Journal of Agricultural and Crop Research
Vol. 8(7), pp. 140-146, July 2020
doi: 10.33495/jacr_v8i7.20.116
ISSN: 2384-731X
Research Paper

Effect of heat stress on soil fertility and sowing date on yield components of sorghum in the Sudanian agro-ecological zone of Burkina Faso

Pane Jeanne d'Arc Coulibaly[1]* • Daniel Okae-Anti[2] • Badiori Ouattara[1] • Jacques Sawadogo[1] • Michel Papaoba Sedogo[1]

[1]Centre National de la Recherche Scientifique et Technologique, Institute de l'Environment et de Recherches Agricoles (CNRST/INERA), Ouagadougou, Burkina Faso.
[2]University of Cape Coast, Ghana.

*Corresponding author. E-mail: panecoul@yahoo.fr. Tel: (+226)71530607, (+226)77729799.

Accepted 11th March, 2020.

Abstract. Productivity of Sorghum has declined in recent years because of climate change. This study aimed to identify the impact of heat stress on soil fertility and sorghum yields and yield components. We conducted this study in Burkina Faso in 2014 under three sowing dates: 17 March (higher temperature: 41.1/23.9°C), 05 July (optimum temperature: 38.1/19.7°C) and 20 October (lower temperature: 31.08/21.8 °C). The study used a randomized split-plot design with four replications under irrigation, N fertilization and two sorghum varieties. The results revealed that cropping sorghum in March led to 46.36 and 68.26% of grain yield reduction compared to grain yields from July and October respectively. Grain yield obtained in March is negligible compared with the potential yields of *Kapelga* (2500 kg ha^{-1}) and *Sariaso 14* (5000 kg ha^{-1}). In this experiment, heat stress decreased grain yield with a higher degree than biomass as a result of which harvest index decreased up to 81.82 and 90.71% compared with the experiments conducted in July and October respectively. This temperature of 41.1/23.9°C significantly decreased content of major nutrients in the soil. Therefore, cropping sorghum in hot dryer condition would not be possible for achieving food security. Growing Sorghum within October might be a solution.

Keywords: Burkina Faso, climate change, heat stress, sorghum yields, soil fertility.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is an important food crop used in human nutrition in arid and semi-arid tropical regions. According to CIRAD (2019), its capacity to provide various ecosystem services makes it a crop of the future. In Africa in general, according to Obalum *et al*. (2011), sorghum stands the second most important crop after maize and is the most important crop in the semiarid tropics. In Burkina Faso especially, among the cereal crops, it is the first and representing 44% of total cereal crops produced (MASA, 2013).

Like other agricultural activities (over 95%) (Abrams, 2018), sorghum production in the Sudanian zone is mainly under rainfed condition. However, according to Abrams (2018), rainfall variability and evapotranspiration are predicted to increase, while annual average rainfall is likely to decrease in much of Africa as a result of climate change, increasing the vulnerability of rainfed agriculture. This increase in rainfall variability is predicted to decrease sorghum yield by 40% in South Africa (Alemaw and Simalenga, 2015) and by 20% in East Africa (Adhikari *et al*., 2015). In Saharan regions, the variability in climate could lead to crop and livestock losses

(Ayanlade *et al*., 2018); this loss means that all components of food security such as food availability, food accessibility, food utilisation and food stability (Kotir, 2011) and hence lead to unacceptable levels of poverty in sub-Saharan Africa (Zougmoré *et al*., 2018).

To mitigate these coming events in the Sudanian zone of Burkina Faso, a study has been conducted from 2014 to 2015 to enhance sorghum production seasons (Coulibaly *et al.*, 2018). Through this study, sorghum, often projected to be able to sustain productivity under harsher weather conditions, has been faced at one point to heat stress that considerably decreased sorghum yield. Several studies have confirmed that rise in temperature during grain filling period, reduced grain yield. According to Sehgal *et al.* (2018), high temperatures (day/night 33/28°C) between germination and initiation resulted in low grain yield. Their study showed that high temperatures at initiation and during the early phases of panicle development did not reduce floret production.

Moreover, according to Siebert (2014), even short exposure to heat stress can reduce crop yield considerably causing low resource use efficiency. This heat stress can also affect food security globally as it can lead to considerable yield losses (Sehgal *et al*., 2018). Through extensive regression modelling, some studies identify a temperature threshold of 33°C, beyond which sorghum yields start to decline (Tack *et al*., 2017). They show that in arid and semi-arid conditions, this decline is robust across both field trial and on-farm data. According to their report, moderate and higher warming scenarios of 2°C and 4°C led to 17% and 44% yield losses, respectively. In addition, according to some climate scenarios, even the most tolerant sorghum cultivars did not offer much resilience to warming temperatures (Tack *et al*., 2017).

This study was therefore undertaken to assess yield losses of sorghum cropped under varied climatic conditions. Specifically, it sought to (1) evaluate the impact of heat stress on sorghum yield and yield components, (2) evaluate the impact of heat stress on soil fertility, and (3) to assess the suitable sowing date of sorghum on its yield and yield components and on soil fertility.

MATERIALS AND METHODS

Description of the study site

We conducted this study in the research field station of the Agricultural and Environmental Research Institute of Saria (12°16' N, 2°9'W and 300 m of altitude) in the Sudanian area of Burkina Faso in 2014-2015 (Figure 1).

This area is located in an agro climatic zone with annual rainfall between 700 and 900 mm. The average monthly minimum temperatures during the study were 23.9, 19.7 and 21.8°C in the hot dried season, rainy season and cold dried season respectively and the average maximum temperatures were 41.1, 38.1 and 31.08°C in the hot dried season, cold dried season and rainy season respectively. We used the tropical ferruginous soil or Luvisols according to the World Reference Base for Soil Resources (FAO, 2006) to lead the experiments. This is the most dominant soils on which sorghum is produced in Burkina Faso. These soils had developed from granite rock as parent material and have upper horizons of sandy loam to sandy clay textures and generally with continuous and massive structure, slightly acidic and low in N, P, K, Ca, Mg and CEC.

Experimental design and treatments applied

Experimental factors were: (1) three sowing dates: 17 March (higher temperature: 41.1/23.9°C), 05 July (optimum temperature: 38.1/19.7°C) and 20 October (lower temperature: 31.08/21.8°C), (2) two nitrogen levels (0N and 60N) and (3) two sorghum varieties: *Kapelga* (100 to 105 days) and *Sariaso 14* (110 to 115 days). These experiments used a randomized split-plot design with four replications.

The dried seasons experiments were watered using drip irrigation system and the rainy season experiment was done under rainfed condition (without any supplementary irrigation).

Urea was the source of nitrogen and was applied in two equal half doses to the fertilized plants: the first dose was applied at 15 days after emergence and the second at 45 days after emergence.

From the two sorghum varieties: *Kapelga* is a local improved variety, while *Sariaso 14* is an improved variety developed in Saria research station.

Management of plots

The experimental area was ploughed with tractor and harrowed manually before planting. Basal applications of P at 23 kg ha^{-1} and K at 14 kg ha^{-1} were applied using triple super phosphate (TSP) and muriate of potash (KCl) respectively. The main plot size was 28.6 m × 7 m and the sub-plot size was 6.4 m × 7 m (8 lines). Seeds were sown by hand with a sowing density of 0.8 m between lines and 0.4 m between seed hills (16 seed hills). Measurements were done on 4 lines in the middle and concerned 12 seed hills.

Measurement of grain yield and yield components

Grain yield was determined after physiological maturity. Straw yield and grain yield were estimated in kilogram per hectare by dividing their weight by the harvested

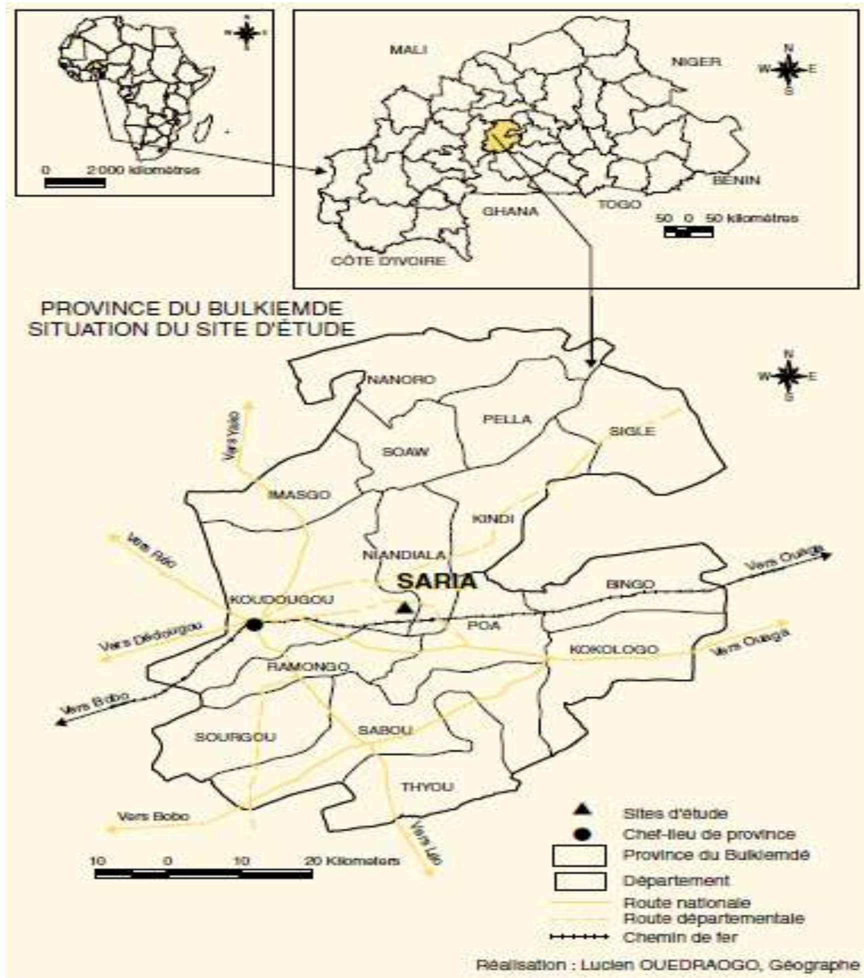

Figure 1. Location of the study site (Saria). Source: from Lucien Ouédraogo, geographer.

area. Similarly, the harvest index (HI) was calculated by dividing grain yield by the total above ground biomass. Thousand grains weight (TGW) was determined by counting 1000 grains.

Soil sampling and laboratory analysis

For each experiment, two composite soil samples were taken before sowing from depths of 0 to 20 cm and 20 to 40 cm. After harvest, soil samples were again taken from all treatment plots and at the same depths. The samples were air-dried and ground to pass through a 2 mm and 0.5 mm sieve. The samples were analyzed at the INERA Kamboinsé soil, water and plant analysis laboratory for physico–chemical that included particle size distribution, pH, N, P, K, Org C, Ca, Mg, and CEC. These analyses were done using standard analytical procedures. Soil organic C was determined using the Walkley and Black method. The pH was measured with a pH-meter (WTW InoLab, Weilheim, Germany). P and N were determined in the digest with a SKALAR automatic colorimeter (Skalar SANplus Segmented flow analyser, Model 4000-02, Breda, Holland). Soil available phosphorus was determined by the Bray-1 method. CEC and exchangeable bases (Ca, Mg) were determined using the silver thiourea method

Statistical analysis

The data on sorghum yield and yield components were subjected to analysis of variance and the simultaneous tests for general linear hypotheses and the multiple comparison of means were done using Tukey contrasts test with 95% family-wise confidence level through R software version 3.5.2 (2018-12-20). The means of soil chemical properties were compared using the L.S.D. at a probability level of 5% through GenStat 9th edition software. A correlation analysis using XLSTAT version 2016.01.26779 was also done to study the effect of heat stress on the selected physico-chemical properties.

Table 1. Analysis of variance of measured parameters.

			Means of squares					
17 March 2014	Source	df	Biom	PW	PY	GW	GY	HI
	varieties	3	102947607***	813688***	410444***	280328***	141404***	0.0004580**
05 July 2014	Source	df	Biom	PW	PY	GW	GY	HI
	varieties	3	4355270**	2379013***	1200028***	1142575***	609550***	0.018957**
20 October 2014	Source	df	Biom	PW	PY	GW	GY	HI
	varieties	3	3726816**	10123107***	5106326***	6141479***	3097902***	0.5872***

Biom: biomass; PW: Panicle weight; PY: Panicle yield; GW: Grain weight; GY: Grain yield; HI: Harvest index; **: Significant at the $p < 0.05$; ***: highly significant at the $p < 0.05$

Table 2. Mean comparisons of some yield and yield components under heat stress.

Sowing dates	Mean				
	Biom (kg ha^{-1})	PW (g)	GW (g)	GY (kg ha^{-1})	HI
17 March 2014	13489^{a}	618.43^{c}	339.69^{c}	241.26^{c}	0.019^{c}
05 July 2014	3489^{b}	1353.97^{b}	926.94^{b}	658.34^{b}	0.19^{b}
20 October 2014	3269^{c}	2918.27^{a}	1801.42^{a}	1279.42^{a}	0.39^{a}

Biom: biomass; PW: Panicle weight; PY: Panicle yield; GW: Grain weight; GY: Grain yield; HI: Harvest index; Means, in each column, followed by different letter (s) are significantly different at the 5% probability level.

RESULTS AND DISCUSSION

The results showed that sowing date and varieties had high significant ($p < 0.05$) effects on all measured parameters (Table 1).

Sorghum yield and yield components as affected by heat stress

The analysis of variance showed that sowing sorghum in hot dryer condition on 17 March 2014 under higher temperatures of 41.1/23.9°C significantly decreased sorghum yield and yield components while the biomass is highly increased (Table 2). These results revealed that cropping sorghum in March led to 46.36 and 68.26% of grain yield reduction compared to grain yields from the 05 July 2014 experiment under optimum temperature of 38.1/19.7°C and October 2014 experiment under lower temperature of 31.08/21.8°C respectively. The grain yield obtained in March was very negligible compared with the potential yields of the varieties *Kapelga* (2500 kg ha^{-1}) and *Sariaso 14* (5000 kg ha^{-1}). These results highlighted the impact of heat stress on sorghum yield. We noted that the temperatures during the cropping period of March were between 23.9 and 41.1°C. These high temperatures were the reason of significant yield reduction of sorghum cropped on 17 March 2014. The finding is in agreement with many others research results especially those of Prasad *et al*. (2017) and Sehgal *et al*. (2017) who reported that the reproductive processes and grain filling are the most sensitive to heat stress. Many empty panicles obtained in this study was due to panicle abortion under this higher temperatures (> 38°C). Such temperatures have been found by Hatfield and Prueger (2015), Singh *et al.* (2015) and Song *et al*. (2015) to cause pollen sterility in sorghum crop.

Contrary to grain yield, this study revealed high biomass of sorghum cropped in the hot dryer period (17 March 2014) (Table 2). The analysis of variance showed a significant increase of biomass up to 58.9% and 60.98% superior to the biomass from the date 2 and date 3. This increase in biomass resulted from the duration of the production cycle noted in this cropping period (Coulibaly *et al*., 2018). Prasad *et al.* (2008), from their study conducted under optimum temperature (OT) of 32/22°C and higher temperature (HT) of 40/30°C also found stem dry weight to be significantly higher at HT compared with OT, seed yields significantly lower and smaller harvest indices at HT compared with OT.

In the current study, Table 2 showed that heat stress affected harvest index considerably and caused harvest index to decrease in the experiment carried out on 17 March 2014. The significant decrease in harvest index from this experiment compared with the experiments conducted on 05 July and 20 October 2014 was up to 81.82 and 90.71% respectively. In this 17 March experiment, heat stress decreased grain yield with a higher degree than dry matter yield as a result of which harvest index decreased. The decrease in sorghum grain yield partly due to heat stress asserted the global concerns on climate change especially in the rising temperature that affect hugely food crop production

Table 3. Soil major nutrients decreased under heat stress.

Soil analysis	pH	P available	P	K	N	C	C/N	Ca^{2+}	Mg^{2+}	CEC
		mg kg^{-1}	g kg^{-1}					cmol kg^{-1}		
Initial sample	4.63	5.33	0.11	0.42	0.24	3.9	18.5	0.9	0.43	4.06
Sample of end	4.65	2.25	0.10	0.50	0.22	3.83	16.5	1.53	0.71	5.25
LSD	NS	0.28	NS	0.06	0.02	NS	1.20	0.08	0.04	0.22

P: Phosphorus; K: potassium; N: nitrogen; C: carbon, Ca^{2+}: ion calcium; Mg^{2+}: ion magnesium; CEC: cation exchange capacity; LSD: least significant difference; NS: no significance.

Table 4. Correlation among sowing dates, sorghum varieties and soil properties.

Variables	Ho	T °C	PET	WR	N level	Genotypes	pH	N	P	P Avail	K	C	C/N	Ca^{2+}	Mg^{2+}	CEC
Ho	**1**															
T °C	0.000	**1**														
PET	0.000	**0.922**	**1**													
WR	0.000	0.000	0.000	**1**												
N level	0.000	0.000	0.000	0.000	**1**											
Genotypes	0.000	0.000	0.000	0.000	0.000	**1**										
pH	**0.184***	0.014	**-0.223**	0.114	**-0.164**	-0.149	**1**									
N	0.079	**-0.263**	**-0.214**	-0.037	-0.037	0.077	-0.044	**1**								
P	-0.010	**-0.283**	**-0.200**	0.150	0.022	0.144	**-0.171**	**0.430**	**1**							
P Avail	0.020	**-0.267**	**-0.347**	0.148	-0.053	**0.161**	**0.247**	0.010	**0.366**	**1**						
K	**0.334***	**0.160**	**0.333**	0.051	-0.005	-0.012	**-0.262**	**0.185**	0.127	**-0.235**	**1**					
C	-0.028	0.108	**0.178**	-0.063	-0.043	**0.200**	-0.123	**0.588**	**0.298**	-0.080	0.127	**1**				
C/N	-0.106	**0.409**	**0.453**	-0.012	0.011	0.133	-0.129	**-0.386**	-0.108	-0.104	-0.024	**0.500**	**1**			
Ca^{2+}	**0.163***	0.039	0.051	0.103	-0.068	0.029	**0.236**	**0.262**	-0.154	**-0.410**	**0.177**	0.137	-0.117	**1**		
Mg^{2+}	**0.190**	0.099	0.123	0.088	**-0.245**	-0.044	**0.259**	**0.405**	0.043	**-0.246**	**0.246**	**0.226**	**-0.165**	**0.702**	**1**	
CEC	0.154	0.127	**0.286**	0.038	-0.012	-0.061	**-0.169**	**0.306**	0.101	**-0.281**	**0.357**	**0.259**	-0.005	**0.451**	**0.523**	**1**

The bold values indicate that the correlation is significant at the 5% probability level
Ho: horizon; T °C: temperature (°C); P: phosphorus; K: potassium; N: nitrogen; C: carbon, Ca^{2+}: ion calcium; Mg^{2+}: ion magnesium; CEC: cation exchange capacity; LSD: least significant difference; NS: no significance.

(Lobell *et al*., 2012).

Soil major nutrients as affected by heat stress

Soil fertility is a determinant yielding factor in sorghum production. However, many environmental stresses constrain its production in Sub-Saharan Africa. In this experiment conducted under heat stress, the analysis of variance (Table 3) and the correlation analysis (Table 4) showed that soil was negatively affected by nutrient depletion. Temperature of 41.1/23.9°C significantly decreased soil N, P, and P available. But under this temperature, K, exchangeable bases (Ca^{2+}, Mg^{2+}) and C:N ratio significantly increased (Table 3). This finding confirmed the assertion that conditions under which Sorghum is produced can negatively affect the environment including soil fertility itself (Reynolds *et al.*, 2015).

The decrease of soil major nutrients due to the

Table 5. Changes in nutrient content in the 20 October experiment.

Soil analysis	pH	P avail	P	K	N	C	C/N	Ca^{2+}	Mg^{2+}	CEC
		mg kg^{-1}	g kg^{-1}					cmol kg^{-1}		
Initial sample	5.20	3.71	0.08	0.45	0.22	3.31	15.5	2.02	0.78	5.96
Sample at end	5.14	5.41	0.11	0.31	0.25	3.38	13.54	1.46	0.63	3.46
L.S.D.	NS	1.115	0.008	0.02	0.02	NS	0.64	0.15	0.08	0.39

P: Phosphorus; K: potassium; N: nitrogen; C: carbon, Ca^{2+}: ion calcium; Mg^{2+}: ion magnesium; CEC: cation exchange capacity; LSD: least significant difference; NS: no significance.

temperature of 41.1/23.9°C and certainly to other natural stresses increase, also the concerns on the impact of climate change on sorghum production. Many researches predicted the increase in temperature over the years, and this will therefore affect soil fertility and food security through the decline in soil fertility and in sorghum yield.

Assessing the suitable sowing date of sorghum on its yield and yield components and on soil fertility

Mean comparisons of sorghum grain yield in each sowing dates (Table 2) showed that highest panicle weight, grain weight and yield, and harvest index were observed in sowing date of 20 October 2014 (under lower temperature of 31.08/21.8°C). The increase of grain yield in this experiment compared with the experiments from March and July was up to 68.26 and 32.06% respectively. In addition, a high degree of increase in harvest index in this experiment compared with March and July experiments was assessed to 90.70 and 50%, respectively. The study also indicated that cropping sorghum in the period starting from 20 October is beneficial to soil fertility as soil major nutrients such as available P, P, K and N contents were increased (Table 5).

The mild temperature of 31.08/21.8°C favoured therefore soil fertility, yield improvement, and led to early maturation of sorghum (Coulibaly *et al*., 2018). The much improvement of grain yield and harvest index in this 20 October experiment was linked to the fact that the low temperature prevented high evaporative demand. Water and nitrogen, which were supplied, were profitable to sorghum plants. This finding is in accordance with the conclusions of Blum (2009) and Fixen *et al*. (2015), who observed that sorghum production was linked to the capacity to use efficiently water and nitrogen. The high grain yield and harvest index under this 20 October experiment was also due to the earlier maturation (Coulibaly *et al*., 2018) allowing this experiment to be more productive (Table 2).

CONCLUSION

This study highlighted the impact of heat stress on sorghum yield and yield components and on soil fertility. The temperature of 41.1/23.9°C significantly decreased soil N, P, and P available, leading to a significant decrease of sorghum yield and yield components. The grain yield obtained from 17 March experiment (241.26 kg ha^{-1}) was very negligible compared with the potential yields of the varieties *Kapelga* (2500 kg ha^{-1}) and *Sariaso 14* (5000 kg ha^{-1}). In the 17 March experiment, heat stress decreased grain yield with a higher degree than dry matter yield as a result of which harvest index decreased. This decrease in sorghum grain yield partly due to heat stress asserted the global concerns on climate change especially in the rising temperature that affect hugely food crop production. Therefore, cropping sorghum in hot dryer condition would not be possible for achieving food security issues but, the sowing date of 20 October might be a solution.

ACKNOWLEDGEMENTS

The lead author is grateful to the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) programme for providing funds for her PhD study. She is also grateful to the staff of the Institute de l' Environment et de Recherches Agricoles (INERA)/ Kamboinse especially to her field assistants and to the laboratory assistant who contributed a lot to the success of the study.

REFERENCES

Abrams L (2018). Unlocking the potential of enhanced rainfed agriculture. Report no. 39. SIWI, Stockholm. pp. 1-24.

Adhikari U, Nejadhashemi AP, Woznicki SA (2015). Climate change and eastern Africa: a review of impact on major crops. Food and Energy Secur. 4:110-132.

Alemaw BF, Simalenga T (2015). Climate Change Impacts and Adaptation in Rainfed Farming Systems: A Modelling Framework for Scaling-Out Climate Smart Agriculture in Sub-Saharan Africa. Am. J. Climate Change. 4:313-329.

Ayanlade A, Radeny M, Morton JF, Muchaba T (2018). Rainfall variability and drought characteristics in two agro-climatic zones: An assessment of climate change challenges in Africa. Science of the Total Environment 630: 728-737. doi: 10.1016/j.scitotenv.2018.02.196.

Blum A (2009). Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Res.112:119-123. doi: 10.1016/j.fcr.2009.03.009.

Centre de coopération internationale en recherche agronomique

pour le développement (CIRAD) (2019). Sorghum. Explore it at CIRAD. https://www.cirad.fr/en/our-research/tropical-value-chains/sorghum/context-and-issues.

Coulibaly PJA, Ouattara B, Gaiser T, Worou N, Tondoh JE, Okae-Anti D, Sedogo MP (2018). Cropping two sorghum varieties under irrigation, an intensification strategy to mitigate climate change induced effect in Burkina Faso, West Africa. IJAER, 04:593-609.

Kotir JH (2011). Climate change and variability in Sub-Saharan Africa: A review of current and future trends and impacts on agriculture and food security. Environment Development and Sustainability 13:587-605. doi: 10.1007/s10668-010-9278-0.

FAO (2006). World Reference Base for Soil Resources - a framework for international classification, correlation and communication. World Soil Resources Report, 103.

Fixen P, Brentrup F, Bruulsema WT, Garcia F, Norton R, Zingore S (2015). Nutrient fertilizer use efficiency: Measurement, current situation and trends. International Fertilizer Industry Association (IFA), International Water Management Institute (IWMI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI): pp. 8-38.

Hatfield JL, Prueger JH (2015). Temperature extremes: effect on plant growth and development. Weath Clim. Extr. 10:4-10.

Lobell DB, Gourdji SM (2012). The influence of climate change on global crop productivity. Plant Physiol. 160:1686-1697. doi: 10.1104/pp.112.208298.

Ministère de l'agriculture et de la sécurité alimentaire (MASA) (2013). Situation de référence des principales filières agricoles au Burkina Faso, note d'information.

Obalum SE, Amalu UC, Obi ME, Wakatsuki T (2011). Soil water balance and grain yield of sorghum under no-till versus conventional tillage with surface mulch in the derived Savanna Zone of South-eastern Nigeria. Exp. Agric. 47:89-109.

Prasad PVV, Pisipati, SR, Mutava RN, Tuinstra MR (2008). Sensitivity of grain sorghum to high temperature stress during reproductive development. Crop Sci. 48:1911-1917. doi: 10.2135/cropsci2008.01.0036.

Prasad PVV, Bheemanahalli R, Jagdish SK (2017). Field crops and the fear of heat stress-opportunities, challenges and future directions. Field Crops Res. 200:114-121. doi: 10.1016/j.fcr.2016.09.024.

Reynolds TW, Waddington SR, Anderson C, Chew L, True Z, Cullen AA (2015). Environmental impacts and constraints associated with the production of major food crops in Sub-Saharan Africa and South Asia. Food Sci., 7:795-822. doi: 10.1007/s12571-015-0478-1.

Sehgal A, Sita K, Kumar J, Kumar S, Singh S, Siddique KHM, Nayyar H (2017). Effects of drought, heat and their interaction on the growth, yield and photosynthetic function of lentil (Lens *culinaris Medikus*) genotypes varying in heat and drought sensitivity. Front. Plant Sci. 8:1776. doi: 10.3389/fpls.2017.01776.

Sehgal A, Sita K, Siddique KHM, Kumar R, Bhogireddy S, Varshne RK, HanumanthaRao B, Nair RM, Prasad PVV, Nayyar H (2018). Drought or/and Heat-Stress Effects on Seed Filling in Food Crops: Impacts on Functional Biochemistry, Seed Yields, and Nutritional Quality. Front Plant Sci. 9:1705. doi:10.3389/fpls.2018.01705.

Siebert S, Ewert F, Rezaei EE, Kage H, Gra R (2014). Impact of heat stress on crop yield - On the importance of considering canopy temperature. Environ. Res. Lett. 9: 1-13.

Singh V, Nguyen CT, van Oosterom EJ, Chapman SC, Jordan DR, Hammer G (2015). Sorghum genotypes differ in high temperature responses for seed set. Field Crops Res. 171:32-40. doi: 10.1016/j.fcr.2014.11.003.

Song Y, Tian Ci D, Zhang DQM (2015). Stable methylation of a non-coding RNA gene regulates gene expression in response to abiotic stress in *Populus simonii*. J. Exp. Bot. 67:1477-1492. doi:10.1093/jxb/erv543.

Tack J, Lingenfelser J, Jagadish SVK (2017). Disaggregating sorghum yield reductions under warming scenarios exposes narrow genetic diversity in US breeding programs. PNAS, 114:9296-9301. doi: 10.1073/pnas.1706383114.

Zougmoré RB, Partey ST, Ouédraogo M, Torquebiau E, Campbell BM (2018). Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks. Cah. Agric. 27(34001):9. doi: 10.1051/cagri/2018019.