Phenotypic Evaluation of Groundnut Germplasm under Drought and Heat Stress[2]

F Hamidou[1*], **V Vadez**[2]
[1]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Sahelian Center, BP 12404, Niamey, Niger; E-mail: f.hamidou@cgiar.org ;
[2]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India
*Corresponding author

Abstract

A groundnut germplasm (268 genotypes) was evaluated in four trials over a period of two years, under intermittent drought and fully irrigated conditions. Two trials were exposed to moderate temperature during the rainy season while the two others were subjected to high temperature during summer. The objectives were to segregate the components of the genetic variance and their interactions with water treatment, year and environment (temperature) for agronomic characteristics so as to select high yielding genotypes under hot conditions and to identify traits putatively related to heat and/or intermittent drought tolerance. Under high temperature conditions, drought stress reduced pod yield up to 72% compared to 55% at moderate temperature. The haulm yield decrease due to drought was 34% at high temperature and 42% under moderate temperature. Haulm yield tended to increase under high temperature. For the three traits, genotype by environment interaction (GxE) was significant under well-watered (WW) and water stressed (WS) treatments. The genotype and genotype by environment (GGE) biplots analyses revealed several mega environments under WW and WS treatments indicating that high yielding genotypes under moderate temperature were different from those at high temperature. The GGE biplots analyses also revealed several genotypes with high performance and stability across year and temperature environments under both WW and WS conditions. Regression analyses indicated that among several traits measured during plant growth, only the partition rate was significantly correlated to pod yield suggesting that this trait was contributing to heat and drought tolerance and could be a reliable selection criterion for groundnut breeding program for this stress.

Keywords: High temperature; Genotype-x-Environment interaction; yield; harvest index, reproduction, groundnut

Evaluation phénotypique du matériel génétique de l'arachide en conditions de sécheresse et de stress thermique

Résumé

Un matériel génétique de l'arachide (268 génotypes) a été évalué dans quatre essais au cours de deux ans en conditions de sécheresse intermittente et entièrement irriguées. Deux essais ont été exposés à température modérée en saison des pluies, tandis que les deux autres ont été soumis à des températures élevées en été. Les objectifs étaient de décomposer la composante de la variance génétique et de leurs interactions avec le traitement de l'eau, l'année et l'environnement (température) pour les caractéristiques agronomiques, sélectionner des génotypes à rendement élevé en conditions chaudes, et identifier les traits supposés liés à la chaleur et/ou tolérant à sécheresse intermittente. Dans des conditions de haute température, la baisse du rendement de cabosses due au stress de la sécheresse réduit à hauteur de 72% par rapport à 55% à température modérée.

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La baisse de rendement des fanes due à la sécheresse était de 34% à haute température et de 42% à température modérée. Le rendement des fanes tend à augmenter sous haute température. Pour les trois traits, par l'interaction du génotype par l'environnement (GXE) était importante sous traitements à arrosage abondante (WW) et au stress hydrique (WS). Les analyses biplots de génotype et du génotype par l'environnement (GGE) a révélé plusieurs méga-environnements sous traitements WW et WS indiquant que les génotypes à haut rendement à température modérée étaient différentes de celles à haute température. Les analyses biplots GCE ont également révélé plusieurs génotypes à haute performance et stabilité au cours de l'année et des environnements de température sous conditions du WW et du WS. Les analyses de régression ont indiqué que parmi plusieurs traits mesurées au cours de la croissance des plantes, que seul le taux de partition a été significativement corrélée au rendement en cabosses suggérant que ce trait a contribuait à la tolérance à la chaleur et la sécheresse et pourrait être un critère de sélection fiable pour les programme de sélection de l'arachide.

***Mots-clés**: Température élevé; interaction Génotype-x-Environnement; rendement; indice de récolte, reproduction, arachide*

Introduction

Climatic changes and variability in the Sahel, resulting in increased drought intensity and high temperatures, will decrease groundnut yield up to 11 to 25% by 2025 (Van Duivenbooden *et al*., 2002). Plant responses to high temperatures vary with plant species and phonologic stage (Wahid *et al*., 2007). In most plants, high temperatures affect the reproductive processes and lead to reduced crop yield. Although, under field conditions drought stress is often associated with high temperature stress in the Sahel, the impacts of drought and high temperature stress on groundnut productivity have mostly been studied, one independent of the other. However, some works have reported the existence of a strong relationship between the plant water status and temperature, thus making it very difficult to separate the contributions of heat and drought stress under field conditions (Vara Prasad *et al*. 2008). Temperature tolerance is an important component of drought resistance and a necessary attribute for varieties destined for the Sahel. This is because large gaps in the rains that cause drought are also accompanied by high temperatures. Moreover, some authors have shown that heat tolerance results in improved photosynthesis, enhanced assimilate partitioning, water and nutrient use efficiency, and membrane stability (Momcilovic and Ristic, 2007). Therefore, in order to improve groundnut productivity in the Sahel as the climate changes, and to predict the consequences of climate change on its productivity, combined effects of heat and drought on physiological traits, yield and its attributes needs to be investigated. The goal of this study was therefore to identify genotypes with specific or combined tolerance to drought and heat.

Materials and Methods

<u>Experimental conditions</u>: Trials were undertaken in the field at the ICRISAT Sahelian Centre (ISC) in Sadore, Niger, 45 km south of Niamey. Two trials were conducted during the rainy seasons of 2008 and 2009 characterized by moderate temperatures (MT08 and MT09) between August and December, and two others during conducted in the summer seasons of 2009 and 2010 characterized by high temperature (HT09 and HT10) between February and June. The moderate temperature experiments were used here to test the genotypic and genotype-by-environment interactions with the high temperature trials. The field was irrigated twice before sowing. Two hundred and sixty eight (268) genotypes, consisting of 259 entries of the groundnut reference collection and 9 farmers preferred varieties, were evaluated. The experimental design was an

incomplete randomized block design with water treatment as main factor and genotypes as sub-factor randomized within each factor and replicated five times. Plants were irrigated with 20 mm, two times in a week, until the time to impose drought stress.

Irrigation Management: In all experiments, two irrigations of 20 mm were done per week for all plots until flowering time (i.e. 30-35 days after sowing). During this period half of the plots were exposed to intermittent stress until maturity. The intermittent drought stress was imposed by irrigating water stress (WS) plots only once; whereas well-watered (WW) plots continued to receive normal irrigation. Thus, 40 mm were provided for irrigating all plots (WW and WS) before onset of flowering. Thereafter, irrigation was supplied to the WW plots only, based on the estimated evapotranspiration. The next irrigation was supplied to all plots (both WW and WS) and the decision to irrigate was based on a leaf wilting assessment of the WS plots, irrigation being supplied when the wilting score of the WS plots reached a value of 3 (Ratnakumar *et al*. 2009; Bhatnagar-Mathur *et al*. 2007).

Measurements**:** The following were measured during crop growth period: soil temperature at 5cm and 10 cm at the hottest period of the day; ambient air temperatures and relative humidity; time of emergence and time to flowering; time to maturity and time to harvest. To record the maturity date, border plants were randomly picked, pods number was counted and the internal pod wall was examined for pod maturity. At harvest, the entire two rows per plot were sampled (2 m^2). The plants were air-dried, and pods were separated from haulms. For each plot, haulm weight and pod weight were recorded. Crop growth rate (CGR, kg ha^{-1} per day), pod growth rate (PGR, kg ha^{-1} 168 per day); and partitioning (P, proportion of dry matter partitioned into pods) were estimated according to Ntare et al., 2001.

Results

Weather**:** The VPD of the four experiments indicate that the VPD of HT09 and HT10 (3.68 and 3.66 kPa respectively) were higher than the VPD of MT08 and MT09 (2.0 kPa and 1.8 kPa respectively). The highest temperature (41^{0}C in average) was also observed during high temperature experiments. The soil temperature recorded at 5cm reached 49^{o}C during high temperature compared to 42^{0}C during the moderate temperature season experiments. At 10cm, the soil temperature in the high temperature season was also higher than in the moderate temperature season.

Water, genotype and genotype x water interaction**:** Analyses of variance (ANOVA) revealed significant water treatment (Trt), genotype (G) and genotype by treatment (GxTrt) effects for pod yield (Py), haulm yield (Hy) and harvest index (HI) of the 268 genotypes for both HT09 and HT10 experiments. The magnitude of G and GxTrt effects was similar for each of the traits in both years. Under fully irrigated conditions the trial mean for pod yield was similar in the high temperature and the moderate temperature seasons. The pod yield ranged from 1.1 to 3.4 t ha^{-1} under WW conditions and from 0.4 to 1.7 t ha^{-1} under WS treatment indicating a large genotypic variation in the germplasm. The haulm weight during the high temperature regime was higher than in the moderate temperature seasons, especially in the HT09 trial (Figure 1). Interestingly, HI in moderate temperature seasons (0.38 and 0.37) was slightly higher in the high temperature seasons (0.25 and 0.34). The duration of the experiments in high temperature seasons was 130 days compared to 120 days in the moderate temperature seasons. The three agronomic traits, Py, Hy and HI, decreased significantly under drought conditions in both moderate and high temperature experiments (Figure 1). For pod yield, the decrease due to drought stress was lower in the MT08 and MT09 (55 and 38% respectively) than in the HT09 and HT10 regimes (72 and 59% respectively). These results indicate that the intermittent drought stress had a more severe effect on pod yield during high temperature than during the moderate temperature regimes. Drought stress decreased the HI under the high temperature regimes (50 and 33% in HT09 and HT10, respectively) than under moderate temperature (25% for both MT08 and MT09). This was not the case for the haulm yield which decreased less in the high temperature seasons (34 and 11%) than in the moderate temperature regimes (42 and 31%).

Genotype and Genotype x Environment: In order to test the hypothesis that 'the selection of high yielding genotypes under WW and or WS conditions in the moderate temperature regimes would be different from those selected during high temperature regime a GGE biplot analysis was performed. ANOVA analysis indicated that large GxE took place. Several GGE biplot analyses revealed the existence of mega environment effects, and this helped in identifying higher yielding genotypes under WW and WS conditions within and across moderate and high temperatures. GGE biplot represents graphically the genotype (G) main effects plus genotype-by-environment interaction (G×E) effects (Figure 2). It also shows each genotype's position across the environments based on its mean performance and stability. Under WW conditions, four mega environments were observed while there were three mega environments under WS conditions. The existence of mega environments under both WW and WS indicates that genotypes behaved differently across environments. Figure 2 shows also that genotypes located at the vertex of the polygon were the highest yielding in each environment. In addition to their specificity to stress adaptation, some genotypes such as 111 and 205 were shown to be adapted to both moderate and high temperature regimes. Thus, based on GGE biplot analyses for ranking the genotypes, the most adapted (or highest yielding) and least adapted (or lowest yielding) in moderate (MT), high (HT) and across both moderate and high temperature (MTHT) environments were selected.

Correlations between pod yield and traits: Amongst the traits measured during the four experiments MT08, HT09, MT09 and HT10, only the partition rate (P) showed significant correlation with pod yield under both WW ($r^2 = 0.17$, $r^2 = 0.25$, $r^2 = 0.18$, $r^2 = 0.22$, respectively) and WS ($r^2 = 0.47$, $r^2 = 0.19$, $r^2 = 0.16$, $r^2 = 0.21$).

Discussion

Wide genotypic variations were observed in this study for pod yield, haulm yield and harvest index under control (WW) and drought (WS) conditions across seasons. The negative effect of drought stress on pod yield was higher under high temperature seasons (72%) than under moderate temperature seasons (55%) confirming earlier studies (Girdthai *et al*., 2010; Mothilal *et al*., 2010). The HI decrease during high temperature treatment under WW conditions suggests an effect of the high temperature on the reproductive processes, but not on plant growth. The differences in pod yield between moderate temperature and high temperature seasons could be explained by a higher growth during high temperatures during which there is a longer duration of the crop growth, than in the moderate temperature season. Also, the differences in VPD between the seasons could have played a major role in pod development. Under high temperatures combined with drought stress, the effect of heat on the reproductive processes was very high. Thus, in additions to drought which affected several physiological processes, high temperatures had a further depressing effect on the reproductive processes thus resulting to the observed low pod yield and harvest index. It had been previously reported that reproductive processes in groundnut were sensitive to temperature changes (Craufurd *et al.* 2003). In addition, Ntare *et al.* (2001) showed that pod yield of groundnut genotypes declined by more than 50% when flowering and pod formation occurred as temperatures averaged 40°C. Results obtained from this current study indicate a difference in partitioning of photosynthates during high and moderate temperature regimes.

Songsri *et al* (2008) reported that the ability to partition dry matter into harvestable yields under limited water supply was an important trait for drought tolerant genotypes. In this study, genotypic and genotype by water treatment interactions (GxTrt) were both significant and had a similar magnitude in their effects for both high temperature regimes in 2009 and in 2010, thus indicating the need to select genotypes under each specific water treatment. The magnitude of GxE therefore suggests that the selection for best genotypes was specific to the screening environment, which was confirmed by GGE biplots. The mega environments observed under both WW and WS conditions revealed that genotypes behaved differently across environments. This indicated that for each water regime the highest yielding genotype in the moderate temperature regime differed from those in the high temperatures.

<u>Conclusions</u>: Contrasting genotypes (highest and lowest yielding for WW and WS) were identified during this study. Such contrasting material could be used in a breeding program to develop cultivars for specific environments with differing temperatures during water stress. The results obtained from these studies have further demonstrated the segregating responses of groundnut genotypes to drought and/or heat stress thus contributing to understanding the interaction of different mechanisms operating conjointly during these stresses. The highest yielding genotypes were those with high yields in different environments, with consistent production from year to year. Using GGE biplots, the broadly adapted genotypes across year and temperature for each of WW and WS treatments were selected. These genotypes could be considered as having the most "stable" yields across seasons. Thus, according to the target environment (moderate or high temperatures), the water treatment (WW, WS) and, the yield and stability, some of the genotypes could be recommended for specific environmental conditions. Finally, based on the correlation with pod yield, photosynthate partition rate could be used as selection criteria for improving intermittent drought and heat tolerance in groundnut. This would require further studies so as to identify additional traits putatively related to combined drought and heat stress.

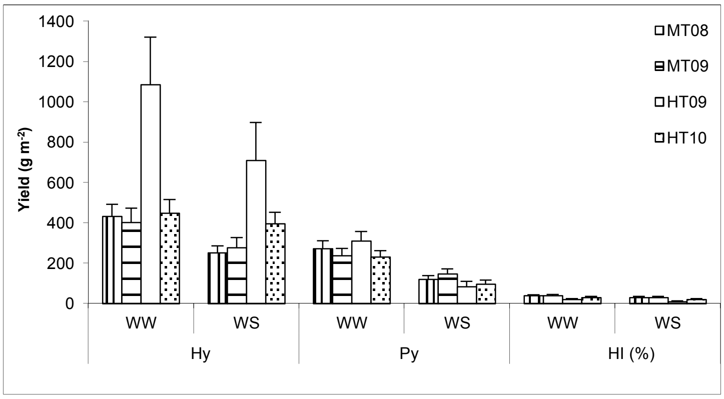

Figure 1: Trial means of pod yield (Py), haulm yield (Hy) and harvest index (HI) during MT08, MT09, HT09 and HT10 experiments at Sadore

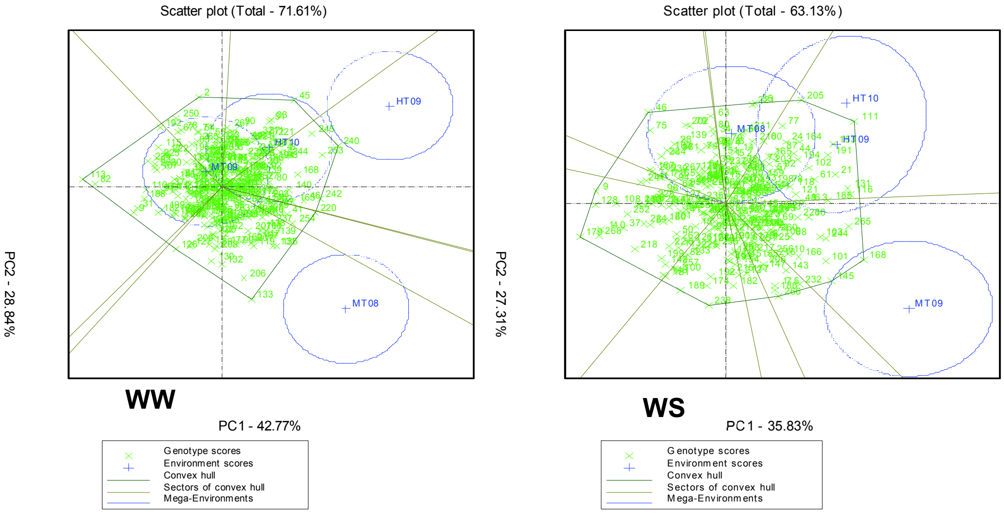

Figure 2: GGE biplot indicating the existence of mega environment under well-watered (ww) and water stress (ws) conditions in moderate (MT08, MT09) and high (HT09, HT10) temperatures.

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