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Impacts of rainfall and temperature on photoperiod insensitive sorghum cultivar : model evaluation and sensitivity analysis

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ABSTRACT

A combination of local-scale climate and crop simulation model were used to investigate the impacts of change in temperature and rainfall on photoperiod insensitive sorghum in the Sudanian zone of Mali. In this study, the response of temperature and rainfall to yield patterns of photoperiod insensitive sorghum (*Sorghum bicolor* L. Moench) using the Agricultural Production Systems Simulator (APSIM) model was evaluated. Following model calibration of the cultivar at varying sowing dates over two growing seasons (2013 and 2014), a long-term simulation was run using historical weather data (1981-2010) to determine the impacts of temperature and rainfall on grain yield, total biomass and water use efficiency at varying nitrogen fertilizer applications. The results showed that model performance was excellent with the lowest mean bias error (MBE) of -2.2 days for flowering and 1.4 days for physiological maturity. Total biomass and grain yield were satisfactorily reproduced, indicating fairly low RMSE values of 21.3% for total biomass and very low RMSE of 11.2 % for grain yield of the observed mean. Simulations at varying N-fertilizer application rate with increased temperature of 2 °C, 4 °C and 6 °C and decreased rainfall by 25 and 50 % (W-25% and W-50%) posed a highly significant risk to low yield compared to increase in rainfall. However, the magnitude of temperature changes showed a decline in grain yield by 10%, while a decrease in rainfall by W-25% and W-50% resulted in yield decline between 5% and 37%, respectively. Thus, climate-smart site-specific utilization of the photoperiod insensitive sorghum cultivar suggests more resilient and productive farming systems for sorghum in semi-arid regions of Mali.

Keywords: Crop simulation model, photoperiod insensitive, sorghum, rainfall, temperature

Among the many small grains that supply approximately 85% of the world's food energy, only three other foods (rice, wheat and maize) are consumed more than sorghum (ICRISAT, 2009). Sorghum is a dietary staple crop that contributes immensely to both domestic and commercial food needs as well as rural household income in most semi-arid environment. With about 24 million hectares under cultivation, sorghum in West Africa ranked the second most important crop after maize, but average yields are low with only 800 $kgha^{-1}$ (Maredia *et al.,* 2000; Akinseye, 2015). From 1979 to 2001, sorghum production in West Africa had increased from 5.1 to 13 million tonnes but regional mean yields were stagnant (890 kg ha^{-1} in 1979–81, 780 kg ha^{-1} in 1992–94) (FAO, 1997). Even with the development and release of improved high yielding sorghum varieties with short growth cycles, significantly higher productivity still a mirage due to unpredictable climatic condition, low inputs applied by farmers as well as low soil fertility (Ajeigbe *et al.,* 2018). However, rainfall and temperature remain key climatic variables to sorghum productivity. Sorghum production continues to depend mainly on traditional cultivars characterized by hardiness, photoperiod sensitivity, long stalks and low harvest index (Akinseye *et al.,* 2017).

MacCarthy *et al.* (2009) reported that there is compelling evidence that climate variability and change will affect crop yields and agricultural activities as seasonal changes in rainfall and temperature could alter growing seasons, planting and harvesting calendars, water availability, increased pest, diseases and parasitic weed (striga) populations. Therefore, altering the evapotranspiration rate, photosynthesis, biomass production, and land suitability for agricultural production (Adejuwon, 2004, Mark *et al.,* 2008, Dimes *et al.*, 2008). Schlenker and Lobell (2010) projected a yield decrease by mid-century (2046–65) of about 20% for C_4 cereals, driven by the increase in temperature. Report by Sultan *et al.* (2013), projected yield losses from millet and sorghum crops was induced by increase temperature leading to

Table 1: Cultivar- specific model parameters used in sensitivity analysis simulation: sources and values

Parameters	Source	Value	Units
Thermal time accumulation			
Duration- Emergence to end of juvenile	C	205	C day^0
Duration- End of juvenile to panicle initiation	C	201	C day^0
Duration-Flag leaf to flowering	C	140	C day^0
Duration- flowering to start of grain filling	C	80	C day^0
Duration- Flowering to maturity	C	580	C day^0
Duration- maturity to seed ripening	D	1	C day^0
Day length photoperiod to inhibit flowering	D	12.8	hours
Day length photoperiod for insensitivity	D	13.8	hours
Photoperiod slope	D	11.5	°C/h
Growing degrees day required to develop the most leaf ligules	C	41	°C day
Growing degrees day required to develop last leaf ligules	C	26.5	C day^0
Base temperature	L	10	C^0
Grain growth rate	C	0.00165	g
Radiation use efficiency	D	1.25	g/MJ

L: literature; D: default value; C: calibrated

increased potential evapotranspiration, crop maintenance respiration and a reduction of the crop-cycle length.

Sorghum yields were predicted to likely decrease by some 5 – 41% in the 21st century over West Africa because of the expected warming, irrespective of whether rainfall increases or decreases. Current innovations with farming system models including Agricultural Production Systems sIMulator (APSIM) provides an insight which integrates knowledge of soils, site information, crops, weather and management practices to estimate crop yield and water productivity (Keating *et al.,* 2003; Holzworth *et al.,* 2014; Mohanty *et al.,* 2017). It is therefore crucial to understand the uncertainty surrounding sorghum yield variability under different management practices, especially fertilizer application, considering that sorghum is one of the sustainable crops to current climate variability and future climate change. This study examined the impacts of rainfall and temperature on photoperiod insensitive sorghum cultivar relative to fertilizer applications using crop simulation model. The specific objectives are to; (i) calibrate and evaluate APSIM model to predict phenology, morphology and yields of photoperiod insensitive sorghum cultivars; (ii) model sensitivity to change in temperature and rainfall under different fertilizer application for grain yield total biomass and water use efficiency.

MATERIALS AND METHODS

Experimental data for model calibration and evaluation

The experimental data used for calibration and evaluation was conducted in 2013 and 2014 growing seasons at International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Bamako, Mali (12.52 °N and −8.07 °W). The experiment had sowing dates and varieties (10) as treatments in a randomized complete block design (RCBD) with four (4) replications. One out of ten (10) varieties tested was selected for this study which was characterized photoperiod insensitive sorghum cultivar (Cleget *et al.,* 2009; Akinseye, 2015).The cultivar name was S621B locally called "Bambey"; a pure-line cultivar developed at ICRISAT-Mali. Sorghum was cultivated under optimum conditions which implied no water and nitrogen stress for the growth conditions during the two growing seasons. In both seasons sorghum was sown at 25 days interval which began in June with three (3) planting dates in 2013 and two (2) in 2014 cropping seasons. These planting dates covered the widest range of farmer's sowing window for sorghum in Sudan savanna zone of Mali. Plant population was 67,000 hillsha^{-1} (0.75 m between rows and 0.20 m between hills) which was achieved by thinned to 1 plant/hill, 15 days after planting (DAP). In 2013 growing season, all the plots were fertilized using 100 kgha^{-1} of di-ammonium phosphate at sowing and 50 kgha^{-1} of Urea (46% N) at 40 days after planting. In addition to application rate used in 2013 growing season, 2014 sowing received two tonnes (2 tons) per hectare of manure prior to sowing incorporated during land preparation (which contain an organic matter content of 44% and C:N ratio of 12 and organic carbon content of 22%). Insecticides were used according to local recommendations and weeding was done manually. The detailed agronomic procedure and measurement has been reported by Akinseye (2015). Only the relevant crop parameters which include crop phenology (planting date, date of flowering and maturity), morphological traits (LAI and total leaf number per plant), grain yield and total biomass were evaluated in this study.

Long-term daily climatic records of rainfall (mm), solar radiation (MJm^{-2}), maximum temperature (^{o}C) and minimum temperature (^{o}C) were obtained between 1981 and 2010 from agroclimatological unit of ICRISAT-Bamako. Meanwhile, 2013 and 2014 daily records of the same weather parameters were downloaded from automatic weather station installed in less than 1 km radius from experimental plots were used for calibration and evaluation accordingly. Furthermore, the soil of the experimental plot sampled prior to sowing each year and characterized as a well-drained, sandy loam (55% sand, 35% silt, and 20 % clay), soil organic carbon content was low (0.24%) and associated with this, total N was measured as 225 mgkg^{-1}. High available phosphorus (Bray-I) of 94.5 mgkg^{-1} can be traced to a long history of P fertilizer use on the station, with a 2.47 cmolkg^{-1} CEC and a pH water of 5.3. Parameters in APSIM related to water dynamics such as runoff curve number and evaporation terms were defined as Probert *et al.* (1998) while additional soil variables not available in the laboratory analysed data were parameterized using APSIM soil protocol reported by Dalgliesh *et al.* (2016).

APSIM model overview, evaluation and sensitivity analysis

The APSIM model is a modular modeling framework (Keating *et al.,* 2003; Holzworth *et al.,* 2014), a farming system model that simulates crop growth and development based on environmental variables. Five in-built modules namely; sorghum crop module (APSIM-sorghum), soil water module (SoilWat), soil nitrogen module (Soiln), residue module (Residue) and the manure module (Manure) were used in this study. The sorghum modules were calibrated and evaluated within the APSIM (APSIM7.9) framework for the selected sorghum cultivar. Generally, input parameterization data required by the model include crop management information, cultivar specific parameters (genetic coefficient), soil properties and daily weather records specified. Crop management and cultivar information was derived from the field experiments described above. Parameterization of drained upper limit (DUL), lower limit of plant extractable water (LL15) and saturated water content (SAT), BD, and organic carbon content (OC), initial NH_4-H and NO_3-N and pH was done using measurements obtained from the experiment and published source reported by Dalgliesh *et al.* (2016). Genetic coefficients are expressed in thermal degrees and photoperiod. Crop development is controlled by temperature (thermal degree days) and photoperiod. Thermal time accumulations were derived using algorithm described in Jones and Kiniry (1986) using observed phenology and weather data, a base temperature of 10°C and an optimal temperature of 30°C. Potential biomass growth is a function of the intercepted radiation and the radiation-use efficiency. Water-limited growth is a function of water supply and the transpiration efficiency of the crop, which varies daily as a function of vapour pressure deficit. Actual biomass increase is simulated from either potential or water-limited growth as modified by temperature and N stresses.

Table 2: Model evaluations for phenological development across sowing dates

Parameter	Days to Flowering		Days to physiological Maturity	
Year/sowing	Observed	Simulated	Observed	Simulated
2013_SD_1	69	71	98	103
2013_SD_2	71	70	97	102
2013_SD_3	74	72	98	104
2014_SD_1	82	76	110	104
2014_SD_2	80	76	108	104
Mean	75	73	102	103.4
RMSE (days)		3.5		5.3
MBE (days)		- 2.2		1.4

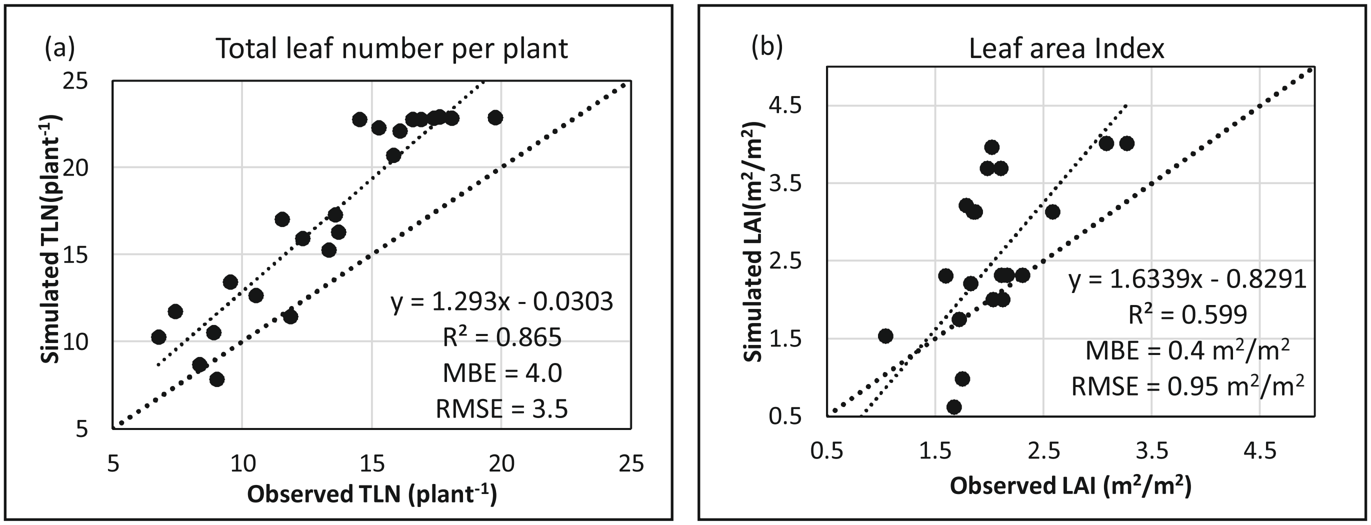

Fig.1: Comparison between model-simulated and observed values for (a) total leaf number (TLN) and (b) leaf area index (LAI) across sowing dates

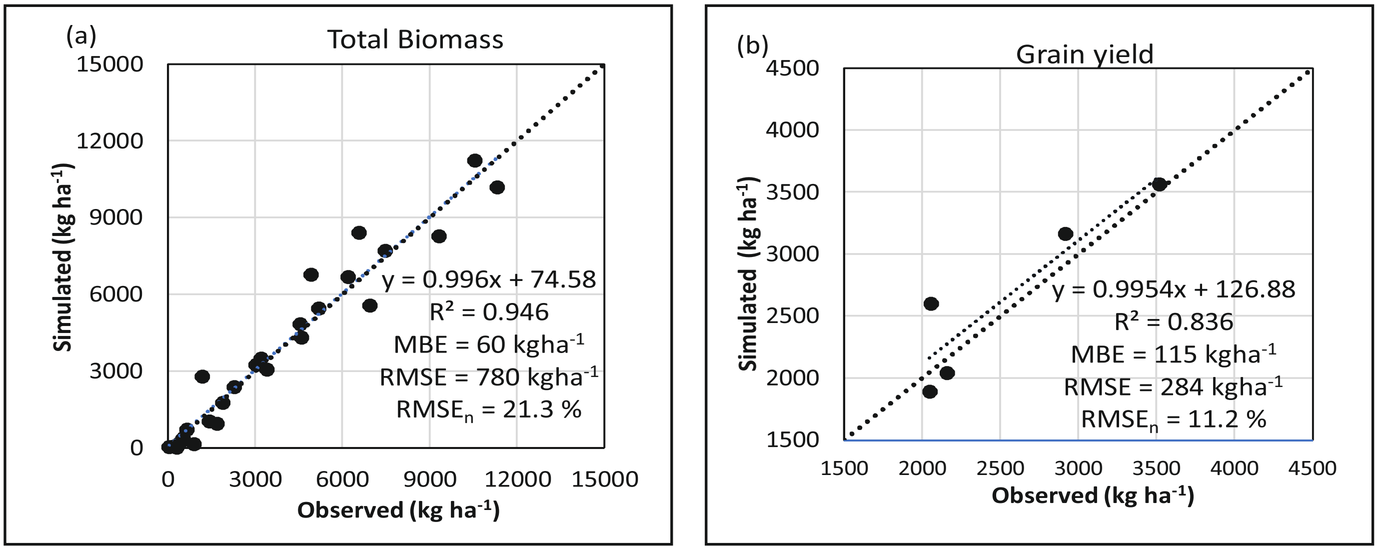

Fig.2: Comparison between model-simulated and observed values for (a) total biomass and (b) final grain yield across sowing dates

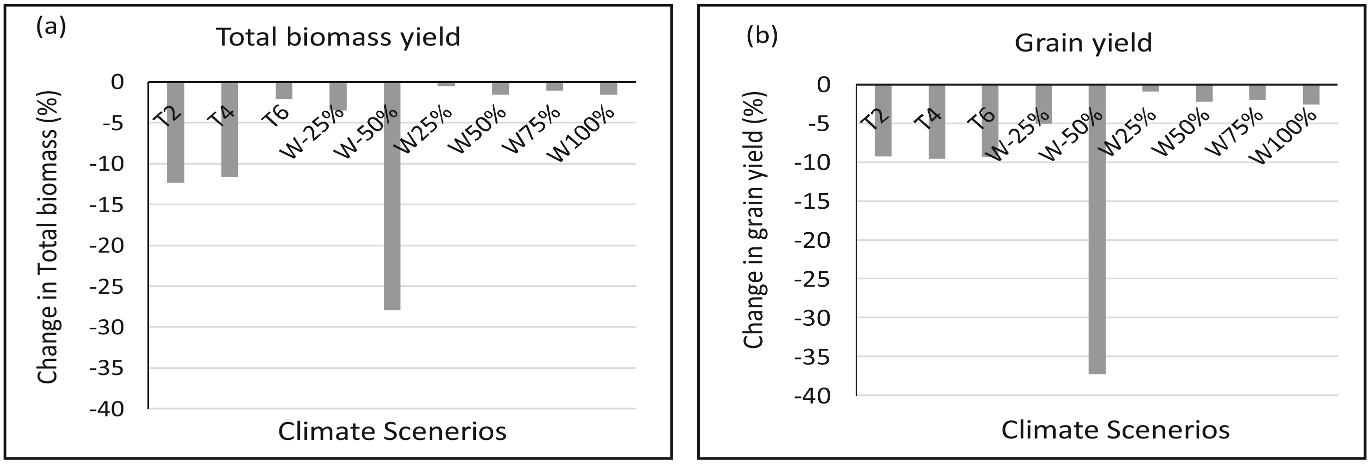

Fig. 3: Mean percentage change for simulated grain yield and total biomass across N-fertilizer rates based on the current climatic condition (1980-2010)

Table 3: Mean simulated grain yield, total biomass and grain yield water use efficiency (GY_WUE) between 1981 and 2010 based on increase temperatures (minimum and maximum) and rainfall changes at varying fertilizer applications for a photoperiod insensitive sorghum cultivar

N-input	Baseline climate	T2	T4	T6	W-25%	W-50%	W25%	W50%	W75%	W100%
					Grain yield (kgha $^{-1}$)					
0	2258	2181	2168	2136	2283	1631	2166	2110	2082	2048
40	2733	2435	2429	2449	2548	1636	2721	2691	2698	2682
80	2752	2441	2435	2458	2552	1636	2764	2744	2767	2765
120	2754	2444	2438	2460	2554	1637	2766	2747	2770	2769
LSD(0.05)	136**									
CV of year(%)	11.2									
					Total Dry matter(kg ha^{-1})					
0	7696	7058	7108	7798	7794	6138	7470	7331	7277	7177
40	8884	7686	7748	8610	8456	6203	8867	8785	8839	8796
80	8932	7702	7766	8636	8468	6207	8977	8921	9013	9004
120	8941	7711	7775	8644	8475	6211	8986	8930	9023	9013
LSD(0.05)	379**									
CV of year(%)	14.6									
					Grain yield water use efficiency (kg ha^{-1}mm^{-1})					
0	6.2	5.8	5.4	4.8	6.4	5.3	6	5.9	5.9	5.8
40	7.1	6.2	5.8	5.2	6.8	5.3	7.1	7.0	7.1	7.1
80	7.1	6.3	5.8	5.2	6.8	5.3	7.1	7.1	7.2	7.2
120	7.1	6.3	5.8	5.3	6.8	5.3	7.1	7.1	7.2	7.2
LSD(0.05)	0.30**									
CV of year(%)	12.2									

***NB:** BC - Baseline Climate, T2 - 6 means increase temperature (minimum and maximum) by T2, T4 and T6 respectively; W -25% & -50% indicates rainfall decline by 25% & 50%; W25-100% indicated increase rainfall by 25-100 %*

Based on the phenological data collected, the cultivar-genetic coefficients were calibrated until there was appreciable agreement between simulated and observed values for phenology and yield data. The experiments were run with each set of genetic coefficients (associated with each in a planting date) and the simulated and observed values were used to compute the root mean square error (RMSE). RMSE is defined as;

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n}(S_i - O_i)^2}}{n}$$

Where: S_i represents the simulated, O_i represents the observed value, n represents the number of iteration taken into consideration.

The normalized root mean square error ($RMSE_n$) expressed in percent gives a measure (%) of the relative difference of simulated versus observed data.

$$RMSE_n = \frac{\sqrt{\sum_{i=1}^{n}(S_i - O_i)^2}}{n} X \frac{100}{M}.$$

Mean bias error (MBE) measures the average magnitude of the errors in a set of predictions to whether overestimated and underestimated by the model.

$$MBE = \frac{\sum_{i=1}^{n}(Si - Oi)}{n}$$

Furthermore, sensitivity analysis was conducted to evaluate Sorghum yield response to changes in key meteorological variables (Temperature and Rainfall) at current concentrations of CO_2 of 380 ppm. The simulation analyses considered a long-term climatic record as a baseline climate (1981-2010) using different N-fertilizer application rate for grain yield, total biomass and grain yield water use efficiency (GY_WUE). The simulations were carried out at varying minimum and maximum temperatures for 2°C (T2), 4°C (T4) and 6°C (T6). Also, decrease in daily rainfall at 25% (W-25%), and 50% (W-50%), increase in daily rainfall at 25% (W25%), 50% (W50%), 75% (W75%), 100% (W100%), respectively.

RESULTS AND DISCUSSION

Model parameterization and evaluation

The cultivar-calibrated and model default parameters are presented in Table 1. Meanwhile, model evaluation for phenology, morphology and yield parameters are presented in Table 2 and Fig. 1&2 respectively. Table 1 shows that the cultivar-specific parameters were well calibrated accounted for the high-yielding characteristics of the photoperiod insensitive sorghum tested. Table 2 indicates excellent agreement between model-simulated and mean observed values for phonological parameters with high accuracy indicated mean bias error (MBE) of 2.2 days for flowering and 1.4 days for physiological maturity of the mean observed value. The results further showed that the model overestimated both total leaf number (TLN) and leaf area Index (LAI) as compared to the mean observed values (Fig. 1). The overestimation could be attributed to model inability to capture the early growth stage of the crop similar to earlier reported by Akinseye *et al.,* (2017) However, there was a good agreement between model simulated and observed values for total biomass and grain yield across the sowing dates (Fig. 2). Model performance shows that MBE estimated 60 kg ha^{-1} for total biomass and 115 kg ha^{-1} for grain yield and RMSE (780 kg ha^{-1}) for total biomass and 284 kg ha^{-1} for grain yield values. Also, the results indicate strong coefficient of determination (R^2) between the simulated and observed values. Since they compared the agreement of simulated versus observed values, thus the lower the values, the better the model in explaining most of the variations in the dataset.

Impacts of temperature and rainfall on sorghum yield at varying N-fertilizer applications

Table 3 displayed the response of the grain yield, total biomass and grain yield water use efficiency (GY_WUE) to climate scenarios (temperature and rainfall changes) and also different N-fertilizer rates as inputs. These climate scenarios include minimum and maximum temperatures increase of 2 °C, 4 °C and 6 °C (T2, T4 and T6), rainfall decrease of 25% and 50%, and increase of 25%, 50%, 75% and 100%. The grain yield, total biomass, and GY_WUE increased significantly with increased N-fertilizer rate; however, there were no significant differences between 40 and 120 under different climate scenarios considered plus baseline climate. Across the fertilizer rate, simulated grain yield and total biomass reduced by a mean of 260 kg ha^{-1} and 1000 kg ha^{-1} with exception of T6 for total biomass when compared baseline climate and increased temperature T2 - T6. Similarly, the mean GY_WUE significantly decrease with increase temperature from T2 - T6 across the N-fertilizer rate, which implies that the amount of grain produced by the amount of water use reduces with increase temperature. Also, the mean simulated grain yield reduced by 140 kg ha^{-1} and 990 kg ha^{-1} at seasonal rainfall decline of 25 % (W-25%) and 50 % (W-50%), while the magnitude of grain yield loss by increase rainfall (W25% - W100%) was significantly low ranged from 20 to 60 kg ha^{-1}across N- fertilizer rate. Additionally, the water use efficiency (WUE) decreased respectively by 4.2% and 25.4% with a regress in daily rainfall by 25 % (W-25%) and 50 % (W-50%). Conversely, water use efficiency remained relatively same with an increase in rainfall from 25% to 100%, and a corresponding rise in the fertilizer usage. Thus, the nine climate scenarios considered indicate a significant negative impact on the grain yield and total biomass at varying magnitude (Fig.3). The results show that grain yield would reduce by closely 10% with temperature increase and 37% yield loss in more drier condition when rainfall amount is reduced by 50% (W-50%).Total biomass indicates a yield loss of 28% for a very pronounced reduction in soil moisture content as a result of rainfall decrease of 50% while temperature increase of T2 and T4 would also give rise to a drop in total biomass by 12% except for T6. The increase in temperature produces a corresponding rise in the evapotranspiration rate, leading to more loss of the water use efficiency. These results are comparable to findings reported by Schlenker and Lobell (2010) projected the effect of temperature and rainfall on sorghum crop. As shown in a report also by Sultan *et al.* (2013), projected yield losses from sorghum crops was induced by increase temperature leading to increased potential evapotranspiration, crop maintenance respiration and a reduction of the crop-cycle length. This study however justifies through simulations that rainfall increase plays a little but important role in affecting the sorghum grain yield, water use efficiency and total biomass. The major factors responsible for grain yield loss at harvest are decrease in rainfall amount and increase in temperature as predicted above.

CONCLUSION

Understanding the crop response towards changing climate is an essential step in formulating adaptation strategies and policy. In this study, we evaluated APSIM model for simulating the phenological and morphological traits as well as grain yield and total biomass of photoperiod insensitive sorghum cultivar planted across sowing dates. The sensitivity analysis of photoperiod insensitive sorghum to climate variables (temperature and rainfall) varied from year to year and is largely dependent on water availability. The sorghum yield is more sensitive to increase in temperature and declined rainfall. The ability to replicate phenological characterization after subsequent calibration and evaluation provide a platform whereby various simulations could be performed with the aim of increasing sorghum productivity. The study therefore, concluded that APSIM model provides a sound scientific anticipation into sorghum yield variations and can serve as an input to policy and decision making for climate change adaptation.

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REFERENCES

Adejuwon, S.A. (2004). Impact of climate variability and climate change on crop yield in Nigeria. Contributed Paper to Stakeholders Workshop on Assessment of Impact and Adaptation to Climate Change (AIACC): 2-8.

Ajeigbe, H.A., Akinseye, F.M., Kunihya, A. and Jonah, J. (2018). Productivity and Water Use Efficiency of Sorghum [Sorghum bicolor (L.) Moench] Grown Under Different Nitrogen Applications in Sudan Savanna Zone, Nigeria. *Hindawi Int. J. Agron.,* https://doi.org/10.1155/2018/7676058

Akinseye, F.M. (2015). Factoring climate variability and change into crop models for enhancing Sorghum performance in the West African Semi-Arid Tropics (Ph.D. Thesis), http://www.wascal.org/publications/doctoral-theses.

Akinseye, F.M., Adam, M., Hoffmann, M.P., Traore, P.C.S., Agele, S.O. and Whitbread, A.M. (2017). Assessing crop model improvements through comparison of sorghum (*Sorghum bicolor L. moench)* simulation models: a case study for West African cultivars. *Field Crop Res.* 201:19-31, http://dx.doi.org/10.1016/j.fcr.2016.10.015.

Clerget, B., Dingkuhn, M., Gozé, E., Rattunde, H.F.W. and Ney, B. (2009). Variability of phyllochron, plastochron and rate of increase in height in photoperiod-sensitive sorghum varieties. *Ann. Bot.,* 101: 579–594.

Dalgliesh, N., Hochman, Z., Huth, N. and Holzworth, D. (2016). A Protocol for the Development of APSOIL Parameter values for the Use in APSIM Version 4. CSIRO, Australia.

Dimes, J., Cooper, P. and Rao, K.P.C. (2008). Climate Change Impact on Crop Productivity in the Semi-Arid Tropics of Zimbabwe in the 21st Century. Proceedings of the Workshop on Increasing the Productivity and Sustainability of Rain-Fed Cropping Systems of Poor Smallholder Farmers, Tamale, 22-25 September 2008, 189-198.

FAO. (1997). The global *economy* of sorghum and millet: Facts, trends and prospects. FAO (Rome, Italy) and ICRISAT, Patancheru, India, p.68.

Holzworth, D.P., Huth, N.I., deVoil, P.G., Zurcher, E.J., Herrmann, N.I., McLean, G. et al. (2014) APSIM – Evolution towards a new generation of agricultural systems simulation. *Environ. Model. Softw.* 62, 327-350.

Jones, C.A. and Kiniry, J.R. (1986). CERES-Maize: A Simulation Model of Maize Growth and Development. College Station, TX: Texas A&M University Press.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., D Holzworth, Huth, N.I, Hargreaves, J.N.G., Meinke, H., Hochman, Z., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, W., Brown, S., Bristow, K.L., Asseng, S., Chapman, S., McCown, R.L., Freebairn, D.M. and Smith, C.J. (2003). An Overview of APSIM: A Model Designed for Farming Systems Simulation. *Eur. J. Agron.,* 18: 267-288

MacCarthy, D.S., Sommer, R. and Vlek, P.L.G. (2009). Modeling the impacts of contrasting nutrient and residue management practices on grain yield of sorghum (*Sorghum bicolor* (L.) Moench) in a semi-arid region of Ghana using APSIM. *Field Crop. Res.* 113(2): 105-115

Maredia, M., Byerlee, D. and Pee, P. (1998). Impacts of food crop improvement research in Africa. SPAAR

Occasional Papers Series No. 1, Washington, D.C., 34p. (Web: http: // www.worldbank.org).

Maredia, M.K., Byerlee, D. and Pee, P. (2000). Impacts of food crop improvement research: Evidence from sub Saharan Africa. *Food Policy*, 25: 531-559.

Mark, R.C., Mandy, E., Gary, Y., Lan, B., Saleemul, H. and Rowena, V.S. (2008). Climate Change and Agriculture; threats and opportunities. Federal Ministry for Economic Cooperation and Development Germany.

Mohanty, M., Sinha, N.K., Sonali, P., Mcdermid, Chaudhary, R.S., Sammireddy, K., Hati, K.M., Somasundaram, J., Lenka, S., Patidar, R.K., Prabhakar, M., SrinivasRao Ch., Patra, A.K. (2017). Climate change impacts vis-a-vis productivity of soybean in vertisol of Madhya Pradesh, *J. Agrometeorol.,* 19(1): 10-16.

Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C. and Strong, W.M. (1998). APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agric. Syst.* 56: 1–28.

Schlenker, W. and Lobell, D.B. (2010). Robust negative impacts of climate change on African agriculture. *Environ. Res. Lett.*, 5:014010, http://dx.doi:10.1088/ 1748-9326/ 5/1/014010.

Sultan, B., Roudier, P., Quirion, P., Alhassane, A., Muller, B., Dingkuhn, M., Ciais, P., Guimberteau, M., Traoreand, S. and Baron, C. (2013). Assessing climate change impacts on sorghum and millet yields in the Sudanian and Sahelian savannas of West Africa. *Environ. Res. Lett.,* 8:014040, http://dx.doi:10.1088/ 1748-9326/8/1/014040.

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