index averaged over life cycle and grain yield potential

The relationship between susceptibility to moisture stress and yield potential was investigated by correlation and regression analyses. Simple correlation between moisture stress susceptibility and yield without moisture stress revealed significant positive correlation coefficients (Table 7). The same positive relationship was obtained when the average stress susceptibility index was regressed on the grain potential yield (Fig. 1). A high coefficient of determination of R^2=0.92 was obtained.

4. DISCUSSION

Tolerance to moisture stress in field crops grown in savannah regions is an important requirement for farmers since production is mainly rain fed and the occurrence of drought is difficult to predict and to manage.

In the present study, moisture stress influenced both the quantity of dry matter produced and partitioning of dry matter between component parts of the plant. This is evidenced by the reduced shoot biomass of moisture stress treatments compared to the control treatment. When the proportions of the shoot and root dry matter were compared between moisture stress treatments and the non-stress treatment, it was apparent that there was increased dry matter partitioned into the roots relative to the shoot for drought stress treatments. Increased dry matter partitioning to roots under moisture stress has been reported in studies [12,13], and it is believed to be an important adaptive mechanism in field crops to obtained moisture much deeper in the soil profile under drought stress. Also, in the present study, drought stress led to increased length of the main shoot, however, this was associated with a reduced weight of the shoot probably resulting from reduced leaf production and branching under stress. This observation corroborates a similar study in Rice by Fahad et al. [14]. As would be expected, moisture stress imposed during the vegetative phase had the most significant reduction on shoot and root dry weight since it is during the vegetative stage that the plant sets up its architecture to begin reproductive growth [15]. Moisture stress imposed after the plant has set up its components (such as during the flowering and pod filling stage moisture stress) will therefore have limited reduction for the shoot and root biomass since all the genotypes used in the study are determinate and little vegetative growth is expected from the beginning of flowering. Indeed, root dry matter was similar among all moisture stress treatments except that imposed during the vegetative phase. For the stress imposed during the pod filling phase, the reduced shoot biomass when compared to that for the flowering stage stress could be due to the hastening of pod ripening and of leaf senescence resulting from moisture stress during the pod filling stage. A lot of leaves produced might therefore have fallen off before data could be taken on shoot dry weight.

In general, the trait correlations suggest that dry matter production played a significant role in grain yield differences between moisture stress treatments. Moisture stress imposed during the vegetative stage had the lowest biomass production (in terms of shoot dry weight) and was consequently the treatment with the lowest grain yield. This is not surprising since a large shoot system is needed for adequate photosynthesis that will supply needed dry matter for grain development as cowpea grain growth relies on photosynthates made available during reproductive growth [16]. Grain yield therefore showed significant positive correlations with both shoot and root dry weights. Drought stress possibly reduced grain yield through other processes as well. Nodulation was reduced by moisture stress, and a significant positive correlation was observed between shoot dry weight and nodule dry weight suggesting that plants with large shoot system supplied more dry matter for nodule formation since shot dry matter and net photosynthesis are usually positively correlated. This corroborates similar study by Zahran [17] on Rhizobium-Legume Symbiosis and Nitrogen Fixation under Severe Conditions in an Arid climate reported that, the existence of rhizobia population densities in desert soils tend to be lowest under water stressed conditions and increases as the moisture stress is relieved. The significant positive relationship observed in this study between nodule dry weight and shoot dry weight corroborates the results of other studies The results generally indicate that dry matter availability may be limiting under the experimental conditions. Although a number of studies have indicated that drought during the vegetative phase has little effect on cowpea grain yield [16,18], the results of the present study contradict these observations. Differences in the intensity of the imposed moisture stress may account for the differences in the conclusions drawn from the different studies. Genotypic differences were observed for most of the reproductive traits studied, of particular importance to producers is the seed size (estimated by the hundred seed weight) since it is a trait that determines cultivar adoption in West Africa. In West African cowpea trade, large seeded varieties are given a premium and this in turn makes such varieties the cultivars of choice for cowpea farmers [19]. For the limited number of genotypes used in this study, IT 87D-885 will be the cultivar of choice for most farmers based on its large seed size. Though significant differences were observed between genotypes for grain yield components, the often-mutual compensatory effects between yield components [20], led to a lack of significance for differences in grain yield among the genotypes. In spite of the lack of significant differences between genotypes for grain yield, grain yield differences closely match differences in the number of pods per plant such that IT 87D-885 that produced 16 pods had the lowest grain yield compared to IT 98K-128-4 that produced 29 pods per plant and had the highest yield. As would be expected therefore, a significant linear correlation of r=0.92 was observed between grain yield and pods per plant. Genotype tolerance to moisture stress as defined by the stress susceptibility index was not consistent across moisture stress treatments. Apagbaala and IT 887D-885, however, stand out as the most tolerant to moisture stress compared to the other genotypes included in the study. Yield loss due to moisture stress indicated that genotypes with high yield potential were more susceptible to moisture stress compared to those with lower yield potential. This is indicated by the significant positive correlation between yield without stress and stress susceptibility index across drought treatments. This observation corroborates the findings of other studies in field crops that have established an inverse relationship between yield potential and tolerance to stress [15,21]. This inverse relationship between tolerance to drought and yield potential will constrain the development of high yielding genotypes adapted to the Guinea and Sudan Savannah regions which are characterised by a high incidence of drought. Unfortunately, it is in these regions that the bulk of cowpea is produced.

5. CONCLUSIONS

In this study, the effects of drought were made manifest not only in reducing grain yield but also a significant reduction in biomass production. This effect on biomass production re-emphasis the need to have drought tolerant genotypes since cowpea producers in northern Ghana rely on the cowpea biomass for feeding domestic livestock during the dry post-rainy season. Yield and drought tolerance were however found to be negatively correlated in the present study, indicating the challenge faced by cowpea breeders to develop high yielding genotypes with tolerance to drought. The results obtained nevertheless offer scope for developing drought tolerant genotypes since no single genotype was found to be tolerant to drought stress for all the growth stages studied. The indication is that, with a large collection of cowpea lines it may be possible to select the most suitably tolerant genotypes for various growth stages as parents in a hybridisation program. Selection can then be made for progeny that combine tolerance to drought imposed at the various growth stages to develop superior cultivars.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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