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Water stress effect on agro-morphological and physiological parameters of three local cultivars of maize (*Zea mays* L.) of South Benin

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ABSTRACT

Water deficit in tropical countries is the main factor limiting agricultural production. This study aimed at evaluating the level of resistance to water deficiency of three local maize cultivars in Benin. The effects of water stress induced supply of 100 (control), 50 and 25 % of the Readily Usable Reserve (RUR) from the 40th day after sowing to the end of the production cycle were studied. The experimental design used was a split plot with 4 replicates. Phenological, agro-morphological and agro-physiological parameters of plants were evaluated. Water deficit reduced plants height, root volume, root dry matter and total leaf area during the flowering stage. The date of female inflorescence setting was extended by water deficiency. Water deficiency also reduced the mean number of cobs per plant from 0.855 ± 0.38 (100% RUR) to 0.64 ± 0.019 (50% RUR) and 0.58 ± 0.17 (25% RUR). Furthermore, 1000 grains weight dropped from 264.63 ± 53.58 g (100 % RUR) to 223.88 ± 37.9 g (50 % RUR) and 217.63 ± 42.66 g (25% RUR). The cultivar Bafogbali was the most resistant to water stress. The variety EV DT 97 and the cultivar Souantokoui were the most affected by the water deficiency.

Keywords: Water pattern, drought, easily usable reserves, *Zea mays*, Benin.

INTRODUCTION

Maize is one of the most important and cultivated crops that provides food and nutrition security in many parts of Africa and the world (Prasanna, 2011; Ranum et al., 2014; Tesfaye et al., 2018). However, average maize yields in developing countries remain low due to abiotic, biotic and socio-economic constraints (Shiferaw et al., 2011). To this end, issues related to climate change and variability are of concern to scientific communities and policymakers because of their damaging effects on ecosystems and human activities (Noufè et al., 2016). In West Africa, the synoptic situation occurs through phenomena such as recurring droughts, disturbances of rainfall patterns and rainfall deficits of the order of 20% to 30% (Paturel et

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al., 2003; Noufé et al., 2016). These changes are very likely to reduce the productivity of cereal crops thus exacerbating food insecurity (Niang et al., 2014). Several studies using different approaches predict the negative effect of climate change on the yield of cereal crops in sub-Saharan Africa (Lobell et al., 2013; Ruane et al., 2013; Waha et al., 2013; Ahmed et al., 2015). In addition, climate change could reduce yields of maize, sorghum and rain-fed millet in sub-Saharan Africa by the middle of the century by more than 12-15% (Jones and Thornton, 2003; Tesfaye et al., 2017). According to Cairns et al. (2012), maize cultivation in semi-arid tropics is often confronted with a multitude of abiotic stresses such as drought and heat. Indeed, drought is the most important abiotic stress for maize production in the tropics (Tesfaye et al., 2018). Average annual yield losses due to drought are estimated at 15% of potential yield worldwide (Edmeades, 2008).

In Benin, maize is the most important foodstuff after yam and cassava. The average consumption of maize is estimated at 85 kg/inhabitant/year and can reach 100 kg/inhabitant/year in the large urban centers of southern Benin, notably Cotonou and Porto-Novo (Affokpon et al., 2013). In fact, cereal crops, particularly maize, are very sensitive to the effects of climate change characterized by the increase in dry periods (Agbossou et al., 2012) with an exposure coefficient of 83% (Tidjani et Akponikpe, 2012). During the exceptional drought of the 1970s in Benin, where the Zou department was heavily affected, maize emerged as the most vulnerable crop before cowpea (Akponikpè, 1999). It is therefore clear that climate change by impacting maize production could lead to a food crisis that would be uncomfortable given the already poor financial conditions of rural populations and threaten in the short medium and long term the entire stability of the country. The growth potential of the Beninese economy would thus be threatened because it depends to a large extent on the agricultural sector, which accounts for nearly 39% of the Gross Domestic Product (Tidjani et Akponikpe, 2012). Adaptation strategies (shift of sowing dates, cultivation association, increase in seeding density) used by growers are becoming increasingly limited in the absence of improved drought resistance varieties. Given this situation, this study aims to assess the impact of different water regimes on the agro-morphological parameters of three local maize cultivars in order to identify those with an acceptable level of resistance to stress for improved maize production in Benin.

MATERIALS AND METHODS

Study area

The experimentation was conducted at research station of International Institute of Tropical Agriculture (IITA) (N 06°25.326’ and E 002°19.634’) of Benin located in the Commune of Abomey-Calavi, department of Atlantic (Figure 1). This region has a sub-equatorial climate with two rainy seasons and two dry seasons, and characterized by huge climatic disturbances in these recent years (Biaou, 2006). Annual average pluviometry is around 1200 mm, 700 mm to 800 mm for the first rainy season and 400 to 500 mm for the second rainy season (INSAE, 2004) and monthly average temperatures ranging from 27 °C to 31 °C.

Plant material

The plant material is made up of three local maize cultivars (Bafogbali, Souantokoui, Gbadé-holikou) and an improved variety used as control (EV DT 97) (Table 1).

Method of culture

The trial was carried out from late March to mid-July 2016, under greenhouse, screen house to transparent roof. Two factors were studied: water regime with three levels: control maintained at 100% of the Readily Usable Reserve (RUR), plants subjected to 50% of RUR and plants subjected to 25% of RUR from 40^{th} day after sowing until the end of their cycle; varieties with four modalities, are the second factor. The experimental design is a split plot with 4 repetitions. Planting was done March 30, 2016 in plastic pots of 30 cm deep and 20 cm in diameter. These pots are filled with homogenized well soil until ¾ or 22.5 cm in height and arranged in three sub-blocks of 20 pots per repetition. The granulometric characteristics of the soil used are presented in table 2. The pots bottom was holed to make drain water after watering. Repetitions and sub-blocks in each repetition were separated by an alley of 0.8 m. Each variety was sown in 5 successive pots in each sub block representing a basic plot. The pots are arranged side by side following a spacing of 0.4 m × 0.5 m between plants.

Meteorological data such as humidity, wind speed and measurements on evaporation pan E_{bac}, collected in IITA station, allowed the calculation of evapotranspiration reference ET0 and of maize crop ETc (FAO, 1987). Every day, evapotranspiration value (ETc) for the previous day is calculated. That enabled to estimate water losses due to crop evapotranspiration (water losses by percolation being zero) and to complete the quantity needed to maintain different water capacities. Different water capacities were determined at Laboratory of Soil Sciences of the Faculty of Agronomic Sciences at the University of Abomey.

$RU = (HpF2{,}5 - HpF4{,}2) \times Z \times da$

(Z = Sand height in pots)

$RFU = \frac{2}{3} RU$

$Sp = 2\pi \times R \times h,$

(Sp= a pot surface)

$ET0 = Kp \times Ebac$

(Kp= coefficient of evaporation pan; E_{bac} = Evaporation in measured pan)

$ETc = Kc \times ET0$ (mm)

(Kc = cultural coefficient)

15 Days After Sowing (DAS), we carried out a thinning, leaving only one plant per pot. NPK and Urea fertilizers were applied at doses of 2.4 g and 0.8 g (150 kg / ha of NPK and 50 kg/ha of urea) per each pot as basal fertilizer and of maintenance. The NPK fertilizer is applied 20 DAS and Urea 45 DAS.

Data collection

The parameters measured were plant height, leaf area, date of inflorescences appearance, primary roots number (NRP), main root length (LRP), root volume (RV), the dry material root (MSR), total chlorophyll content, number of cobs per plant and weight of 1000 seeds.

The height measurements started from the 40^{th} day after sowing and were took every ten days, and covered the first three plants of each elementary plot. The measurements were made from the collar to the last visible node on the plant.

The leaf area of maize plants was estimated from length and width dimensions of limb. The length was measured from the sheath top to the limb tip, and the width in the limb middle. For leaf area estimation, maize leaf is similar to a lozenge (Sinsin, 1994). Leaf area is determined by the following formula:

$$SF = \frac{L \times l}{2}$$

With: SF = leaf area, L = leaf length and l = leaf width. This measure gives an idea of leaf area index.

The date of inflorescences appearance was determined through daily counting of flowers at the onset respectively of the first male flower and first female flower on one of the plots until the date where 50% of the plants reached the flowering phase (DF50). On each elementary parcel, there was observed total number of days required for 50% of the plants have exceeded the vegetative stage and panicles well clear of panicle leaf.

The evaluation of plants root system was made after the final maturity. This operation focused on plants in last place in each elementary plot. To facilitate uprooting, the pots were wet the day before. After uprooting, the roots are dipped in a water bucket to get rid of the earth. The studied parameters are:

i) The primary root number (NRP) was determined by counting the root length higher than 1 cm;
ii) The Main root length (LRP), most frequently selected parameter was measured in cm;
iii) The root volume (RV), expressed in cm^3, was assessed according to the method of

Musick et al. (1965) and Sayar et al. (2008). This method involves comparing the water levels before and after immersion of the whole roots in a known volume of water;

iv) The mass of dry material roots (MSR), expressed in gram, was determined after drying in a drying oven of roots at 60 ° C for 96 hours (Heitholt, 1989).

The total chlorophyll content of leaves was determined using a chlorophyll meter SPAD 502 of Minolta (Nouri, 2002). In our study, three measurements are performed on three different leaves located at the last visible node at rate of one plant per elementary plot. The planned average of the three values is displayed on the device screen at the end.

The yield components were determined at harvest. At maturity, the cobs were harvested and counted per plant for each of varieties studied. To determine the weight of 1000 seeds (PMG) of four maize varieties compared, a sample of 50 seeds of each variety by water regime and by replication (or 4 replications) was taken and weighed with an electronic balance. This technique was described by Douib (2013) for determining the wheat PMG in.

Data analysis

Collected data were entered using Excel software. Normality and equal of variances of the data have been tested with MINITAB 16 software. These data were then analyzed using R software 3.3.1. Moreover, analysis of variance was performed and followed of Student Newman Keuls (SNK) test for mean discrimination at the 5% threshold.

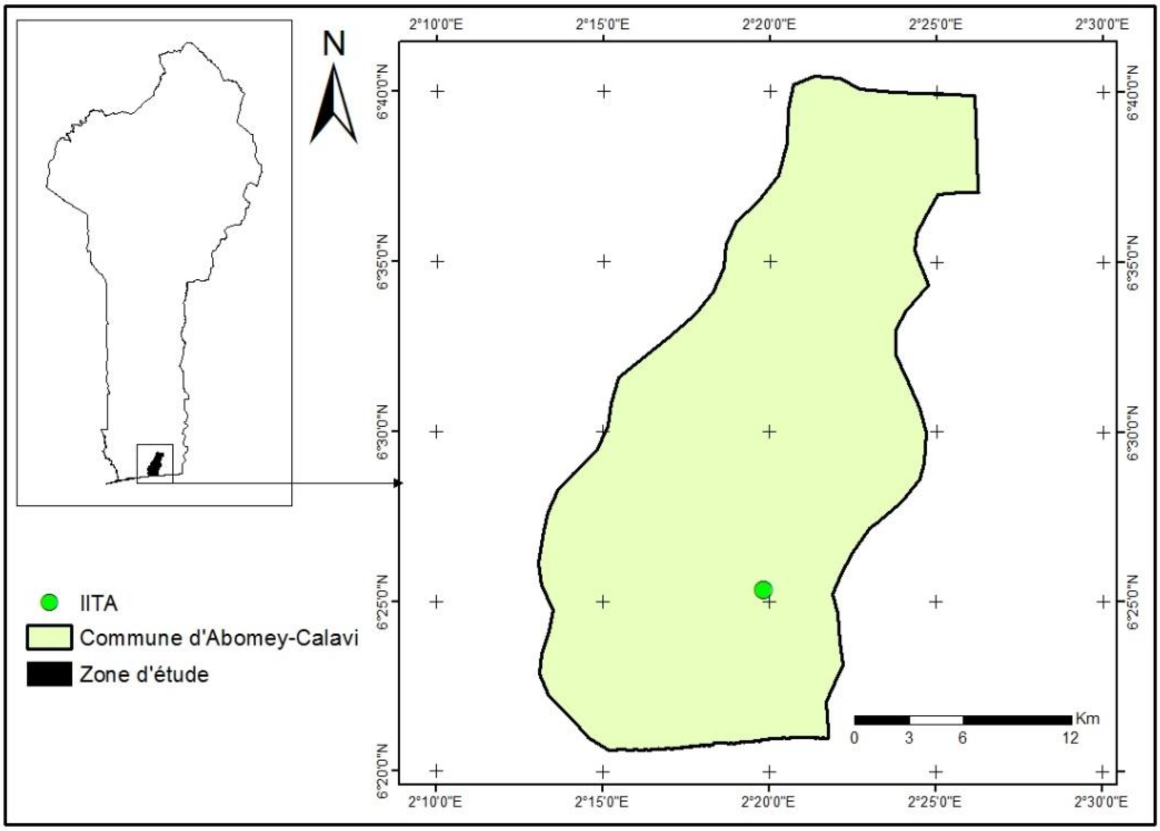

Figure: Localization of the study area.

Table 1 : Characteristics of the four varieties studied.

Varieties	Type	Colour	Cycle	Origin	Village
EV DT 97	Improved	white	90 days	N'Dali	INA
Bafogbali	Local	white	120 days	Aplahoué	Bogandji
Souantokoui	Local	white	90 days	Djidja	Djidja- center
Gbadé-holikou	Local	White	75 à 90 days	Adja-Ouèrè	Adja-Ouèrè center

Table 2 : Granulometric characteristics of substrate used.

Elements	pF 2.5 (%)	pF 4.2 (%)	Lg (%)	Lf (%)	Ag (%)	Sg (%)	Sf (%)	Da
Hydrous capacity or proportion	18.66	9.89	5.78	4.45	17.15	56.83	15.35	1.49

da: apparent density; pF2.5: retention capacity; pF 4.2: permanent wilting point; Lg: coarse limon; Lf: Fine limon; Ag: Clay; Sg: coarse Sand; Sf: Fine sand; da: Apparent density

RESULTS

Plant height

The results showed that the effect of the interaction between water regime and variety wasn't significant on plant height. By cons, plant height was significantly affected by imposed water stress conditions during the entire cycle development of maize plants (Table 3). The tallest plants are found respectively at 100% RUR and 50% RUR regime, and the smallest at the 25% RUR regime. The results showed significant genetic variability (p = 0.000) of plant height in the varieties tested throughout their development period (Table 3). The local cultivar Gbadé-holikou had the tallest plants (188.75 ± 20.57 cm). Souantokoui (157.75 ± 19.82 cm) and Bafogbali (169.08 ± 17.98 cm) cultivars showed plant height statistically identical to the variety EV DT 97 (153.25 ± 17.92 cm) (Table 3).

Appearance period of male and female inflorescences

The results showed significant interaction between water regime and variety (p = 0.021) on the date of female flowering on the one hand, and highly significant effect (p = 0.007) on the number of days separating male flowering from female flowering on the other hand.

However, the interaction was not significant on male flowering date (Table 4). It is the same for water regime (P = 0.679) on male flowering date. In contrast, the date of female flowering was very highly affected (p = 0.000) by water stress conditions with a delay of 2 and 6 days respectively at 50% and 25% of RUR (Table 4). The analysis of variance (Table 4) revealed a highly significant effect (p = 0.000) of genotype on the appearance dates of different inflorescences. No significant difference (p = 0.115) was observed among varieties as regards the days difference between male and female flowering.

Evolution of leaf area

The analysis of variance revealed the interaction between water regime and variety was not significant during all the plants development. The effect of water regime was significant (p = 0.018) only at 58th DAS and resulted in a reduction of the leaf area under water stress conditions (50% and 25% RUR). Also, between local cultivars and control variety, leaf area variability was significant (p = 0.040) only at 30th DAS. To this date, cultivar Souantokoui has the largest leaf area, Gbadé-holikou and Bafogbali cultivars showed the smallest leaf areas. The Control variety EV DT 97 was intermediated between the two classes (Table 5). By cons, on the 44th, 58th and 72th DAS, all varieties have statistically identical leaf areas.

Content of total chlorophyll (SPAD unit)

A significant difference (p = 0.039) was observed among genotypes on the 30th day after sowing (Table 6). The variety EV DT 97 has the highest chlorophyll content; Gbadé-holikou and Bafogbali cultivars the lowest content. The difference among varieties was also significant (p = 0.013) at 51st DAS. Thus, Gbadé-holikou and Souantokoui cultivars have the highest chlorophyll contents and Bafogbali the lowest chlorophyll content (Table 6). However, the water regime on the one hand, and the interaction between hydrous regime and varieties on the other hand showed no significant effects on chlorophyll content.

Rooting characteristics variation

The analysis of variance showed a highly significant effect of hydrous regime and varieties on dry matter and root volume (Table 7). These two characteristics have considerably been reduced by the severe hydrous conditions (25% RUR). The varieties Gbadé-holikou (MSR = 5.617 ± 2.24 g; VR = 41.75 ± 16.87 cm^3) and Bafogbali (MSR = 6.19 ± 3.58 g; VR = 42.17 ± 20.81 cm^3) have the best characteristics root respectively (table 7). Neither the hydrous regime, neither the varieties, nor their interaction have significantly influenced (P > 0.05) the primary roots number and the main root length.

Yield components following hydrous regimes and varieties

The results of table 8 showed that the average number of cobs per plant and the weight of 1000 seeds respectively presented significant differences not only under hydrous regime effect but also under the influence of studied varieties. The interactions between water regime and varieties weren’t significant on these two yield characteristics. The number of cobs per plant and the weight of 1000 seeds were negatively affected by water stress conditions with lower yields under severe stress (25 % RUR).

The genotype effect showed that control variety EV DT 97 was most productive with the best values of yield components (0.86 ± 0.39 cob/plant and PMG = 264.33 ± 30.39 g). The genotypes Gbadé-holikou and Bafogbali were the least productive.

Table 3: Plant height (cm) in maize varieties, irrigation regimes and following different dates after sowing.

Observation dates	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS
Water regimes					
100 % RUR	70.94±10.06[a]	125.38±20.08[a]	165,94±24,90[a]	172.13±22.70[a]	173.63±21.71[a]
50 % RUR	71.35±10.02[a]	125.69±18.24[a]	164.25±24.96[a]	171.56±22.75[a]	172.13±22.60[a]
25 % RUR	72.31±10.41[a]	114.44±17.79[b]	141±18.77[b]	155.94±22.24[b]	155.88±21.99b
P	0.780ns	0.041*	0.000***	0.011 *	0.003 **
Cultivars					

EV DT 97	74.67±6.61^{a}	128.17±18.04^{a}	140.92±16.99^{b}	150.25±18.07^{b}	153.25±17.92^{b}
Gbadé-holikou	78.25±6.96^{a}	127.917±15.5^{a}	180.92±25.61^{a}	188.5±19.99^{a}	188.75±20.57^{a}
Bafogbali	58.5±5.58^{b}	99.25±11.23^{b}	157.58±21.65^{b}	168.25±17.62^{b}	169.08±17.98^{b}
Souantokoui	74.75±6.65^{a}	132±16.92^{a}	148.83±18.65^{b}	159.17±20.36^{b}	157.75±19.82^{b}
P	0.000***	0.000***	0.000***	0.000***	0.000***
P (WR*cultivar)	0,732ns	0.834ns	0,205ns	0.851ns	0.8289ns

RFU: Readily usable reserve, JAS: Number of days after sowing, P probability, *: significant effect, **: highly significant effect, *** very highly significant effect. Means in the same column followed by the same letter are not significantly different from the Student Newman Keuls test at 5% threshold, RI: hydrous regime.

Table 4 : Dates of inflorescences appearance based on water regimes and varieties.

Parameters	**Male flower**	**Female flower**	**Deviation**
Water regimes			
100 % RUR	46.56±2.78a	58.69±4.91b	12.13±3.22b
50 % RUR	46.69±3.3a	61.25±5.89b	14.56±4.80b
25 % RUR	47.25±4.43a	65.25±5.17a	18±4.73a
P	0.679ns	0.000***	0.000***
Cultivars			
EV DT 97	44.92±2.23c	58±6.59b	13.08±6.79a
Gbadé-holikou	48.08±2.61b	64.83±3.99a	16.75±3.89a
Bafogbali	50.25±3.41a	65.25±4.99a	15±4.33a
Souantokoui	44.08±1.56c	58.83±3.97b	14.75±3.77a
P	0.000***	0.000***	0.115ns
P (WR*cultivar)	0.083ns	0.021 *	0.007**

RUR: Readily usable reserve, JAS: Number of days after sowing, P probability, *: significant effect, **: highly significant effect, *** very highly significant effect. Means in the same column followed by the same letter are not significantly different from the Student Newman Keuls test at 5% threshold, RI: hydrous regime

Table 5 : Leaf area of maize cultivars according to irrigation regimes (cm^2).

Observation dates	**30 DAS**	**44 DAS**	**58 DAS**	**72 DAS**
Water regimes				
100 % RUR		1827.4±352.77^{a}	2283.82±504.12^{a}	2060.07±693.42^{a}
50 % RUR	-	1811.49±350.47^{a}	1910.2±519.16^{ab}	1684.19±569.83^{a}
25 % RUR		1668.22±411.54^{a}	1674.13±615.11^{b}	1532.68±644.29^{a}
P		0.432ns	0.018 *	0.097ns

Cultivars				
EV DT 97	585.24±128.05[ab]	1791.46±268.01[a]	1701.02±384.57[a]	1586.59±528.05[a]
Gbadé-holikou	534.696±103.59[b]	1793.72±248.72[a]	1999.88±574.91[a]	1753.73±676.32[a]
Bafogbali	552.913±184.03[b]	1576.35±434.21[a]	2051.22±678.57[a]	1995.41±763.55[a]
Souantokoui	713.7±160.78[a]	1914.61±451.05[a]	2072.08±684.44[a]	1700.2±680.12[a]
P	0.040 *	0.193ns	0.374ns	0.527ns
P (WR* cultivar)	-	0.981ns	0.744ns	0.927ns

WR: Water regimes; RUR: Readily usable reserve, DAS: Number of days after sowing, P: probability, *: significant effect, **: highly significant effect, *** very highly significant effect. Means in the same column followed by the same letter are not significantly different from the Student Newman Keuls test at 5% threshold, RI: hydrous regime

Table 6 : Chlorophyll content of varieties (SPAD unit).

Observation dates	**30 DAS**	**51 DAS**	**72 DAS**
Water regimes			
100 % RUR		40,2±3,51[a]	40,33±4,02[a]
50 % RUR	-	40,68±3,79[a]	39,77±5,19[a]
25 % RUR		38,55±3,47[a]	39,78±5,73[a]
P		0,147ns	0,941ns
Cultivars			
EV DT 97	39,57±1,64[a]	39,32±3,72[ab]	40,14±4,71[a]
Gbadé-holikou	37,47±2,22[b]	41,36±2,99[a]	40,68±4,16[a]
Bafogbali	37,55±1,75[b]	37,39±3,91[b]	38,99±6,7[a]
Souantokoui	38,13±1,87[ab]	41,15±2,68[a]	40,02±4,22[a]
P	0,039 *	0,013 *	0,881ns
P (WR*cultivar)	-	0,681ns	0,965ns

RUR: Readily usable reserve, DAS: Number of days after sowing, ns: not significant, P probability, *: significant effect, **: highly significant effect, *** very highly significant effect. NRP: number of primary roots, LRP: main root length, VR: root volume, MSR: dry material root. Means in the same column followed by the same letter are not significantly different from the Student Newman Keuls test at 5% threshold, RI: hydrous regime

Table 7 : Values of root characteristics of maize varieties.

Characteristics	**NRP (L>1cm)**	**LRP (cm)**	**MSR (g)**	**VR (cm3)**
Water regimes				
100 % RUR	46.63±40[a]	20.66±8.38[a]	5.52±2.37[a]	40.25±12.31[a]
50 % RUR	43.88±14.50[a]	21.56±14.32[a]	5.25±3.56[a]	39.31±22.82[a]
25 % RUR	38.19±9.04[a]	18.74±11.25[a]	2.78±1.57[b]	21.75±10.47[b]

P	0.164ns	0.768ns	0.006 **	0.002 **
Cultivars				
EV DT 97	35.17±6.88^{a}	21.54±10.73^{a}	2.475±1.33^{c}	21.5±8.93^{b}
Gbadé-holikou	43.08±11.39^{a}	20.62±15.46^{a}	5.617±2.24^{ab}	41.75±16.87^{a}
Bafogbali	48.33±9.73^{a}	21.63±9.30^{a}	6.19±3.58^{a}	42.17±20.81^{a}
Souantokoui	45±16.95^{a}	17.5±10.06^{a}	3.78±2.41^{bc}	29.67±15.99^{ab}
P	0.084ns	0.781ns	0.003 **	0.004 **
P (WR*Cultivar)	0.858ns	0.164ns	0.995ns	0.934ns

RUR: Readily usable reserve, ns: not significant, P probability, *: significant effect, **: highly significant effect, *** very highly significant effect. NRP: number of primary roots, LRP: main root length, VR: root volume, MSR: dry material root. Means in the same column followed by the same letter are not significantly different from the Student Newman Keuls test at 5% threshold, RI: hydrous regime

Table 8 : Number of cobs by plant and average weight of 1000 seeds.

Parameters	**Number of cobs by plant**	**Weight of 1000 seeds (g)**
Water regimes		
100 % RUR	0.855±0.38^{a}	264.63±53.58^{a}
50 % RUR	0.64±0.019^{b}	223.88±37.9^{b}
25 % RUR	0.58±0.17^{b}	217.63±42.66^{b}
P	0.009 **	0.007 **
Varieties		
EV DT 97	0.86±0.39^{a}	264.33±30.39^{a}
Gbadé-holikou	0.6±0.19^{b}	210.17±32.25^{b}
Bafogbali	0.55±0.15^{b}	230.67±56.59^{ab}
Souantokoui	0.74±0.29^{ab}	236.33±58.74^{ab}
P	0.020 *	0.031 *
P (RI*variety)	0.507 ns	0.372ns

RFU: Readily usable reserve, ns: not significant, P probability, *: significant effect, **: highly significant effect, *** very highly significant effect. Means in the same column followed by the same letter are not significantly different from the Student Newman Keuls test at 5% threshold, RI: hydrous regime

DISCUSSION

The availability of genetic variability is essential in plant breeding. His demonstration by the use of morphological characters is the first essential step in genetic resources description (Radhouane, 2004). Descriptive analysis showed significant differences among the values for all agro-morphological and physiological characteristics studied.

Water regime had a significantly negative effect on all studied characters. Indeed, the severe water stress (25% RUR) and extended significantly reduced height growth of plants relative to control non-stressed, and all varieties are affected. This result is linked to insufficient water for plants. This situation could disrupt some of their physiological functions including growth. Many authors have reported similar results on different cultures. Ahmad et al. (2017) noted that water stress decreased the physiological parameters of maize compared to non-stress. On sorghum, Osman et al. (2014) obtained a significant reduction in morphological characters including plant height due to water stress. Also, the similar results were reported on sesame (*Sesamum indicum*) and on two lines of cowpea (*Vigna unguiculata*) and showed that water stress during vegetative phase reduced plant growth (Compaoré et al., 2011; Aziadekey et al., 2014). The reduction of aerial part during the lean hydrous periods with stomatal closure is one of the plants adaptation strategies to water stress. This strategy seems to be implemented by studied local cultivars and control variety to limit the effects of water stress imposed.

The date of inflorescences onset or cycle planting-flowering is an important agronomic parameter that reflects the precocity. The results showed that the date of female flowering was longer with reduced water intake. This delay was 2 with moderate water stress (50% RUR) and 6 with the lowest water availability (25% RUR) compared with control without stress (100% RUR). Maize plants had to delay some of their physiological functions under water stress effect. The most affected is the control variety EV DT 97 with a delay of about 11 days. The cultivars Gbadé-holikou, Bafogbali and Souantokoui less affected. Contrary results were found in okra (Aziadekey et al., 2013). These authors showed then, the extended drought accelerates flowering that occurs 2 to 3 days earlier compared to control without stress. This seems to be a reaction of certain species survival, which conducts them to enter early in the reproductive phase during excessive stress in order to ensure renewal by descent.

Water stress reduced significant the leaf area. This result could be explained by the lack of water to the plants to adequately ensure this physiological function. This situation combined with transpiration loss of water would force plants to reduce their leaf area to adapt to the water conditions imposed on them. A sharp reduction in leaf growth parameters including width, length and leaf area of maize was obtained under water stress conditions (Avramova et al., 2016; Li et al., 2018). Or the intercepted radiation proportion is estimated from the leaf area which is therefore an important variable in crop production determination. Similar results were also found on durum wheat (Adra, 2010) and on sesame (Compaoré et al., 2011). Water stress (50% and 25% RUR) had also resulted in a leaf area reduction of plants during the flowering period and all studied maize cultivars are affected. These authors indicated that flowering phase is the most sensitive to water stress application. Indeed, the leaf area is an important determinant of perspiration and one of the first responses of plants to water deficit is to reduce the leaf area (Lebon et al., 2004). This decrease is one of plants responses to dehydration. It helps in water resources conservation, allowing plant survival (Lebon et al., 2004).

The water stress effect on total chlorophyll content was not significant. Contrary results were reported by other authors. Indeed, a decrease in chlorophyll content was observed in corn under water stress conditions compared to non-stress. (Avramova et al., 2016; Ahmad et al., 2017; Li al., 2018). On the other hand, Adra (2010) found an increase in total chlorophyll content and Amoumen et Benhebireche (2013) obtained decrease in chlorophyll content in water stress conditions in durum wheat. It is important to note that these authors worked on wheat. Despite the absence of negative effect of water stress on chlorophyll content, it was observed a decrease in total chlorophyll content on the cultivar Bafogbali the 51st and 72nd DAS, and on cultivar Souantokoui 51st DAS in water stress conditions compared with normal condition. This behavior would depend on intrinsic characteristics of each genotype reflecting different adaptive strategies to water stress. When the plant is subjected to water stress, the level of chlorophyll decreases, affecting the color of the plant and slowing down its growth activities (Amoumen et Benhebireche, 2013). Indeed, it appears that the chlorophyll content is a key indicator of measures such as physiological status, photosynthetic capacity and stress conditions. The fall of total chlorophyll content observed in Bafogbali and Souantokoui cultivars probably results from the synergy of several factors: reduced stomatal opening that limits water losses through evapotranspiration and increase of resistance, decrease of CO_2 atmospheric entry for photosynthesis. However, in cultivar Gbadé-holikou, it was found the opposite effect in water stress conditions (25% and 50% RUR). The increase in total chlorophyll content would be a consequence of the size reduction of leaf cells under water stress effect which generates a higher concentration.

A well-developed root system would allow the plant to supply of water into deeper soil layers when this one isn’t available on the surface. The sustained growth of root system under stress conditions would be a resistance factor to water stress. No root characteristic has been improvement in water stress conditions in maize varieties compared. Moreover, the reduction of the volume and root dry weight under severe water stress (25% RUR) compared with normal condition was significant. This result is similar to those obtained by Sayar et al. (2008). Indeed, the root dry matter would be used to produce new roots, their proliferation (root volume), their elongation (increase in length) and their maintenance. These characteristics can be very beneficial on two levels, promoting better extension of root system (Manske et Vlek, 2002) and maintaining soil humidity for grain filling towards development cycle end.

Primary roots number emitted along main roots length haven’t changed significantly from a water regime to another. Our results are contrary to those of Temagoult (2009) which obtained that root total length decreases in maize and increases in millet and sorghum under drought stress, and those of El fakhri et al. (2010) who found the emitted primary roots number and the main root length increased in nine of the ten durum wheat varieties tested. The fact that Bafogbali and Gbadé-holikou genotypes have root volumes and dry material root quantities significantly higher than EV DT 97 and Souantokoui proves that these two cultivars produced primary roots longer than those of EV DT 97 and Souantokoui cultivars. El Fakhri et al. (2010) reported that root volume increases depending on the number and root length, and this explained by the positive correlation between root parameters. The total root length indicates deep rooting for water pumping in-depth when it is limited in the upper soil layers (Curtis et al., 2002). This trait is particularly important on crops that regularly suffer from hydrous deficits of cycle end. Its impact on yield is particularly high because it is directly involved in the efficiency use of water stress conditions. These different results also reflect high genetic diversity existence between these genotypes. The maize root system architecture is genetically controlled (Hochholdinger et al., 2017).

The average number of cobs per plant was generally low in the three water regimes. Indeed, during the entire test period within the greenhouse, a high heat due to the temperature increase was noticed. The low air circulation in the greenhouse could also be a factor limiting maize plants production; which could also adversely affect maize yield. Crop yields such as millet, sorghum, maize, rice and wheat may drop by more than 10% if the temperature rises from 1 °C to 5 °C (Tripathy Rojalin Ray et Singh, 2008). The yield components evaluated in this study were significantly reduced by the imposed hydrous stress. The values of number of cobs per plant and weight of 1000 seeds decreased with the reduction of applied water levels. These losses of average number of cobs per plant and average weight of 1000 seeds would be due to the lack of water for the different plant development phases. Our results are similar of Çakir (2004) who found a fall in yields per hectare and grain per ear and the weight of 1000 grains of maize under water stress. Agbossou et al. (2012) also reported that exposure of maize to more dry than wet periods during its cycle results in reduced yield. Similar results were also obtained on other crops. Aziadekey et al. (2014) were founded that all yield components of two cowpea lines including the number of pods per plant, mass of seeds per plant, weight of 100 seeds and number of seeds per pod were significantly reduced by an extended water stress. On the other hand, Osman et al. (2014) found in their study on the effect of water stress on five local cultivars of sorghum, a significant improvement in the number of grains. The weight of grains was not so affected by water stress. Note that these components were less affected in Bafogbali and Gbadé-holikou cultivars. Indeed, the considerable decline in the maize yield on the control variety (EV DT 97) and cultivar Souantokoui under water stress conditions can only be explained by the poor performance of their root systems not enabling them to supply water. Many studies showed a positive correlation between rooting depth and grain yield. Indeed, the varieties characterized by a low root volume, produced less cobs per plant under water stress. Mu et al. (2015) found at the end of their work a positive relationship between the root system of the plant, which would facilitate the supply of water and mineral elements of the plant, and improved grain yield of corn. Selection for drought resistance can be based on the length of the longest root. Thus, Bafogbali and Gbadé-holikou cultivars have shown more interesting root characteristics, indispensable for hydrous stress resistance.

Conclusion

After this study that focused on the agro-physiological characterization of three maize local cultivars (Bafogbali, Gbadé-holikou and Souantokoui) for their resistance to water stress, it appears that water stress has a significant impact on most of measured parameters. The results show a decrease in plant height, leaf area, volume and dry material root and even the production of cobs per plant and weight of 1000 seeds under water stress conditions. These results evidence positive correlation between souterrain and aerial plants parts, and root system importance in plant production improvement. Thus, the varieties with more developed root system showed less loss of production. These results also showed high genetic variability among compared genotypes. From our results, the cultivar Bafogbali showed the best adaptive response to water stress conditions. This cultivar is more drought resistant than improved variety EV DT 97 which is considered as drought tolerant by the researchers of National Center for Agricultural Research of Benin. To better refine the results, this study should be continued in order to assess all yield parameters taking into account the influence of other abiotic and biotic factors affecting agricultural production *in situ*.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS’ CONTRIBUTIONS

All authors contributed to the realization of this work. They also read and approved this manuscript.

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