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Potential impact of climate change on peanut yield in Senegal, West Africa

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A R T I C L E I N F O

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A B S T R A C T

Crop models are useful tools to investigate climate change impacts and suitable adaptations strategies on crops. In order to evaluate the impact of climate change on peanut yield in Senegal, a solution of the SIMPLACE crop modelling framework using the Lintul5 crop model together with a T_c model and FAO-56 based approach to simulate evapotranspiration was used with consideration of T_c versus T_a in driving heat stress with output from four regional climate models (RCMs) and two climate change scenarios (RCP4.5 and RCP8.5). Results from six field experiments at two sites (Bambey and Nioro) in Senegal in the dry seasons of 2014 and 2015 and the rainy season of 2014, were used for calibration and evaluation for two peanut varieties. Our calibration and evaluation exercise revealed that simulation skill was markedly improved when T_c was considered under irrigated, dry season conditions during which time the plants were subject to periodic heat stress. Under future climatic conditions, positive changes of up to 2.4% for RCP4.5 and 8.3% for RCP8.5 for seed yield were found when increasing [CO_2] is taken into account for the period 2016–2045 in dry season. While, in rainy season seed yield increased by 11.0% for RCP4.5 and 19.0% for RCP8.5. The effect of climate change on seed yield was negative in the dry season where maximum T_a is often higher than 38 °C compared to the rainy season in particular when T_a is used for simulating heat stress effects. It is concluded that climate change could have limited negative impacts on peanut yield in Senegal due to the effect of elevated [CO_2]. However, simulated T_c should be used instead of T_a to accurately account for heat stress impact on peanut especially during the dry season.

1. Introduction

Peanut (*Arachis hypogaea* L.) is an important oil seed and food crop, grown across West Africa, a region characterized by high temperature and low or erratic rainfall (Hamidou et al., 2013). Peanut is cultivated mainly by small-holder and resource-poor farmers (Tarawali and Quee, 2014), providing the main source of income in rural areas. Together with Nigeria, Senegal is one of the largest producers in the West African region, with peanut production occurring in all districts of the country. However, peanut productivity has decreased in Senegal since 1990 due to soil degradation, seed quality, delay of distribution of inputs (Montfort, 2005; Noba et al., 2014). As high temperature and drought stress are the main yield limiting climatic factors for peanut (Prasad et al., 2010; Hamidou et al., 2013), downward pressure on productivity can be expected to be further exacerbated by climate change.

Climate change is expected to lead to increased temperatures and a decline in average rainfall, including repeated droughts in West Africa (IPCC, 2014). The impact of climate change on crop yields in West Africa without adaptation of crop management is expected to be negative across the main crops (Roudier et al., 2011). While the exact impacts remain highly uncertain when elevated temperatures, higher atmospheric [CO_2] and changed rainfall occur simultaneously (Roudier et al., 2011), temperature is expected to be the largest driver of negative impacts (Schlenker and Lobell, 2010; Roudier et al., 2011). However, differences in study methodologies, data, models and assumptions (Webber et al., 2014), as well as scientific uncertainty in process interactions at the canopy scale (Tubiello et al., 2007) and likely adaptations make climate change impact projections highly uncertain.

To support the improvement of peanut yield and provide policy makers and planners with information to formulate strategies to adapt to climate change, a clear picture of what is likely to happen in the future is necessary. In this regard, crop models are commonly used for scenario analysis. Recent improvements for their application in West Africa with peanut include responsiveness to abiotic stresses, such as

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Table 1
Summary of the treatments in the six field experiments.

Sites	Seasons	Irrigation Levels	Fertilizer Levels	Variety Levels	Repetition	Experi-mental Design	Planting Month
Bambey	Rainy season (RS) 2014	No irrigation	Six (T0, T1, T2, T3, T4, T5)	Fleur11, 73-33	Four	RCBD	August
Nioro							July
Bambey	Dry Season (OS) 2014	Three (E,S1,S2)	Two (T0, T3)	Fleur11, 73-33	Four	Split split plot	March
Nioro		One (E)	Four ((T0, T1, T2, T3)	Fleur11, 73-33	Four	RCBD	March
Bambey	Dry Season (OS) 2015	Three (E,S1,S2)	Two (T0, T3)	Fleur11, 73–33	Four	Split split plot	February
Nioro							February

T0 without fertilizer, T1 = 50 kg ha^{-1}of 6-20-10 (33% of recommended dose), T2 = 100 kg ha^{-1}of 6-20-10 (66% of recommended dose) and T3 = 150 kg ha^{-1}of 6-20-10 (recommended dose), T4 = 150 kg ha^{-1}of 6-0-10 and T5 150 kg ha^{-1}of 6-10-10. RCBD = Randomized Complete Block Design.

soil phosphorus, disease and nutrient deficiencies (Prasad et al., 2010; Naab et al., 2015). CROPGRO-peanut model was successfully used to quantify the yield potential and yield gaps associated with yield-reducing stresses and crop management in Ghana (Naab et al., 2004), peanut contamination with aflatoxin in Mali (Boken et al., 2008) and low phosphorus soils in Ghana (Naab et al., 2015). CROPGRO-peanut is the most widely used crop model in West Africa in published studies, and though it considers the impacts of heat stress on seed yield it does not yet integrate the effect of canopy temperature (T_c). While large scale observational evidence suggests that high temperature, not rainfall, will drive losses in crop yield in much of Sub Saharan Africa (Schlenker and Lobell, 2010), we expect heat and drought stress to interact and reinforce one another. In fact, some observational evidence suggests that the interaction of heat and drought stress is already evident in panel datasets for SSA in which yield losses above 30 °C are greater under water stressed conditions than well-watered ones (Lobell et al., 2011). To capture these interactions, T_c is here suggested as a more appropriate indicator to estimate the effect of heat stress than air temperature (T_a) (Siebert et al., 2014). Use of T_a alone neglects the interaction between crop soil water status and temperature, which can cause an error in temperature by up to six or more degrees in hot dry environments resulting in large under or over predictions of crop heat stress (Siebert et al., 2014; Webber et al., 2016).

The current study quantifies the effects of climate change and elevated [CO_2] on crop growth under well-watered and typical rainfed conditions, capturing the interaction of high temperature, crop water status and [CO_2] through consideration of crop T_c (De Boeck et al., 2016). The model structure was developed with the SIMPLACE modelling framework (www.simplace.net), which offers the flexible combination of re-usable model sub-routines into so called model solutions. From this model basis, the first objective of this study was to evaluate the performance of the model solution SIMPLACE < Lintul5,Slimwater,CanopyT,HeatStressHourly > to simulate peanut growth and yield under varying conditions of heat and water stress in Senegal. The evaluation was conducted using both T_a and simulated T_c to drive the heat stress response. The second and main objective was to assess the impacts of climate change on peanut yield in Senegal based on the calibrated and validated model solution.

2. Materials and methods

2.1. Field experiments for model calibration and evaluation

Field experiments were conducted in Bambey located at 14°42′ N and 16°29′ W and in Nioro located at 13°45′ N and 15°46′ N in Senegal during the dry and rainy seasons of 2014 and dry season of 2015 (Faye et al., 2016). A total of six field experiments were carried out; two dry season and one rainy season field experiment at each site (Table 1). The peanut cultivars selected were Fleur11 and 73-33 which are known to be early (90 days) and medium (110 days) maturity cultivars, respectively. Compound fertilizer NPK 6-20-10 was applied one day after sowing as recommended by the National Agricultural Research Institute of Senegal (ISRA) and incorporated at a depth of 5 cm with a hoe. However, during the rainy season single doses of Urea (N 46%), DSP (24% P2O5) and KCl (60% K_2O) were applied in treatment T4 and T5 (Table 1). The three irrigation levels were: E (field capacity), S1 (water stress during flowering) and S2 (water stress during seed filling). Experimental units measured 16 m^2 (4 m by 4 m); rows were spaced at 50 cm, with 15 cm within rows plant spacing. Before sowing each year, the field was disc-plowed to a depth of 12 cm, harrowed and leveled. The seeding was done by hand at a depth of about 4 cm with two seeds per seed hole. Thinning to one plant per seed hole was done after emergence at 11 days after sowing (DAS). Weed control was conducted by hand. Insecticide and fungicide were applied to avoid insects' attacks and diseases.

Phenology observations were taken approximately every seven days to determine parameters such as day of emergence, day of flowering, beginning of peg, beginning of pod formation, beginning of seed and physiological maturity as described in (Boote, 1982; Meier, 2001). Total dry matter was determined in leaves, stems and pods at weekly basis. Time series of leaf area index (LAI) were measured before each biomass sampling at both sites with a Plant Canopy Analyzer (LAI 2000). At final harvest biomass and seed yield was determined in each plot in an area of 3.9 m^2 (1.95 m × 2 m). Ten composite soil samples were collected in 10 cm intervals from 0 to 100 cm depth using an auger two weeks before sowing. Chemical and physical analyses of the soil were done at the Water-Soil-Plant laboratory of (ISRA). Weather stations were located at less than 1 km from the field experiments and rainfall, maximum and minimum T_a, sunshine hours, maximum and minimum relative humidity and wind speed were measured daily.

2.2. Soil properties

The model solution requires initial values for the total mineral soil N, P and K available at the start of the growth period (g m^{-2}). Laboratory analyses for chemical soil properties were used to estimate these values at 100 cm depth (Table 2) in all soil layers in which effective peanut root can access (Faye et al., 2016). The value of 0.025

Table 2
Soil properties at the start of the growth seasons 2014 and 2015 used in the model.

	2014		2015	
	Bambey	Nioro	Bambey	Nioro
Depth (cm)	100	100	100	100
N (g m^{-2})	8.2	8.7	9.1	10.1
P (g m^{-2})	42.0	17.8	3.8	6.9
K (g m^{-2})	67.4	68.9	9.8	9.3
LL (cm cm^{-1})	0.08	0.1	0.08	0.1
DUL (cm cm^{-1})	0.19	0.2	0.19	0.2
SAT (cm cm^{-1})	0.29	0.38	0.29	0.38
OC (%)	0.13	0.30	0.24	0.29
BD (g cm^{-3})	1.43	1.32	1.43	1.32
pH	5.8	5.7	6.8	5.3
Sand (%)	92.0	82.0	68	65
Silt (%)	2.4	8.2	23	24
Clay (%)	5.6	10.1	9	11

LL: permanent wilting point, DUL: Field capacity, SAT: volumetric water content at saturation, OC: organic carbon, BD: bulk density.