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Effects of Moisture Deficit on the Yield of Cowpea Genotypes in the Guinea Savannah of Northern Ghana

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Abstract

Cowpea is multipurpose, leguminous, high protein crop in the tropics that provides food for humans and fodder for animals. The crop adds nitrogen and other nutrients to the soil through symbiotic relationship with rhizobia and direct decomposition of cowpea by-products. Despite its multiple benefits for humankind, the yield of cowpea is far below its potential and its production in the crop's birthplace of Africa is especially affected by abiotic factors. Soil moisture deficit is one of the main abiotic factors that affect the yield of cowpea in the semi-arid tropics, including the Sahelian and Guinea Savannah regions in West Africa. Even though cowpea is a drought tolerant legume, different genotypes respond differently to drought, resulting in up to 100% or more yield increases in the case of resistant genotypes or 50% or more yield loss in case of susceptible types. Mitigating the effect of soil moisture deficit on cowpea production requires selection of genotypes that can withstand drought. With this in mind, the goal of this study was to identify drought tolerant cowpea germplasm for the Savannah region of Northern Ghana using cultivated genotypes from the United States Department of Agriculture (USDA) tested with and without irrigation at the Bontanga irrigation facility during the dry season in 2018. Fifty genotypes were used, which included 45 imported from USDA and five (5) local genotypes from the Savannah Agriculture Research Institute (SARI). The experiment had 2 × 50 factorial treatments (irrigation × genotypes) and consisted of randomized complete block design with three (3) replications per treatment. Two (2) watering regimes were introduced namely, drought stressed (no irrigation) and non-stressed/control (irrigated). Morpho-physiological, phenological and yield data were taken on the cowpeas evaluated with drought tolerance assessed based on grain yield data and derived indices. All parameters measured showed significant differences ($p \le 0.05$) except for the number of branches per plant. Genotypes PI339600, PI527263, PI527302, PI582793, PI582867 and SARI-6-2-6 produced high grain yields under both drought stress and non-stress conditions. These genotypes could be exploited for future breeding programs for developing drought tolerant cowpea varieties for the savannah ecology and other areas with similar environmental conditions.

Keywords

Tolerance, Cowpea, Stress, Selection, Drought

1. Introduction

The cowpea [*Vigna unguiculata* (L.) Walp.] is a vital crop for Africa. It is predominantly grown by small-scale farmers in West Africa, where the crop is crucial to the livelihood and health of the economies and societies of most Sahelian countries from Nigeria and Chad in the east to Senegal in the west [1]. The grain and leaves of cowpea are highly nutritive, serving as a cheap source of protein for rural and urban dwelling consumers [2]. The cowpea grain contains about 25% protein and 64% carbohydrate and substantial quantities of fiber, minerals and vitamins [3]. The grains, leaves or fodder and food processed by-products from the harvest are sold, proving economic benefits for farming households in the region. The crop is often called a hunger crop since it matures early, which allows the edible leaves to be used during the hunger-prone part of the season when food reserves from previous harvest have been depleted and recently planted seeds of other farm crops are not yet ready for harvest. Aside from the grain which is an important human food [4] [5] [6], farmers also sell the fodder of cowpea for animal production. The rotation of cowpeas and livestock create a virtuous circle of legume and grazing animals, with cowpeas serving as green manure or cover crop to improve soil fertility and control erosion throughout the rainy season [5], goats and cattle are feeding on the stems during the dry season. The crop is also capable of fixing atmospheric nitrogen through its root nodules to enhance the nutrient status of the soil for the next crop in a rotation [6] [7]. Cowpea is adapted to the drier and hotter regions of the tropics and subtropics due to its drought tolerant qualities [8]. The crop is a healthy food legume that is considered as an important complement to soybean or groundnut that is high in oil content but lower in fiber [9].

In Ghana, cowpea ranks second to groundnut in terms of consumption [10] [11]. The cultivation of cowpea in Ghana is concentrated in five regions of the country namely Northern, Upper West, Upper East, Brong Ahafo and Ashanti regions [12]. The Northern region is the highest producer of cowpea and Yendi municipality is the highest producer of cowpea among the districts in the

Northern region [12]. However, despite its widespread cultivation and importance, the productivity of cowpea in West Africa is very low. The normal typical yields across the region range from 100 to 500 kg/ha [13]. According to [12], the average yields on farmers' fields in Ghana are between 400 and 600 kg/ha as compared to values of 1600 to 2500 kg/ha of potential yield recorded on research fields. The yield gap is attributed to biotic and abiotic factors affecting the crop's production in the tropics and sub tropics of the world.

Globally, increasing human population has led to higher demands for increased agricultural productivity [14]. The challenges to achieving higher crop yields is further compounded by drought and heat stress resulting from climate change [15]. Terminal and intermittent drought are known to cause substantial crop yield reduction due to their negative impacts on plant growth, physiology and reproduction [16]. The main effect of drought stress is the reduction of crop yield [17] [18] [19] through reduction in biomass [20] and seed weight. Shoot and root growth by plants are also limited by terminal and intermittent drought [21]. Drought is a complex phenomenon [22] dependent on the type of soil and rainfall patterns on agricultural lands but mostly is always responsible for major yield losses in the case of cowpea. The effect of drought varies with the duration and intensity of moisture deficits resulting from irregular or shortage of normal rainfall or late rains and late plantings that are affected by the prolonged drought of the dry season [23].

Cowpea is known to be a drought tolerant crop [24]. However, the crop still suffers from yield losses from intermittent and terminal drought in its main growing environments. As a result, genotypes that can grow and produce appreciable yield under drought conditions are required for increased yields. Researchers and plant breeders have made efforts to identify cowpea varieties with enhanced levels of drought and heat tolerance, as well as high biological nitrogen fixation [6] but generally this work has been conducted with local germplasm rather than introduced genotypes. The aims of this study were: 1) to introduce cowpea accessions into Northern Ghana from the USDA germplasm collection, as this is publicly available set of plant introductions from around the world; and 2) to identify drought tolerant cultivars among the USDA genotypes compared to local control varieties for use in future breeding programs in order to gain maximum genetic recombination and development of drought tolerant varieties suitable for Ghana and other African countries. Given the importance of cowpea in ensuring food and nutritional security in many developing countries, there is the need to develop and/or select available germplasm for improved yields.

2. Materials and Methods

2.1. Experimental Site

The research was conducted at the Bontaga station field in the Kumbungu district within the guinea savannah ecology in the northern region of Ghana. Bontaga is located at western part of Kumbungu on latitude 9.583884 and longitude −1.023843, and at an altitude of 116 m above sea level. Planting of the cowpea genotypes was done on 3rd February 2018 during the dry season. The Bontaga station has a water source and irrigation facilities, allowing different levels of irrigated treatments to be compared at the same site. The area has a unimodal rainfall of 1100 mm per annum which occurs between May and October each year [25]. The soil being a sandy loam does not retain water well.

2.2. Source of Cowpea Seeds Used

The experiment included a total of 50 cowpea genotypes. Of these, 45 genotypes were selected from United States Department of Agriculture (USDA) germplasm and five (5) from the Savannah Agricultural Research Institute (SARI), Ghana. The USDA genotypes were all plant introductions (PIs) selected based on their survival and yield potential under drought stress from an earlier seed multiplication field trial.

2.3. Irrigation Levels Used and Experimental Design

The experiment involved the 50 genotypes and two levels of water supply. A non-stress (NS) treatment was based on full supply of irrigation water (every 3 days) throughout the growing period. This treatment was considered as control for high productivity compared to a drought stress (DS) treatment which involves the terminal withdrawal of irrigation water at flowering. The combination of genotypes x irrigation regimes resulted in 100 treatment combinations. The treatments were planted as a randomized complete block design with three (3) replications per treatment. Seeds were planted on 2 m × 1.2 m plots using inter and intra row spacings of 60 cm and 20 cm, respectively. Weeds were manually controlled.

2.4. Soil Data

Before planting, soil samples were collected from holes dug from the surface to a 30 cm depth across 5 different points chosen at random from the experimental site. The soil samples were mixed, and subsamples analyzed for chemical properties such as pH (H_2O), organic carbon [26], total nitrogen (Kjeldahl method), phosphorus (P) concentration using Bray-2 [27], K, Na, Ca, Mg, S concentrations were also estimated. Finally, cation exchange capacity (CEC) was measured using ammonium acetate method according to [28]. Soil texture was also determined.

2.5. Morpho-Physiological Plant Data

The morpho-physiological data on each cowpea genotypes were monitored by recording the following parameters: 1) plant height (PLHT), measured at mid pod filling stage on five plants per plot using a meter stick; 2) number of branches per plant (NBP); 3) number of leaves per plant (NLP); 4) number of pods per plant (PDPL) were measured by randomly selecting five plants per plot; 5) dry shoot weight (DSW) was measured on two (2) plants after oven-drying at 65˚C for 48 hours. Means were calculated from two plants per plot for each measurement.

2.6. Phenological Data

Days to flowering was recorded when 50% of the plants in a plot had at least one opened flower. Days to maturity was calculated based on the number of days from sowing to physiological maturity of at least 90 percent of the plants in a plot.

2.7. Yield and Yield Components

In addition to pods per plant (PDPL), the following yield traits were measured total seed yield (YLDH) and hundred (100) seed weight (100 SW), both recorded on per plot basis using sensitive digital balance. The 100 SW was based on a random sample taken from the total yield. Finally, yield was corrected based on seed moisture content determined with a seed moisture meter (Dickey John Corporation, USA). The grain yield per plot was converted to yield per hectare using plant population after adjusting to 12% moisture content.

2.8. Drought Indices

Eight (8) indices were derived from the original data by comparing NS and DS treatments.

1) Drought Intensity Index (DII) = $1-\dfrac{\text{YDS}}{\text{YNS}}$ (1) [29]

2) Stress Susceptibility Index (SSI) = $\dfrac{1-\left(\dfrac{\text{YDSi}}{\text{YNSi}}\right)}{1-\left(\dfrac{\text{YDS}}{\text{YNS}}\right)}$ or $\dfrac{1-\left(\dfrac{\text{YDS}}{\text{YNS}}\right)}{\text{DII}}$ (2) [29]

3) Stress Tolerance Index (STI) = $\dfrac{\text{YDSi}*\text{YNSi}}{(\text{YNS})^2}$ or $\dfrac{\text{YDSi}*\text{YNSi}}{\text{YNS}*\text{YNS}}$ (3) [30]

4) Mean Productivity (MP) = $\dfrac{\text{YDSi}+\text{YNSi}}{2}$ (4) [31]

5) Geometric Mean Productivity (GMP) = $\sqrt{\text{YDSi}\times\text{YNSi}}$ (5) [30]

6) Yield Index (YI) = $\dfrac{\text{Ydsi}}{\text{Ys}}$ (6) [32]

7) Yield Reduction Rate (YRR) = $\left(\dfrac{\text{YNSi}-\text{YDSi}}{\text{YNSi}}\right)\times 100$ (7) [31]

8) Yield Stability Index (YSI) = $\dfrac{\text{YDSi}}{\text{YNSi}}$ (8) [33]

where DS =drought stress, NS = non-stress, DSi = drought stressed individual, NSi = non stressed individual, YDSi = yield of drought stressed individual and YNSi = yield of non-stressed individual.

2.9. Statistical Analysis

Phenotypic data collected from the field experiment were subjected to analysis of variance using GENSTART version 12 after the data was tested for normality. Means of treatments that were significantly different from each other were separated using a Fisher's protected least significant difference (LSD) means comparison method.

3. Results

3.1. Weather and Soil Conditions

Relative humidity, rainfall and average temperature during the experimental period are presented in **Figure 1**. The soil was sandy loam in texture with a pH of 5.89 and low organic matter. Organic carbon was found to be 0.82%, Nitrogen was 0.08%, phosphorus was 7.15 mg/kg, potassium was measured at 0.22 cmol/kg, and the cation exchange capacity of the soil was 5.17 cmol/kg. Rainfall was scant during the entire experiment with one event of less than 10 mm at 70 days after planting. Average Daily temperatures ranged from 29˚C to 32˚C during the growing season with minimum and maximums of 26.25˚C and 34.65˚C respectively. Relative humidity was low (25%) in February, increasing in March to 50% and April to 70%. All experimental plots were supplied with water to field capacity until emergence of flower buds. Thereafter, moisture stress was imposed on the appropriate DS plots, while watering was continued for the NS plots.

3.2. Genetic Variability of Cowpea Genotypes in Response to Water Stress

ANOVAs showed that the genotypes showed significant variation in the number of days to flowering and maturity, dry shoot weight, number of branches and leaves, number of pods per plant, hundred seed weight and grain yield (**Table 1**).

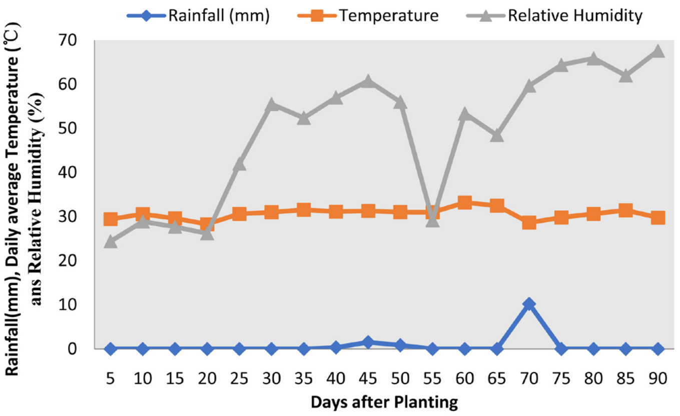

Figure 1. Climatological conditions of rainfall, relative humidity and average daily temperature across the growing season for 50 cowpea genotypes at the site of Bontaga field station in the Kumbungu district within the guinea savannah ecology in the northern region of Ghana.

Table 1. Analyses of variance results for 50 cowpea genotypes evaluated at two irrigation levels, with means squares of biomass, yield and yield component traits and reduction of trait means under drought stress (DS) versus non-stress (NS) conditions.

Source of variation	DF	DM	DSW	HSW	NBplt	NLplt	NPplt	YLDha
Genotype (df = 49)	24.28***	42.47***	3031.3***	78.76***	2.46***	2166***	168.30***	11,658,008***
Treatment (df = 1)	1430.08***	12,168.10***	52,323.9***	12.41***	0.19ns	70334.1***	12,802.07***	100,312,405***
G * T (df = 49)	24.15***	36.79***	1075.5***	7.94***	1.86***	673.3***	84.68***	1,244,491***
Residual (df = 198)	2.79	2.68	165.9	1.24	0.49	217.8	9.61	663,390
Mean	43.34	64.52	65.05	11.23	3.92	67.56	17.43	2090
SED	1.67	1.64	12.88	1.11	0.70	14.76	3.1	814.5
CV	3.9	2.5	19.8	9.9	17.9	21.8	17.8	39.0
NS	45.52	70.89	78.25	11.44	3.94	82.88	23.96	2668.12
DS	41.15	58.15	51.84	11.03	3.89	52.25	10.90	1511.7
% Reduction	9.60	17.97	33.75	3.58	1.27	36.96	54.51	43.33

***Significant at $P \leq 0.001$, ns = not significant. Abbreviations: NS = Non-Stress, DS= Drought Stress, df = Degree of freedom, G = Genotype, T = Treatment, DF = Days to flowering, DM = Days to maturity, DSW = Dry shoot weight, HSW = Hundred seed weight, NBplt = Number of branches per plant, NLplt = Number of leaves per plant, NPplt = Number of pods per plant and YLDha = Grain yield per hectare.

All measured traits were significantly affected by the drought treatment except for the number of branches per plant. The interaction between watering regime and genotypes showed marked influences on all the traits measured. The interaction between water regime and genotypes was highly significant, with drought stress consistently reducing the performance of the genotypes tested.

3.3. Physiological Response of Cowpea Genotypes to Water Stress

The number of days to flowering and maturity of the genotypes was influenced by watering regime. The drought stressed genotypes consistently flowered and matured earlier (Table 2). Flowering among genotypes ranged from 38 to 52 days after sowing, with a mean of 43 days. The number of days to maturity ranged from 56 to 82 days after sowing, with a mean of 65 days. Genotypes PI583182 and PI583209 flowered earlier while PI582867 flowered late. As a result, genotypes PI583182 and PI293463 matured earlier compared to other genotypes while genotypes SONGOTRA and PI354466 matured late. Exposing the test genotypes to drought caused 9.6% and 18.0% reduction in the number of days to flowering and maturity, respectively.

The growth and development of the plants varied significantly among genotypes and was also markedly influenced by the watering regime used. For example, the number of leaves showed significant variation between treatments, with values ranging from 22 to 125 leaves per plant. The DS plants recorded 52.3 lower number of leaves per plant compared to control plants under NS conditions. However, there was no significant effect of watering regime on the number of branches per plant and only 1.3% reduction was observed between treatments despite significant genotypic differences for this trait.

Table 2. The means for days to flowering (DF), days to maturity (DM), number of branches per plant (NBplt) and number of leaves per plant (NLplt) for 50 genotypes of cowpeas grown in Northern Ghana under drought stress (DS) and non-stress (NS) conditions. Values (Mean ± SE) followed letters in a column are significantly different at p ≤ 0.05.

Genotype	Non-Stress				Drought Stress			
	DF	DM	NBplt	NLplt	DF	DM	NBplt	NLplt
IT86D-610	46.00 ± 0.58g-l	72.33 ± 0.33f-i	4.5 ± 0.29c-e	42.00 ± 5.77ab	40 ± 0.58a-d	57.00 ± 0.58a-d	4.00 ± 0.58c-e	42 ± 6.35c-i
ITOHC-303-1	44.00 ± 0.58d-i	70.00 ± 0.00d-g	3.5 ± 0.87a-c	129.33 ± 12.02xy	39.00 ± 0.00ab	56.00 ± 0.00ab	5.5 ± 0.87f	39.5 ± 10.68a-h
ITOK-837-1	41.33 ± 0.88b-d	65.00 ± 1.15b	4.00 ± 0.00b-d	50.17 ± 2.62a-e	40.67 ± 0.88b-f	57.67 ± 0.88b-f	3.00 ± 0.00a-c	41.33 ± 1.76b-i
PADITUYA	43.67 ± 1.45d-h	66.33 ± 0.88bc	4.50 ± 0.29c-e	84.17 ± 8.46g-s	41 ± 0.58bc-g	58.00 ± 0.58b-g	2.5 ± 0.29ab	61.5 ± 2.02j-q
PI165486	47.00 ± 0.00i-m	72.33 ± 0.33f-i	3.50 ± 0.29a-c	49.50 ± 3.75a-e	40.33 ± 1.33b-e	57.33 ± 1.33b-e	3.5 ± 0.29b-d	43.00 ± 5.2c-i
PI186460	47.67 ± 1.45j-n	70.00 ± 0.00d-g	4.00 ± 0.58b-d	86.50 ± 10.33h-t	42.67 ± 1.45f-h	59.67 ± 1.45f-h	3.5 ± 0.29b-d	22.00 ± 6.35a
PI194207	50.67 ± 0.88n-r	77.00 ± 1.15k-m	2.50 ± 0.87a	42.50 ± 6.06a-c	41 ± 1.15bc-g	58.00 ± 1.15b-g	2.5 ± 0.29ab	23.5 ± 2.6ab
PI194208	51.67 ± 0.88qr	77.67 ± 1.45lm	2.50 ± 0.29a	48.50 ± 6.06a-d	41.33 ± 0.33c-g	58.33 ± 0.33c-g	2.00 ± 0.00a	26.00 ± 0.00a-c
PI194212	47.00 ± 1.73i-m	69.33 ± 0.33c-f	3.00 ± 0.00ab	38.00 ± 1.15a	42.33 ± 0.33e-h	59.33 ± 0.33e-h	3.00 ± 0.00a-c	34.00 ± 4.04a-f
PI200867	51.33 ± 0.88p-r	78.33 ± 1.45lm	5.00 ± 0.58de	79.50 ± 12.99f-r	42 ± 0de-h	59.00 ± 0.00d-h	5.00 ± 0.00ef	62.00 ± 3.46k-r
PI205141	51.00 ± 0.58o-r	77.00 ± 1.15k-m	4.00 ± 0.00b-d	93.00 ± 15.59l-u	42 ± 0.58d-h	59.00 ± 0.58d-h	5.00 ± 0.58ef	51.5 ± 7.22e-m
PI214354	47.00 ± 1.73i-m	69.33 ± 0.33c-f	5.00 ± 0.00de	102.5 ± 17.03p-x	40.67 ± 1.2b-f	57.67 ± 1.2b-f	5.50 ± 0.87f	73.5 ± 8.95n-s
PI221732	51.33 ± 1.45pqr	79.00 ± 1.73mn	3.00 ± 0.00ab	117.50 ± 0.29u-y	41.67 ± 0.33c-h	58.67 ± 0.33c-h	5.50 ± 0.29f	49.00 ± 1.73e-l
PI225922	48.00 ± 1.73k-o	76.00 ± 1.15j-m	5.50 ± 0.29e	97.33 ± 16.19n-v	41 ± 0bc-g	58.00 ± 0.00b-g	2.00 ± 0.58a	42.67 ± 14.15c-i
PI292894	43.00 ± 1.15c-g	74.00 ± 0.58h-k	3.50 ± 0.29a-c	67.50 ± 1.44b-m	40.33 ± 0.33b-e	57.33 ± 0.33b-e	4.00 ± 0.00c-e	48.00 ± 5.77e-l
PI292899	44.00 ± 1.15d-i	67.00 ± 0.58b-d	4.00 ± 0.58b-d	59.00 ± 6.93a-h	40.33 ± 0.33b-e	57.33 ± 0.33b-e	4.00 ± 0.00c-e	43.5 ± 0.87c-j
PI293468	48.67 ± 2.03l-q	77.00 ± 1.15klm	3.00 ± 0.00ab	57.00 ± 0.58a-g	40.67 ± 1.2b-f	57.67 ± 1.2b-f	3.00 ± 0.00a-c	43.00 ± 6.93c-i
PI293470	42.00 ± 0.58b-f	68.00 ± 0.58b-e	4.00 ± 0.00b-d	125 ± 38.68v-y	40.33 ± 0.33b-e	57.33 ± 0.33b-e	4.00 ± 0.00c-e	45.5 ± 3.18d-k
PI304150	44.67 ± 1.45e-j	67.00 ± 0.58b-d	4.50 ± 0.29c-e	104.17 ± 9.06q-x	41.67 ± 0.88c-h	58.67 ± 0.88c-h	4.00 ± 0.58c-e	74.33 ± 6.64o-s
PI339600	49.67 ± 0.33m-r	74.00 ± 0.58h-k	5.50 ± 0.29e	74.00 ± 0.58d-o	39.67 ± 0.67a-c	56.67 ± 0.67a-c	3.50 ± 0.29b-d	45.5 ± 1.44d-k
PI339607	51.33 ± 0.88p-r	75.33 ± 0.88i-l	4-00 ± 0.00b-d	66.5 ± 4.91b-m	40 ± 0.58a-d	57 ± 0.58a-d	3.00 ± 0.58a-c	58.5 ± 4.33i-p
PI354466	52.00 ± 2.89r	82.00 ± 2.31n	4.50 ± 0.29c-e	64.5 ± 10.1a-j	40 ± 0a-d	57 ± 0a-d	3.5 ± 0.87b-d	51.5 ± 4.33e-m
PI354864	42.00 ± 0.58b-f	66.33 ± 0.88bc	4.00 ± 0.00b-d	91.5 ± 22.23j-u	40.67 ± 1.2b-f	57.67 ± 1.2b-f	4.00 ± 1.15c-e	41.5 ± 2.6b-i
PI358716	43.33 ± 0.33c-g	69.33 ± 0.33c-f	3.50 ± 0.29a-c	112.5 ± 20.5t-y	41.67 ± 0.67c-h	58.67 ± 0.67c-h	4.00 ± 0.58c-e	52 ± 5.77f-m
PI487518	42.00 ± 1.15bc-f	65.00 ± 1.15b	4.00 ± 0.00b-d	65.00 ± 3.46a-k	40.67 ± 0.88b-f	57.67 ± 0.88b-f	3.5 ± 0.29b-d	34 ± 8.08a-f
PI527263	43.67 ± 0.33d-h	68.00 ± 0.58b-e	2.50 ± 0.29a	132.50 ± 5.48y	39 ± 0ab	56.00 ± 0.00ab	5.00 ± 0.00ef	63 ± 5.77k-r
PI527302	44.00 ± 1.73d-i	66.33 ± 0.88bc	4.00 ± 0.00b-d	130.00 ± 4.62xy	39 ± 0.58ab	56.00 ± 0.58ab	4.00 ± 0.00c-e	77.5 ± 12.41q-t
PI527561	49.33 ± 0.33m-r	74 ± 0.58h-k	4.00 ± 0.58b-d	92.5 ± 12.41k-u	41 ± 0b-g	58.00 ± 0.00b-g	5.00 ± 0.00ef	87 ± 12.12st
PI582531	43.00 ± 0.58c-g	67 ± 0.58b-d	4.00 ± 0.00b-d	61 ± 1.73a-i	40 ± 0.58a-d	57.00 ± 0.58a-d	4.00 ± 0.00c-e	47.5 ± 1.44e-l
PI582581	49.00 ± 1.15l-r	76 ± 1.15j-m	4.00 ± 0.00b-d	52 ± 6.93a-f	41 ± 0b-g	58.00 ± 0.00b-g	3.5 ± 0.87b-d	56.5 ± 4.91h-o
PI582697	46.67 ± 1.45h-m	74 ± 0.58h-k	4.00 ± 0.00b-d	119 ± 6.24u-y	41.33 ± 0.33c-g	58.33 ± 0.33c-g	4.00 ± 0.58c-e	76 ± 15.37pq-s
PI582707	41.67 ± 0.33b-e	67 ± 0.58bcd	5.00 ± 0.00de	87.83 ± 5.45i-t	42.33 ± 0.33e-h	59.33 ± 0.33e-h	3.5 ± 0.29b-d	50.17 ± 9.59e-l
PI582785	41.00 ± 0.00a-d	66.33 ± 0.88bc	5.00 ± 0.00de	99 ± 10.97o-w	40.33 ± 0.88b-e	57.33 ± 0.88b-e	3.00 ± 0.00a-c	42.5 ± 0.29c-i

Continued

PI582789	43.00 ± 1.15c-g	66.33 ± 0.88bc	5.00 ± 0.58de	78.33 ± 5.04f-r	41.33 ± 0.88c-g	58.33 ± 0.88c-g	4.00 ± 0.58c-e	46.17 ± 7.58d-k
PI582793	45.00 ± 1.73f-k	67 ± 0.58bcd	3.5 ± 0.87a-c	75.17 ± 4.8d-p	43.67 ± 0.33h	60.67 ± 0.33h	3.00 ± 0.58a-c	47.33 ± 5.78e-l
PI582853	46.00 ± 1.73g-l	74 ± 0.58h-k	3.00 ± 0.00ab	54 ± 0.58a-f	40.67 ± 1.2b-f	57.67 ± 1.2b-f	4.5 ± 0.29d-f	29 ± 4.62a-d
PI582867	51.67 ± 0.33qr	77 ± 1.15k-m	4.00 ± 0.00b-d	126 ± 17.32w-y	43.67 ± 0.88h	60.67 ± 0.88h	4.5 ± 0.29d-f	95 ± 9.81t
PI583182	38.00 ± 1.15a	61.00 ± 1.73a	5.00 ± 0.00de	78.33 ± 4.91f-r	41 ± 1.15b-g	58 ± 1.15b-g	4.5 ± 0.29d-f	69.17 ± 0.17m-s
PI583205	42.00 ± 0.00b-f	67 ± 0.58b-d	4.00 ± 0.00b-d	106.17 ± 11.12r-y	40.67 ± 0.67b-f	57.67 ± 0.67b-f	5.00 ± 0.58ef	79.83 ± 1.83r-t
PI583209	42.67 ± 0.88c-f	66.33 ± 0.88bc	3.50 ± 0.29a-c	98.5 ± 7.09o-w	38 ± 0.58a	55.00 ± 0.58a	3.5 ± 0.29b-d	57 ± 13.28h-o
PI583254	47.33 ± 0.33j-m	73.00 ± 0.58g-j	3.00 ± 0.58ab	102.5 ± 0.29p-x	43 ± 1.15gh	60.00 ± 1.15gh	3.00 ± 0.00a-c	53.5 ± 5.48g-m
PI610520	48.33 ± 2.03l-p	77.0 ± 1.15k-m	5.00 ± 0.00de	86.17 ± 3.56h-t	40 ± 0.58a-d	57 ± 0.58a-d	4.5 ± 0.29d-f	72.5 ± 2.57n-s
PI293463	42.67 ± 0.33c-f	61.54 ± 4.50a	3.00 ± 0.58ab	73.5 ± 23.38d-o	40.67 ± 0.33b-f	57.67 ± 0.33b-f	4.5 ± 0.29d-f	45 ± 7.51d-k
PI339598	46.67 ± 0.88h-m	73.00 ± 0.58g-j	4.50 ± 0.29c-e	70 ± 7.51c-n	41 ± 1.15b-g	58 ± 1.15bc-g	4.00 ± 0.00c-e	49.5 ± 3.75e-l
PI632777	45.00 ± 1.15f-k	72.33 ± 0.33f-i	4.50 ± 0.29c-e	93.5 ± 8.95m-u	41.33 ± 1.2c-g	58.33 ± 1.2c-g	5.50 ± 0.29f	55.5 ± 11.84h-n
PI632796	45.00 ± 0.58f-k	71.00 ± 0.00e-h	4.00 ± 0.58b-d	76.67 ± 9.21e-q	41 ± 0.58b-g	58 ± 0.58b-g	4.5 ± 0.29d-f	49.83 ± 4.21e-l
PI663009	41.33 ± 0.33b-d	66.33 ± 0.88bc	2.50 ± 0.29a	65.5 ± 7.52a-l	41 ± 0b-g	58.00 ± 0.00b-g	2.5 ± 0.29ab	36.5 ± 2.6a-g
SARI-6-2-6	40.33 ± 0.88a-c	68 ± 0.58b-e	4 ± 0.58b-d	84.33 ± 6.77g-s	43.67 ± 0.33h	60.67 ± 0.33h	5.00 ± 0.00ef	65.5 ± 2.02lm-r
SONGOTRA	43.00 ± 0.58c-g	74 ± 0.58hi-k	3.5 ± 0.29a-c	45.17 ± 0.44a-c	48.67 ± 0.33i	65.67 ± 0.33i	3.00 ± 0.58a-c	33.33 ± 6.36a-e
WANGKAE	39.33 ± 0.33ab	66.33 ± 0.88bc	3.5 ± 0.29a-c	109 ± 6.35s-y	42.67 ± 0.88f-h	59.67 ± 0.88f-h	4.00 ± 0.58cde	79 ± 2.31q-t

DF = Days to flowering, DM = Days to maturity, NBplt = Number of branches per plant, NLplt = Number of leaves per plant.

3.4. Biomass and Yield Responses of Cowpea Genotypes

Large effects were observed of watering regime on biomass accumulation and yield traits. The biomass reduction was reflected in 33.8% lower dry shoot weight of the drought treated plants when compared to the control/non-stressed plants. Similarly, the number of pods per plant was negatively affected by watering regime, causing 54.5% pods reduction in DS plants compared to the NS plants (Table 1). Seed size as reflected by the 100SW trait showed less of a reduction of 3.9% even though the differences between DS and NS were highly significant. NS plants produced average seed weights of 11.44 g/100 seed while DS plants were 11.03 g/100 seed although this varied greatly between genotypes. The variety "Padituya" had notably large seed of 25.3 and 22.1 g/100 seed in the two conditions, while some genotypes had seed as small as 5 to 7 g/100 seed, especially under the DS condition (Table 3).

Overall yield per hectare was reduced on average by 43.3% comparing the NS and DS conditions. The average yield under well-watered condition was 2668.12 kg/ha for the fifty genotypes but was only 1511.7 kg/ha under DS. The calculated drought intensity index was 0.57, with the stress negatively affecting the yield of the cowpeas tested. Drought tolerance and susceptibility indices were estimated for individual genotypes. Based on mean and geometric productivity, PI527561, PI582707, PI527302, PI304150, PI583205, PI632777, PI610520, PI339600, PI582867, PI205141, PI200867, PI582697, SARI-6-2-6, PI292899, PI582789 and PI527263 produced high yields, with values ranging from 2551.5 kg/ha to 6158 kg/ha (Table 4).

Table 3. The means of dry shoot weight (DSW), number of pods per plant (NPplt), hundred seed weight (100SW) and yield in kg/ha (YLDha) for 50 genotypes of cowpeas grown in Northern Ghana under drought stress (DS) and non-stress (NS) conditions. Values (Mean ± SE) followed letters in a column are significantly different at p ≤ 0.05.

Genotype	Non-Stress				Stress			
	DSW (g)	NPlt	HSW (g)	YLDha (Kg)	DSW (g)	NPlt	HSW (g)	YLDha (kg)
IT86D-610	30.53 ± 0.27ab	23.25 ± 1.3e-i	16.51 ± 0.52r	794.58 ± 275.44a-d	19.29 ± 2.6a-c	4.5 ± 0.5a-e	12.86 ± 1.48s-u	486.53 ± 55.78a-f
ITOHC-303-1	63.49 ± 0.60e-i	21.17 ± 1.42b-g	20.81 ± 1.95u	3370.83 ± 561.95j-p	73.74 ± 6.67s-w	17.92 ± 0.51o-s	23.00 ± 1.15y	362.5 ± 7.22a-e
ITOK-837-1	87.89 ± 0.13j-q	27.00 ± 0.00h-l	16.65 ± 0.33rs	753.75 ± 4.09ab	39.51 ± 1.12d-k	2.5 ± 0.29a-c	17.08 ± 1.64x	349.17 ± 0.96a-e
PADITUYA	108.02 ± 2.95q-t	33.00 ± 1.73mn	25.3 ± 0.12v	2154.17 ± 28.56c-k	46.7 ± 4.69g-o	1.5 ± 0.29ab	22.14 ± 0.36y	1695 ± 217.88l-n
PI165486	25.31 ± 1.28a	18.00 ± 0.87a-e	13.11 ± 0.31op	677.08 ± 18.52ab	24.93 ± 4.54a-f	6 ± 0.58c-g	12.4 ± 0.28r-t	430.83 ± 0.96a-f
PI186460	30.58 ± 0.25ab	13.75 ± 0.66a	8.23 ± 0.02a-f	512.92 ± 3.13a	25.10 ± 0.20a-f	1.33 ± 0.33ab	8.75 ± 0.03e-k	145.83 ± 1.44a
PI194207	20.59 ± 1.48a	17.25 ± 1.15a-d	7.69 ± 1.18a-c	780.56 ± 283.42a-c	17.30 ± 1.70ab	6.5 ± 1.04c-g	7.30 ± 0.00b-e	620 ± 268.47d-g
PI194208	62.36 ± 1.68e-h	17.25 ± 2.17a-d	10.9 ± 0.13h-n	2479.17 ± 12.03g-l	32.18 ± 0.1a-g	7.33 ± 1.2d-h	12.4 ± 1.08r-t	467.92 ± 43.54a-f
PI194212	42.65 ± 6.37a-e	17.58 ± 1.02a-d	7.81 ± 0.17a-d	772.36 ± 246.19a-c	16.13 ± 0.22a	15.17 ± 0.17m-q	7.69 ± 0.44b-f	499.17 ± 6.25a-f
PI200867	76.15 ± 5.48g-o	22.50 ± 0.87d-h	9.78 ± 0.54d-k	3692.92 ± 42.1l-q	40.68 ± 1.02e-l	8.5 ± 1.44e-j	11.09 ± 0.19n-r	2838.33 ± 1281.24rs
PI205141	90.04 ± 1.09j-q	20.25 ± 1.30b-f	16.7 ± 0.53rs	4622.92 ± 1150.61p-t	22.57 ± 5.67a-d	5.5 ± 0.87b-f	13.12 ± 0.98tu	1932.5 ± 198.7m-o
PI214354	98.04 ± 4.46o-s	27.50 ± 0.50h-m	8.5 ± 0.02a-g	3253.33 ± 881.9j-p	51.90 ± 5.00h-q	15.5 ± 3.18n-r	8.39 ± 0.04d-h	1577.5 ± 146.26k-m
PI221732	81.69 ± 0.86h-p	28.5 ± 1.73i-m	11.02 ± 0.04i-n	2343.47 ± 142.42e-l	42.04 ± 1.16f-m	10.00 ± 1.15g-l	11.43 ± 0.97o-s	1891.25 ± 821.04m-o
PI225922	96.81 ± 2.11n-r	17.25 ± 0.43a-d	7.64 ± 0.18a-c	1466.25 ± 2.17a-i	58.57 ± 0.03m-s	12.33 ± 1.2i-n	7.54 ± 0.09b-f	436.25 ± 4.09a-f
PI292894	75.37 ± 2.54g-o	16.50 ± 0.87a-c	10.19 ± 0.03f-m	2403.75 ± 4.09f-l	61.07 ± 1.99n-t	15 ± 0.58m-p	9.97 ± 0.4i-o	1639.17 ± 162.14k-n
PI292899	100.73 ± 2.56p-t	23.25 ± 1.30e-i	9.18 ± 0.01b-i	3641.94 ± 1121.64l-q	56.83 ± 0.36k-s	4.5 ± 0.29a-e	13.1 ± 0.12tu	1756.81 ± 773.88l-n
PI293468	81.27 ± 7.66h-p	14.25 ± 0.43a	10.01 ± 0.09e-m	1032.5 ± 101.52a-f	49.13 ± 2.21g-p	6.00 ± 0.00c-g	11.11 ± 0.03n-r	562.50 ± 7.22c-f
PI293470	94.12 ± 6.09m-q	13.50 ± 0.87a	7.88 ± 0.71a-d	390.00 ± 61.1a	48.45 ± 5.25g-p	2.5 ± 0.29a-c	8.96 ± 0.37f-m	283.33 ± 124.13a-d
PI304150	90.84 ± 5.22k-q	31.83 ± 1.59l-n	11.12 ± 0.36i-o	4993.75 ± 157.09q-t	107.9 ± 8.15x	26.42 ± 0.68t	10.74 ± 0.25n-q	3950.42 ± 957.68uv
PI339600	87.83 ± 5.11j-q	40.50 ± 6.06op	9.36 ± 0.04c-j	5473.33 ± 620.17st	71.24 ± 12.08r-v	12.5 ± 0.29j-n	9.66 ± 0.02g-n	1974.17 ± 403.66no
PI339607	81.46 ± 10.61h-p	32.25 ± 0.43l-n	8.74 ± 1.47a-g	3930.42 ± 348.09m-r	44.91 ± 3.41g-o	5.5 ± 0.87b-f	8.35 ± 0.40c-h	977.08 ± 456.83hi
PI354466	108.21 ± 7.80q-t	22.5 ± 1.73d-h	11.81 ± 0.84l-o	2440.83 ± 1144.12g-l	89.03 ± 3.34w	8.5 ± 2.02e-j	10.46 ± 0.55m-q	1205.83 ± 203.03ij
PI354864	37.91 ± 0.05a-d	24.75 ± 1.30f-j	9.8 ± 1.09d-l	1109.17 ± 85.16a-g	55.17 ± 7.21j-r	7.5 ± 0.29e-h	9.84 ± 0.33h-n	200.56 ± 45.16ab
PI358716	35.86 ± 1.89a-c	21.00 ± 0.00b-g	11.59 ± 0.16k-o	2562.92 ± 273.52i-m	56.23 ± 4.96k-r	19.5 ± 0.29q-s	4.94 ± 0.17a	952.08 ± 39.21g-i
PI487518	66.55 ± 0.26f-j	16.50 ± 0.87a-c	9.32 ± 0.09c-i	929.58 ± 13.23abcd	56.55 ± 0.26k-s	16 ± 2.89n-s	8.94 ± 0.02f-m	235.42 ± 2.17a-c
PI527263	110.17 ± 18.12q-t	18.00 ± 0.87a-e	10.52 ± 0.02g-m	2979.17 ± 157.33j-n	68.96 ± 1.94q-u	16.5 ± 0.29n-s	11.16 ± 0.16n-r	2124.17 ± 90.45op
PI527302	118.97 ± 9.65r-u	24.67 ± 1.09f-j	11.34 ± 0.28j-o	5127.22 ± 537.19rst	60.3 ± 5.14n-t	20.33 ± 1.09s	11.9 ± 0.25q-t	4195.28 ± 220.4v
PI527561	54 ± 12.12b-g	29.25 ± 4.76j-m	9.99 ± 0.27e-m	7345.28 ± 394.64u	125.28 ± 12.38x	11 ± 1.15h-m	11.82 ± 0.04p-t	4970.97 ± 550.07w
PI582531	54.89 ± 0.06c-g	29.25 ± 3.90j-m	8.61 ± 0.04a-g	1161.67 ± 168.39a-h	23.66 ± 0.2a-e	18.5 ± 3.75p-s	8.97 ± 0.07f-m	962.08 ± 0.72g-i
PI582581	50.02 ± 2.5b-f	25.50 ± 0.87f-k	9.33 ± 0.59c-j	4015.83 ± 97.67n-r	19.21 ± 0.92a-c	8.00 ± 0.58e-i	10.88 ± 0.12n-r	678.75 ± 98.39e-h
PI582697	74.29 ± 15.12g-n	24.75 ± 0.43f-j	7.12 ± 0.1a	3388.33 ± 325.24j-p	37.97 ± 2.93d-j	16 ± 1.53n-s	7.06 ± 0.52b-d	2386.67 ± 637.49pq
PI582707	122.81 ± 7.4tu	30.75 ± 0.43k-m	8.93 ± 0.18a-h	5937.64 ± 349.33t	52.58 ± 12.65i-q	13 ± 1.73k-n	8.86 ± 0.61f-l	3659.44 ± 1073.66u
PI582785	68.75 ± 0.72f-l	36.75 ± 0.43no	9.41 ± 0c-j	840.00 ± 11.07a-d	40.98 ± 0.01e-l	12.5 ± 0.87j-n	11.84 ± 0.03p-t	756.25 ± 2.17f-h

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PI582789	63.73 ± 12.86e-i	42.75 ± 3.90p	8.75 ± 0.39a-g	3416.67 ± 626.43k-p	51.84 ± 0.48hi-q	19.5 ± 4.33q-s	8.26 ± 0.07b-g	1704.17 ± 388.75l-n
PI582793	91.53 ± 4.55l-q	16.25 ± 0.90a-c	12.89 ± 0.64n-p	3025.83 ± 726.70j-n	50.56 ± 10.62hi-p	10 ± 1.73g-l	10.35 ± 1.22l-p	1803.75 ± 735.07l-o
PI582853	83.99 ± 2.08h-p	22.50 ± 3.46d-h	16.59 ± 0.24rs	2490.42 ± 16.60g-l	77.33 ± 1.46tu-w	15.67 ± 0.33n-r	13.09 ± 0.05tu	1487.92 ± 365.51j-l
PI582867	120.93 ± 3.93s-u	23.25 ± 0.43e-i	14.2 ± 0.09pq	4448.47 ± 585.01o-s	88.47 ± 6.65vw	9.00 ± 1.15f-k	13.99 ± 0.45uv	2981.53 ± 720.11st
PI583182	89.1 ± 3.58j-q	24.75 ± 0.43f-j	9.78 ± 0.44d-k	2885.00 ± 353.15j-n	60.41 ± 9.81n-t	7.5 ± 1.44e-h	10.03 ± 0.31j-o	1525.83 ± 72.17j-l
PI583205	53.6 ± 1.69b-g	27.75 ± 0.43h-m	8.67 ± 0.16a-g	4648.19 ± 263.89p-t	35.41 ± 1.36c-i	13.5 ± 2.02l-o	8.49 ± 0.38d-i	3934.72 ± 189.29uv
PI583209	83.82 ± 35.56h-p	29.25 ± 3.03j-m	10.44 ± 0.22g-m	2019.44 ± 291.98b-j	52.89 ± 0.06j-q	18.33 ± 2.03p-s	9 ± 0.33f-m	1293.47 ± 217.31i-k
PI583254	108.01 ± 17.88q-t	12.75 ± 0.43a	8.13 ± 0.18a-e	633.75 ± 163.82ab	61.81 ± 17.81o-t	1.00 ± 0.00a	10.22 ± 0.01k-o	247.5 ± 60.14a-c
PI610520	86.73 ± 0.71i-q	33.00 ± 4.33mn	16.16 ± 3.24qr	4553.33 ± 667.8pq-t	64.27 ± 10.84p-u	11 ± 0.58h-m	10.03 ± 0.04j-o	2980 ± 331.98st
PI293463	163.56 ± 0.33v	30.50 ± 3.91k-m	7.21 ± 1.39ab	3405.42 ± 1686.58j-p	80.96 ± 1.26u-w	9.5 ± 3.75f-l	8.5 ± 0.43d-j	629.58 ± 231.66d-h
PI339598	69.56 ± 4.27f-l	29.75 ± 0.90j-m	8.56 ± 0.81a-g	2520.00 ± 505.77h-l	42.2 ± 9.48f-m	15 ± 0.58m-p	6.85 ± 0.31bc	1135.83 ± 253.38i
PI632777	82.09 ± 10.02h-p	21.33 ± 1.45c-g	11.97 ± 0.17m-o	4481.67 ± 675.85o-s	57.15 ± 7.74l-s	13.17 ± 2.89k-n	17.29 ± 0.03x	3269.17 ± 933.17t
PI632796	49.02 ± 0.06b-f	23.25 ± 0.43e-i	8.17 ± 0.01a-e	2185.00 ± 105.32d-k	34.61 ± 1.65b-h	19.67 ± 3.76rs	8.54 ± 0.07d-j	1682.5 ± 246.66l-n
PI663009	60.46 ± 1.29d-h	15.75 ± 2.17ab	11.09 ± 0.05i-o	951.39 ± 256.94a-e	51.99 ± 2.47h-q	4.33 ± 0.88a-e	6.79 ± 0.76b	509.44 ± 353.5b-f
SARI-6-2-6	67.78 ± 12.82f-k	23.25 ± 0.43e-i	18.58 ± 0.24st	3103.33 ± 509.31j-o	40.57 ± 8.59e-l	13.83 ± 1.69l-o	16.54 ± 0.45wx	2497.5 ± 558.2qr
SONGOTRA	72.28 ± 5.92f-m	26.25 ± 3.03g-k	16.11 ± 0.58qr	717.5 ± 184.75ab	43.67 ± 5.55g-n	6.5 ± 0.29c-g	15.11 ± 0.38vw	406.67 ± 16.84a-f
WANGKAE	138.34 ± 14.77u	15.75 ± 0.43ab	19.78 ± 0.03tu	544.17 ± 1.44a	61.84 ± 17.33o-t	3.00 ± 0.00a-d	14.82 ± 0.46v	288.75 ± 62.31a-d

DSW = Dry shoot weight, NPplt = Number of pods per plant, HSW = Hundred seed weight and YLDha = Grain yield per hectare.

Table 4. Drought indices of 50 cowpea genotypes grown under drought stress (DS) and non-stress (NS) conditions at the Bontanga site in Northern Ghana.

Genotype	NS	DS	DSI	DTI	MP	GMP	YI	YRR	YSI
PI582785	840	756	0.18	0.90	798.00	796.89	0.5	0.10	0.90
PI583205	4648	3935	0.27	0.85	4291.50	4276.67	2.6	0.15	0.85
PI582531	1162	962	0.30	0.83	1062.00	1057.28	0.6	0.17	0.83
PI527302	5127	4195	0.32	0.82	4661.00	4637.65	2.8	0.18	0.82
PI221732	2343	1891	0.34	0.81	2117.00	2104.90	1.3	0.19	0.81
SARI-6-2-6	3103	2498	0.34	0.81	2800.50	2784.11	1.7	0.19	0.81
PI194207	781	620	0.36	0.79	700.50	695.86	0.4	0.21	0.79
PI304150	4994	3950	0.37	0.79	4472.00	4441.43	2.6	0.21	0.79
PADITUYA	2154	1695	0.37	0.79	1924.50	1910.77	1.1	0.21	0.79
PI632796	2185	1683	0.40	0.77	1934.00	1917.64	1.1	0.23	0.77
PI200867	3693	2838	0.41	0.77	3265.50	3237.40	1.9	0.23	0.77
PI632777	4482	3269	0.47	0.73	3875.50	3827.75	2.2	0.27	0.73
PI293470	390	283	0.48	0.73	336.50	332.22	0.2	0.27	0.73
PI527263	2979	2124	0.50	0.71	2551.50	2515.43	1.4	0.29	0.71
PI582697	3388	2387	0.52	0.70	2887.50	2843.79	1.6	0.30	0.70

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PI292894	2404	1639	0.56	0.68	2021.50	1984.98	1.1	0.32	0.68
PI527561	7345	4971	0.57	0.68	6158.00	6042.52	3.3	0.32	0.68
PI582867	4448	2982	0.58	0.67	3715.00	3641.97	2.0	0.33	0.67
PI610520	4553	2980	0.61	0.65	3766.50	3683.47	2.0	0.35	0.65
PI194212	772	499	0.62	0.65	635.50	620.67	0.3	0.35	0.65
PI583209	2019	1293	0.63	0.64	1656.00	1615.72	0.9	0.36	0.64
PI165486	677	431	0.64	0.64	554.00	540.17	0.3	0.36	0.64
PI582707	5938	3659	0.67	0.62	4798.50	4661.24	2.4	0.38	0.62
IT86D-610	795	487	0.68	0.61	641.00	622.23	0.3	0.39	0.61
PI582853	2490	1488	0.71	0.60	1989.00	1924.87	1.0	0.40	0.60
PI582793	3026	1804	0.71	0.60	2415.00	2336.43	1.2	0.40	0.60
SONGOTRA	718	407	0.76	0.57	562.50	540.58	0.3	0.43	0.57
PI293468	1033	563	0.80	0.55	798.00	762.61	0.4	0.45	0.55
PI663009	951	509	0.82	0.54	730.00	695.74	0.3	0.46	0.54
WANGKAE	544	289	0.82	0.53	416.50	396.50	0.2	0.47	0.53
PI583182	2885	1526	0.83	0.53	2205.50	2098.22	1.0	0.47	0.53
PI582789	3417	1704	0.88	0.50	2560.50	2413.00	1.1	0.50	0.50
PI354466	2441	1206	0.89	0.49	1823.50	1715.76	0.8	0.51	0.49
PI214354	3253	1578	0.90	0.49	2415.50	2265.66	1.0	0.51	0.49
PI292899	3642	1757	0.91	0.48	2699.50	2529.62	1.2	0.52	0.48
ITOK-837-1	754	349	0.94	0.46	551.50	512.98	0.2	0.54	0.46
PI339598	2520	1136	0.96	0.45	1828.00	1691.96	0.8	0.55	0.45
PI205141	4623	1933	1.02	0.42	3278.00	2989.36	1.3	0.58	0.42
PI583254	634	248	1.07	0.39	441.00	396.52	0.2	0.61	0.39
PI358716	2563	952	1.10	0.37	1757.50	1562.04	0.6	0.63	0.37
PI339600	5473	1974	1.12	0.36	3723.50	3286.90	1.3	0.64	0.36
PI225922	1466	436	1.23	0.30	951.00	799.48	0.3	0.70	0.30
PI186460	513	146	1.26	0.28	329.50	273.67	0.1	0.72	0.28
PI487518	930	235	1.31	0.25	582.50	467.49	0.2	0.75	0.25
PI339607	3930	977	1.32	0.25	2453.50	1959.49	0.6	0.75	0.25
PI194208	2479	468	1.42	0.19	1473.50	1077.11	0.3	0.81	0.19
PI293463	3405	630	1.43	0.19	2017.50	1464.63	0.4	0.81	0.19
PI354864	1109	201	1.44	0.18	655.00	472.13	0.1	0.82	0.18
PI582581	4016	679	1.46	0.17	2347.50	1651.32	0.4	0.83	0.17
ITOHC-303-1	3371	363	1.57	0.11	1867.00	1106.20	0.2	0.89	0.11
Mean	2668.12	1511.7	0.7774	0.5578	2089.91	1963.661	1.002	0.4422	0.5578

NS = Non-Drought Stress, DS = Drought stress, DSI = Drought Susceptibility Index, DTI = Drought Tolerant index, MP = Mean Productivity, GMP = Geometric Mean Productivity, YI = Yield Index, YRR = Yield Reduction Rate and YSI = Yield Stability Index.

Drought susceptibility and tolerance, yield index, yield reduction rate and yield stability index ranked the test genotypes PI582785, PI583205, PI582531, PI527302, PI221732 and SARI-6-2-6 as more drought tolerant than the other genotypes. Even though some genotypes which are considered drought tolerant did not produce the highest yields under non-stressed conditions, they were nonetheless, able to withstand the stress and also produced substantial yields. Genotypes PI225922, PI186460, PI487518, PI339607, PI194208, PI293463, PI354864 and PI582581 were considered susceptible genotypes although some produced high yields under well-watered conditions.

4. Discussion

The imposition of the drought stress was effective since the trial was carried out during the dry season and irrigated water could be supplied to the trials in controlled amounts and on a strict time schedule. The daily average temperature was 29.7˚C which is within favorable range for cowpea growth and development [34], although towards the end of the season maximum temperatures exceeded 33˚C or more. The soil was sandy loam with pH of 5.89 which was conducive for cowpea production [34] [35]. However, total rainfall below 15 mm would not produce a cowpea crop without irrigation which was added to both treatments but in different amounts for NS and DS conditions.

The withdrawal of irrigation water after flower buds' initiation for the DS treatment subjected the crop to moderate to high drought stress. The terminal drought that was experienced in this experiment was typical of the major abiotic stress problem for cowpea production in Sub-Saharan Africa, namely early termination of rains. Short insufficient rains are typical of the Sahelian region of West Africa and sometimes affect the Guinea Savannah region as well and are a major issue for agriculture in Northern Ghana. Terminal drought resulted in poor yield performance of the cowpea plants subjected to the water deficit, which is consistent with the findings of [36] and [37].

The drought stress index of the experiment was 0.57 indicating a moderate to high drought stress subjected to the cowpea genotypes. Variability in the individual values for the genotypes in the trial could be attributed to the genotypic differences and genotype x environment interactions in the experiment based on how drought affected yielding capacity of each accession. Researches [38] and [39] reported noticeable reduction in the grain yield of cowpea genotypes evaluated under drought condition which was attributed to genotypic differences.

The genotypes showed marked variations in their response to the watering regimes imposed on the cowpeas evaluated in the trial. The significant effect of genotype, watering regime and their interaction on the test cowpeas showed that the genotypes exhibited contrasting responses to the DS versus NS in the present study. Researchers [40] [41] [42] reported variable response of cowpea to drought adaptation which subsequently affected growth and yield. According to [36], the response cowpea can have to drought depends on the genotype, intensity of the drought as well as the duration of the drought exposure. The genotypes expressed varied response to drought stress based on the measured traits, with the extent of response being more pronounced in some genotypes than others owing to genotypic differences [43].

The significant variation among genotypes in response to drought in this experiment confirmed the findings of [44], that cowpea genotypes will vary in their productivity when exposed to drought at vegetative or reproductive stages. Days to flowering and maturity, hundred seed weight and number of branches were not highly sensitive to drought as their percentage reduction were smaller as compared to other parameters. Dry shoot weight, number of leaves and pods per plant and grain yield were highly sensitive to drought stress. Researchers [45] and [46] reported similar effects of drought on dry matter and yield of cowpea.

The drought stress caused 18.0% reduction in days taken to reach physiological maturity of cowpea in the current experiment which is similar to the growth period shortening caused by drought in previous reports [47]. The reduction in days to flowering in the current study also confirmed an earlier report by [48]. The variation in days to flowering and maturity among the genotypes in this current trial is a genetic response of those genotypes to water deficit or stress in the soil. Even though the drought stress occurred at the reproductive stage, it affected both flowering and maturity of the cowpea plants.

The genotypes that responded to drought stress through a reduction in the number of days to physiological maturity while maintaining high yields could be linked to drought escape mechanism of the cowpea plants [49].

In this study, some genotypes flowered and matured late and still gave maximum grain yield under drought stressed conditions, suggesting that those genotypes could be linked to drought tolerance [49]. On the other hand, genotypes PI582793, PI582867, SARI-6-2-6, PI583254 and SONGOTRA flowered and reached maturity late under drought stressed conditions. The genotypes PI583209, PI339600, ITOHC-303-1, PI527263 and PI527302 that showed earliness in physiological maturity together with genotypes PI339600, PI527263 and PI527302 produced substantial grain yield under drought conditions, showing that drought escape through early pod set is one mechanism of drought tolerance.

The overall number of pods per plant and grain yield was significantly reduced by the drought stress conditions. Yield component traits are good indicators of drought stress in cowpea [45] [46]. Researcher [48] reported significant reduction of seed yield of cowpea subjected to similar drought stress conditions. The higher reduction in the number of pods per plant under drought stress conditions could be due to flower abortion [50]. Poor carbohydrate partitioning and photosynthate assimilation to the developing seed could be associated with the reduction in 100 seed weight among genotypes in this study [51]. Drought tolerant genotypes have strong association between photosynthate assimilation and carbohydrate accumulation in the developing seed and could maintain high 100 seed weight regardless of the soil water. Understanding the response of yield component trait to drought could be utilized in plant breeding programs to select or develop superior genotypes with drought tolerance in future. Current breeding programs in SARI, the Savannah Agricultural Research Institute together with IITA, the International Institute for Tropical Agriculture, could benefit from the germplasm evaluated by this study and the results of drought tolerance trait dissection.

5. Conclusion

The response of cowpea plants to water deficit depends on genotype, drought intensity, and the growth stage at which drought occurs. In our trial, the number of leaves per plant and dry matter of cowpea were negatively affected by water deficit at flowering, which manifested in up to 50% yield reduction when compared to well-watered plants. Similarly, the number of days to flowering and maturity were shortened by imposing terminal drought on the test cowpeas in this study. Genotypes PI339600, PI527263, PI527302, PI582793, PI582867 and SARI-6-2-6 have promising yield potentials under drought stress conditions. These genotypes could be exploited for future breeding program that will develop drought tolerant varieties for the savannah ecology of northern Ghana and other areas with similar environmental conditions across West Africa.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

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