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*Full Length Research Paper*

# Modelling heat stress effect on two maize varieties in Northern Region of Ghana

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**Agriculture in Ghana accounts for more than 30% of GDP and three-quarters of export earnings. In Sub-Saharan Africa, climate change is predicted to affect the agricultural sector most. The objectives of this study were: to use the SIMPLACE (Scientific Impact assessment and Modelling Platform for Advanced Crop and Ecosystem management) to simulate maize yield under heat stress. To compare SIMPLACE model output with heat stress, and without heat stress. Finally simulate the effect of heat stress on maize yield depending on the sowing date. The study collected and analysed data from field experiments during the 2012/2013 dry season and repeated in 2014 at Bontanga irrigation site and the 2014 rainy season at Gbulahagu farming community based on three (3) sowing dates (SD). Comparing the SIMPLACE model output to the observed field data, the duration of development phases were predicted with acceptable accuracy among the three sowing dates. Simulated and observed showed good agreement for maize biomass at several growth stages of the maize. The heat stress component of SIMPLACE gave a good prediction for yield under heat stress when no other stress (water, nutrients) occurred. The estimations of the final yield showed an over estimation when the model was run with no heat stress condition in the rainy season experiment in particular under nutrient stress. The model was successfully parameterized and evaluated for simulating the effect of heat stress on maize yield under no nutrient and drought stress and can therefore be used as a research tool in the study area.**

**Keywords:** maize, sowing date, heat stress, no heat stress biomass, yield

## INTRODUCTION

Maize is vital for food security of many vulnerable populations (Bruinsma, 2009). It is also an important crop for its impact on the economy as a commodity. Since crop production is climate-dependent and yields vary from year to year depending on climate variability, the agricultural

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sector is particularly exposed to changes in climate. Maize production is sensitive to climate, and climate is changing at a rate that is expected to alter maize crop productivity (FAO, 2012). In warm regions such as the Sudan Savannah of West Africa, average daily maximum temperatures are close to the threshold level of maize, beyond which large yield losses due to heat stress can be, expected (Lobell *et al*., 2011).

Under field conditions, crops are usually exposed to episodes of abiotic stress such as water deficit and nutrient deficiency that may be extreme depending upon the opportunity, intensity and duration of the stress. The magnitude of the response can be analysed in terms of the physiological determinants of grain yield; i.e., amount of resource captured by the crop, efficiency for converting a resource into biomass, and biomass partitioning to reproductive organs. Under heat stress, loss in productivity is mainly related to decrease assimilatory capacity (Sinsawat *et al*., 2004). This response is caused by reduced photosynthesis due to negative effects of above-optimum temperatures on membrane stability (Barnabás *et al*., 2008) and enhanced maintenance respiration costs (Hay and Porter, 2006). At the crop level, the consequence is a reduction in radiation use efficiency (RUE, biomass production per unit of light intercepted by the canopy), as has been reported for wheat (Reynolds *et al*., 2007) and maize (Cicchino *et al*., 2010b). Heat stress can also reduce grain yield due to a decline in harvest index (Craufurd *et al*., 2002). This response usually takes place when above-optimum temperatures occur around flowering, and is linked to their negative effects on kernel set. In maize, these effects were primarily attributed to reduced pollen shed and pollen viability. Recent research, however, demonstrated that poor grain yield and low harvest index of temperate maize hybrid did not improve when fresh pollen was added to ears of plants heated around silking (Cicchino *et al*., 2010b).

Variations in kernel growth rate during active grain filling, the main determinant of final kernel weight (Borrás and Otegui, 2001), is linearly related to plant growth rate during the critical period of kernel formation (Gambín *et al*., 2006). Therefore, it is expected that heat stress during the critical period may promote a decline in both grain yield components through reductions in plant growth rate, but its effects on biomass partitioning to the ear are less clear. Evidence indicates that prolonged exposure to temperatures above 32 $^0$C can reduce maize pollen germination of many genotypes to levels near zero. This negative effect on pollen viability may influence a severe decline in kernel number per plant due to pollination failure (Uribelarrea *et al*., 2002). Additionally reduced tassel growth and pollen production may promote a decline in apical dominance (Uribelarrea *et al*., 2008) with the expected increase in biomass allocation to ear growth (Echarte and Tollenaar, 2006).

Rattalino and Otegui, (2012) on the response of temperate and tropical maize hybrids to brief episodes of above optimum temperature around flowering, documented a superior performance of the tropical genotype. The advantage of this genetic background seemed related to reduced kernel abortion (Rattalino *et al*., 2011) and stable harvest index (Rattalino and Otegui, 2012) under heat stress, but no link was established between observed differences in grain yield and the response of kernel number per plant to assimilates production (e.g. plant growth rate during critical period) or reproductive growth (e.g., ear growth rate during critical period).

As for other abiotic stresses, the superior performance of the tropical genotype under heat stress might be attributable, at least in part, to a higher ability to sustain plant growth and assimilate partitioning to the ear, a lower threshold value of plant growth rate during critical period for avoiding plant barrenness, and/or a reduced response of kernel number per plant to plant growth rate during critical period variations for minimizing kernel loss when plant growth rate during critical period declines. Genotypic differences in response to heat stress, however, could also be attributable to other limiting factors that are not directly related to assimilate availability per plant. These limiting factors are generally associated with severe constraints or failures in reproductive processes, such as reduced pollen shed and pollen viability, poor synchrony between anthesis and silking (Cicchino *et al*., 2010a; Rattalino *et al*., 2011), fertilization problems, and/or kernel abortion. Because these constraints are usually over expressed under abiotic stress, they are responsible for the lack of fitness of response of kernel number per plant to plant growth rate during critical period or to ear growth rate during critical period.

Simulation models may be helpful for assessing the impact of heat stress on crop yield. In contrast, while crop models are increasingly used in climate impact studies (Gaiser *et al*., 2011; Asseng *et al*., 2013; Mueller *et a*l., 2011), very few explicitly consider heat stress, and fewer still compare the performance of the model specifically for heat stress resulting in a probable underestimation of yield losses. There are several studies using models that allow determining biomass and yields and that may also be used for evaluating crop and irrigation management practices. Examples of applications of these models to maize include the use of CERES-Maize (Panda *et al*., 2004; DeJonge *et al*., 2012), Crop-Syst (Stöckle *et al*., 2003), EPIC (Cavero *et al*., 2000; Ko *et al*., 2009), and STICS (Katerji *et al*., 2010) and Lintul3 (Farre *et al*., 2000).

Although many results have already been obtained using, the application of ecosystem or crop models, many research questions remain; these questions are often related to processes or impacts that are insufficiently considered by single crop models or modelling approaches (Rötter *et al*., 2011). A related issue is that large-scale crop simulation studies do not consider the variability of region-specific conditions sufficiently (White *et al.*, 2011), and therefore there is a need for high-spatial resolution of inputs for the calibration of regional models (Eitzinger *et al.*, 2008; Strauss *et al.*, 2012).

Based on these considerations, this study aims to:
1- Use the SIMPLACE to simulate maize yield under heat stress
2- Compare SIMPLACE model output with heat stress, and without heat stress
3- Simulate the effect of heat stress on maize yield depending on the sowing date.

## MATERIALS AND METHODS

### Study area

Production observations were performed in an experimental field at Bontanga, located in the Northern Region of Ghana. Daily weather data were observed in a meteorological station located in Savannah Agricultural Research Institute (SARI) which included maximum and minimum temperatures ($^0$C), wind speed (m $s^{-1}$), solar radiation (W m−2), relative humidity (%) and precipitation (mm). The region has savannah characteristics, with monomodal rainfall. Daily weather data over the period 2012–2013 are presented in Table 1. The field was cropped with Zea mays L. hybrid Wang Dataa (YDT) and Bihilifa (YDT) with a density of approximately 64,000 plants $ha^{-1}$. Management practices, including fertilization and irrigation, were performed according to the standard practices in the region. Direct sowing was done. The main soil hydraulic properties of the experimental field observed are presented in Table 2. Two undisturbed soil samples 0-15 and 15-30 cm depth were collected prior to the beginning of the experiment to determine the soil water content and the dry bulk density. The soil water content for each layer was determined in the laboratory. The saturated hydraulic conductivity (Ksat, cm $d^{-1}$) values were obtained using pedotransfer functions of texture and bulk density (Ramos *et al.*, 2014. The soils are Gleyic Lixisol (Silitic) soil (Soil Survey Staff, 1994). Soils have loamy sand texture with total available water (TAW), difference between the soil water stored at field capacity and at the wilting point to a depth of 113 cm. The saturated hydraulic conductivity (Ksat, cm $d^{-1}$) was moderate for the entire profile except for the top 0.10 cm where higher value was observed associated with moderate to high organic matter content in that layer as a result of crop residues from the previous cropping season.

### Model Description

The SIMPLACE (Scientific Impact assessment and Modelling Platform for Advanced Crop and Ecosystem management) modelling framework was used in this study. SIMPLACE allows various dynamic and process-based crop growth and development model components to be combined at an appropriate level of process detail, as dictated by the specific application and spatial and temporal scales considered to simulate crop response to climate, environment, crop characteristics and management (Gaiser *et al.*, 2013). The specific solution used in this study was SIMPLACE<Lintul-5, Heat>. Lintul5 utilizes radiation use efficiency allowed to vary with crop development stage and daily mean temperature to determine daily biomass accumulation as a function of intercepted radiation (Wolf, 2012). Lintul5 employs a single layer soil water balance and uses a variation Penman (1948) to estimate daily crop transpiration. The heat stress model used is described in Rezaei (2013) and is based on the approach found in GLAM (Challinor *et al.*, 2005). SIMPLACE can be applied to assess the impact of changes in $CO_2$, temperature, rainfall and basic crop management (sowing date, varietal characteristics, and nitrogen, phosphorus and potassium fertilization) on crop yield. The user can input management variables such as sowing date, fertilizer and irrigation amounts and application dates, soil profile properties (soil texture, depth), and atmospheric $CO_2$ concentration, etc. Lintul5 considers the effect of climate of limited water supply as described in Farré *et al.*, (2000), and of limited N supply as described by Shibu *et al.*, (2010). In this research the model was used to simulate crop development and growth in response to different levels of nitrogen fertilization and heat stress.

### An over view of LINTUL 5

The original version of the LINTUL model was described by Spitters and Schapendonk (1990). LINTUL is based on the fact that crop growth rate under favourable conditions is proportional to the amount of light intercepted by the canopy (Monteith, 1977). The model is implemented in the FORTRAN simulation translator, FST (Rappoldt and Van Kraalingen, 1996). Simulations run at a time step of 1 day, which is based on the characteristic time coefficient of the model.

LINTUL5 simulates the growth of a crop as a function of intercepted radiation, temperature and light use efficiency. Soil water (with free drainage) and simple nitrogen, phosphorus and potassium balances are simulated and also the effects of water and nitrogen, phosphorus and

**Table 1** Mean soil hydraulic properties of Bontanga and Gbulahagu field experiments (2012/2013)

| Soil layer depth (cm) | FC (m3 m–3) | WP (m3 m–3) | Sat (m3 m–3) | Air dry (m3 m–3) | Wetness |
|---|---|---|---|---|---|
| **Bontanga** | | | | | |
| 0-113 | 0.28 | 0.15 | 0.44 | 0.08 | 0.36 |
| **Gbulahagu** | | | | | |
| 0-110 | 0.33 | 0.20 | 0.55 | 0.14 | 0.49 |

FC is volumetric water content at field capacity; WP is volumetric water content at wilting point; sat is volumetric water content at saturation.

**Table 2** Treatments

| Experiment | Description | Evaluation File |
|---|---|---|
| **Gbulahagu SD1, N2, rainfed** | No heat stress, no water stress, minimal NPK stress | SD1_N2_Calibration_of_Gbulahagu |
| **Bontanga , SD3, N2, irrigated** | Low heat stress, no water stress, , minimal NPK stress | SD3_N2_Calibration_of_Bontanga_2012 |
| **Gbulahagu SD1, N1, rainfed** | No heat stress, no water stress, NPK stress | SD1_N1_Calibration_of_Gbulahagu |
| **Bontanga E1, SD3, N1, irrigated** | Low heat stress, no water stress, NPK stress | SD3_N1_Calibration_of_Bontanga_2012 |
| **Bontanga E1, SD1, N2, irrigated** | Heat stress, no drought, no NPK stress SD1 | SD1_N2_Evaluation_of_Bontanga_2012 |
| **Bontanga E1, SD2, N2, irrigated** | Heat stress, no drought, no NPK stress, SD2 | E1_SD2_N2_Evaluation_of_Bontanga_2012 |

Where N1- infertilized, N2- fertilized, SD1, SD2 and SD3- sowing dates, E1- experiment 1

potassium supplies on crop growth. LINTUL5 is similar to the LINTUL4 model, except that not only the effects of nitrogen limitation on crop growth are considered but also the effects of limited availability of phosphorus and/or potassium.

## Field observations

Measured crop data consisted of phenology (emergence, flowering, and maturity dates) and seasonal time series information [soil water content, leaf area index (LAI, $m^2m^2$) measured on a 14 day interval, crop biomass] as well as end of season yield components. Plant samples were taken to the laboratory, where they were separated into leaves, stem, tassel cob and grains; samples were weighted to obtain fresh weight and then oven dried to constant weight at 70 $^0$C to obtain dry weight. Irrigation depths (D, mm), was calculated using the Irrigator's Equation. Rainfall was obtained using rain gauge placed at 200 cm above the ground surface. All plots were furrow irrigated with water from a nearby dam.

The highest Tmax was recorded in March, 2013 with a value of 41.5 $^0$C while Tmin and Tmean recorded 28.8 $^0$C and 33.5 $^0$C respectively as indicated in (Figure 4.1). On the other hand, the lowest Tmax was recorded for January, with a value of 33 $^0$C while Tmin and Tmean recorded 15 $^0$C and 25 $^0$C respectively for the same perio

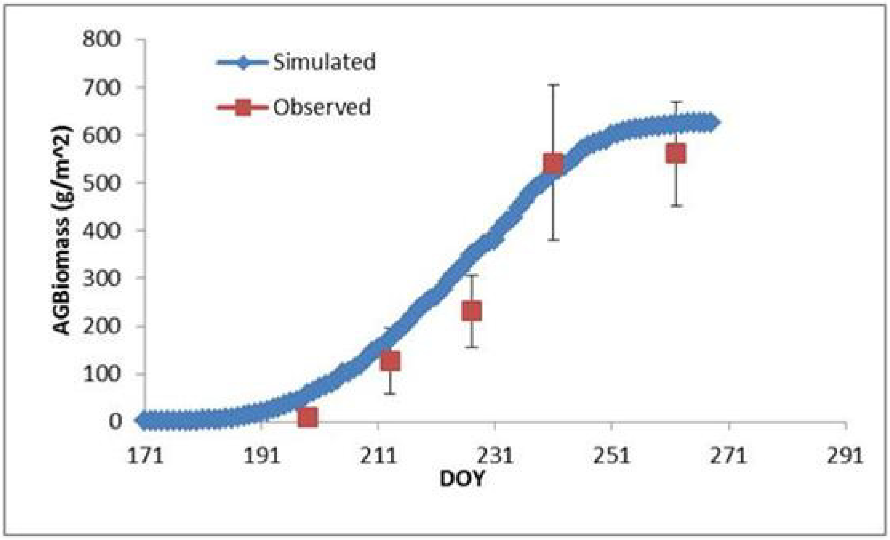

**Figure 1** Observed and simulated above ground biomass SD1_N2_ Gbulahagu _2013

## Input data

In order to apply the model, date of emergence, flowering and maturity were used to calibrate the rate of phenological development which in turn controls the partitioning of assimilates to various organs that determines biomass and grain yield. The main input data for SIMPLACE are daily weather data on maximum and minimum air temperatures (C), precipitation (mm), net solar radiation (J $m^{-2}$ $s^{-1}$), wind speed (m $s^{-1}$) and , atmospheric $CO_2$ concentration, crop data i.e. dates of emergence, root depth, date of maturity and flowering and senescence . The required soil data consist of mean soil water content at field capacity FC ($m^3m^{-3}$), wilting point WP ($m^3m^{-3}$) and saturation sat ($m^3m^{-3}$).

The sowing and harvest dates for the crops simulated with SIMPLACE were obtained from the Bontanga 2012/2013 dry season and Gbulahagu rainy season 2013 experiments. The yields for each sowing date were available. The data of sowing and harvest dates and of yield data were then used for the calibration of SIMPLACE.

## Model calibration

Model calibration was conducted in a stepwise manner with the datasets such as phenology, growth (final above ground biomass and final yield) and heat stress. Crop development, i.e. the order and rate of appearance of vegetative and reproductive organs, is defined in terms of phenological developmental stage as a function of heat sum, which is the cumulative daily effective temperature. Daily effective temperature is the average temperature above a crop-specific base temperature (for maize 8 $^0$C). First a dataset judged to contain no/minimal heat, drought and nutrient stress was used to calibrate the model phenology and parameters related to potential growth. The varieties were set to be photoperiod sensitive and the default sensitivity was changed from 8 hours/day to 12.5 hours/day. Days from emergence to silking were used to calibrate Temperature sum (TSUM1) (required temperature sum for crop development from emergence to silking) for each sowing date for each experiment individually, and likewise for TSUM2 (required temperature sum for crop development from silking to physiological maturity). The assumed initial values for TSUM1 and TSUM2 were 1000 °Cd and TSUM2 = 715$^0$Cd respectively.

## Unstressed Calibration of relative growth rate of leaf area index (RGRLAI), specific leaf area (SLA), and radiation use efficiency (RUE)

The model was calibrated using Gbulahagu SD1_N2, fertilized – rainfed, but with minimal water stress, (and one irrigated treatment, Bontanga experiment 1 (Bontanga SD3_N2 irrigated minimal water stress when temperatures were cooler) and well fertilized treatments which were assumed to have minimal heat, drought and nutrient stress.

For nutrient stress, Gbulahagu SD1_N1, no N – rainfed, but with minimal water stress was used with no nitrogen application but with no or minimal heat or drought stress while Bontanga Experiment 1 SD3_N1 no N – irrigated, with minimal water stress was also used.

The maximum leaf N, P and K concentrations were adjusted to default values of WOFOST as the default for Lintul5 was too high. Iterative approach between RUE was reduced, SLA and NLAI were decreased to 0.7, and NLUE was increased to 1.2 since less NPK stress on LAI was

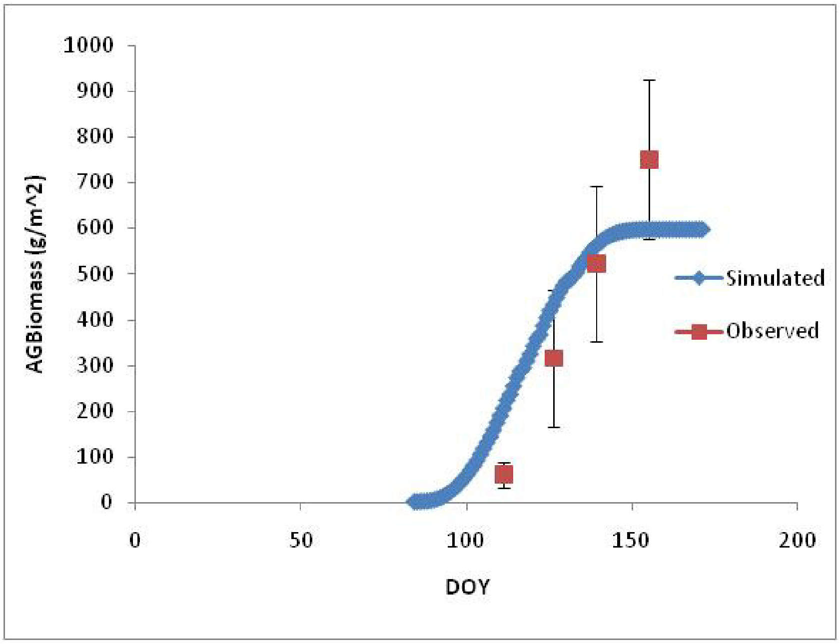

**Figure 2** Observed and simulated above ground biomass SD3_N2_Bontanga_2012

desired and more on RUE was desired. In the Gbulahagu weather file, 05/08/2013 value for precipitation was changed from 0.3 mm to 30.0 mm due to a ground water contribution and vTRANCO set at 4.0.

### Calibration of heat stress effects

Heat stress for maize starts at 227 $^0$C d before silking to 100 $^0$C d after silking (Otegui and Bonhomme, 1998) which corresponds to approximately a development stage index (DVS) of 0.75 (vBeginDevStage = 0.75) for the start of the sensitive period and a DVS of 1.15 (vEndDevStage = 1.15) for the end of the sensitive period. Two temperature limits were used 35 $^0$C as the critical daily maximum temperatureas reported in vHSTCritical =35 and 45 $^0$C as high sensitive temperature limit, (vHSTLimit = 45).

Bontanga Experiment 1 SD1_N2 fertilized – irrigated, minimal water stress and Bontanga Experiment 1 SD2_N2 fertilized – irrigated, minimal water stress were used. The model has the ability to determine biomass potential growth under optimal conditions (without water and nitrogen stress) based both on intercepted photosynthetic active radiation by the crop. The potential growth is then corrected by the most limiting of water and nitrogen limitations, and the actual daily biomass gain is determined.

### Model evaluation

The model performance was evaluated using final biomass and yield without correction for heat stress based on daily maximum air temperature and final yield with a correction for heat stress base on daily maximum air temperature.

## RESULTS

### Model performance with no heat stress, no water stress, no NPK stress (rainfed) (Gbulahagu SD1, N2)

In the no heat, no drought stress and minimal nutrient stress experiment at Gbulahagu there was fairly good agreement between the observed and simulated above ground biomass (Figure 1). This relationship is opposite to the simulations at Gbulahagu in plots with nutrient stress (section 3.1.2). Even though the SIMPLACE<Lintul5> model simulated aboveground biomass under no heat, no drought and no nutrient stress conditions in Gbulahagu fairly well, yield was highly overestimated as shown in Table 3.

### Low heat stress, no water stress, minimal NPK stress (irrigated) (Botamga SD3, N2)

In the low heat, no water stress and minimal nutrient stress experiment at Bontanga there was fairly good agreement between the observed and simulated above ground biomass (Figure 2) though the SIMPLACE<Lintul5> model highly underestimated yield as shown in Table 3.

**Table 3. Summary of observed and simulated above ground biomass and yield in (g/m$^2$) under no heat stress (SD3) and with heat stress (SD1 and SD2) at Bontanga with full irrigation and fertilizer application**

| **Sowing date** | **Harvest date** | **Harvested above ground biomass (g/m$^2$) observed** | **Harvested above ground biomass (g/m$^2$) simulated** | **Observed yield (g/m$^2$)** | **Simulated yield (g/m$^2$) with no heat stress** | **Simulated yield (g/m$^2$) with heat stress** | **Model agreement (Above ground Biomass)** | **Model agreement (Yield)** |
|---|---|---|---|---|---|---|---|---|
| **28/12/2012 (SD1)** | 25/03/2013 | 931 | 1003.85 | 291.49 | 393.52 | 292.96 | F | F |
| **28/01/2013 (SD2)** | 24/04/2013 | 511.93 | 448.61 | 205.65 | 188.46 | 153.95 | F | F |
| **24/03/2013 (SD3)** | 04/06/2013 | 751.56 | 976.10 | 355.73 | 387.60 | 380.53 | O | F |

O: simulated value of heat stress overestimates observations; U: simulated value of heat stress underestimates observations Underestimation, F: simulated value of heat stress fits within standard deviation of observations

### No heat stress, no water stress, NPK stress (rain-fed) (Gbulahagu, SD1, N1)

Under no heat and drought stress, but NPK stress at Gbulahagu observations above ground biomass were generally lower than the simulated values by SIMPLACE<Lintul5>, for maize with no heat stress for the June 2013 sowing date (Figure 4 and Table 3.) in the unfertilized plots. As a consequence both simulations either with heat stress adjustment or without heat stress adjustment overestimated final maize yield (Table 3).

### Low heat stress, no drought stress, NPK stress (irrigated) (Bontanga, SD3, N1)

Under low heat and no drought stress, but without nutrient stress, the model over predicted biomass by approximately 20% but the simulated value was close to the standard deviation of the measurements (Figure 4). With respect to the yield prediction, the model simulated yield accurately matched the observed yields for both no heat stress and heat stress conditions (Table 3).

### Model performance with heat stress, no drought, no NPK stress, January sowing (irrigated) (Botamga, SD1, N2)

The heat stress impact model was evaluated for maize using the data obtained from Bontanga 2012/2013 field experiment. According to the experimental setup, the model was evaluated by comparing the simulated above ground biomass and yield with the observed values (Table 4). The simulated final biomass as the simulated biomass at 28 DAS were within the standard deviation of the observed values, however the simulated biomass at 38, 52 and 72 DOY was above the standard deviation of the observed values (Figure 6).

To test the performance of the SIMPLACE model (SIMPLACE + heat stress model) in simulating yield during heat stress conditions, the modified version of SIMPLACE was applied and SARI daily meteorological (observed) data were used as input data for the crop model. Maize yield was then simulated for both considering no heat stress and heat stress in the simulations. The results of these two simulations were compared to the observed data.

The goodness of simulated versus observed was compared. The results for no heat stress over predicted yield while the impact of heat stress was accurately estimated by the simulations when considering heat stress impact on maize yield (Table 4).

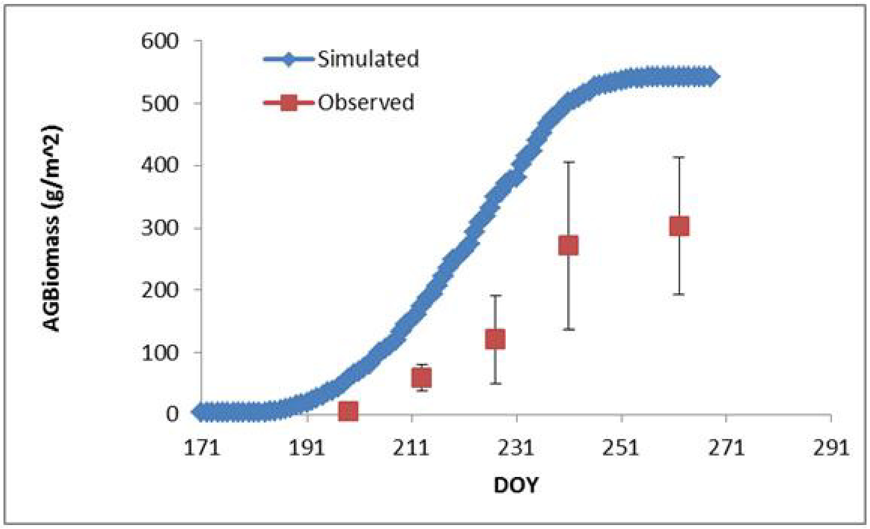

Figure 3 Observed and simulated above ground biomass SD1_N1_ Gbulahagu _2013

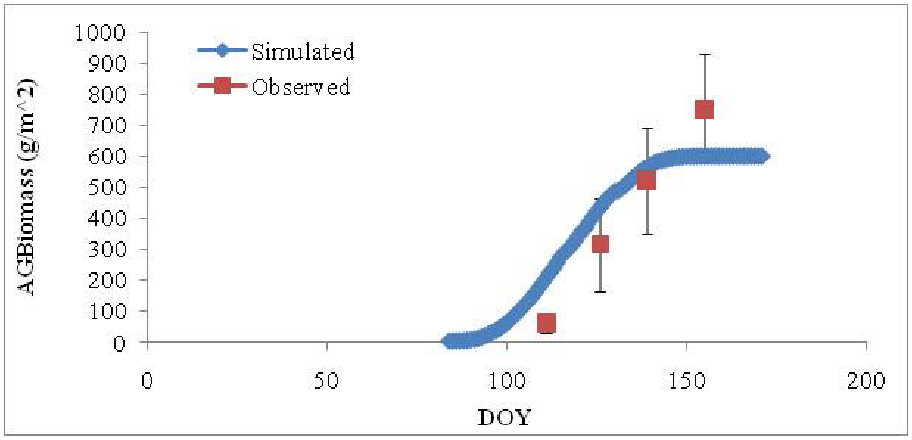

Figure 4 Observed and simulated above ground biomass SD3_N1_Bontanga_2012

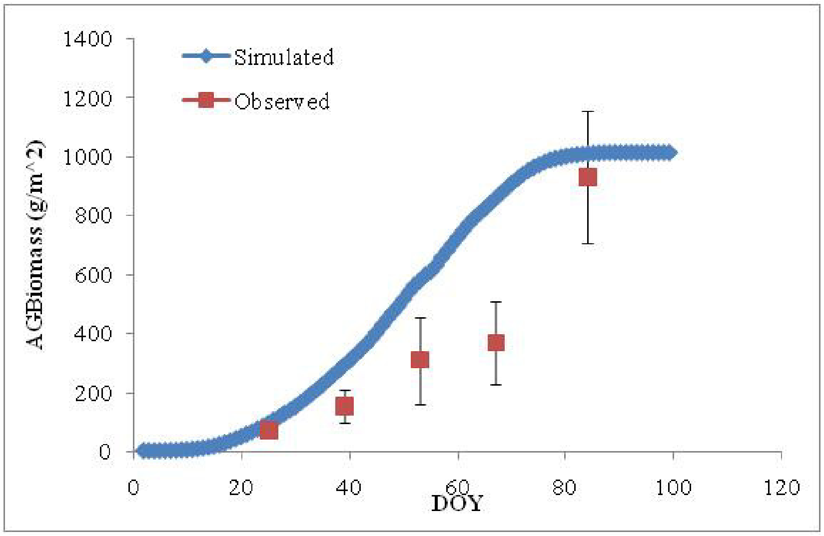

Figure 5 Observed and simulated above ground biomass SD1_N2_Bontanga_2012

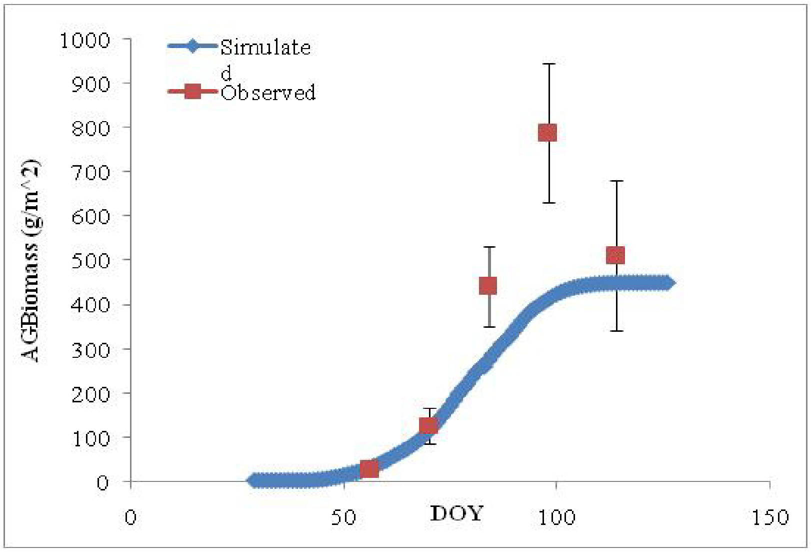

Figure 6 Observed and simulated above ground biomass SD2_N2_Bontanga_2012

## Model performance with heat stress, no drought, no NPK stress (irrigated) (Bontanga, SD2, N2)

For the February sowing date under heat stress (but no drought and NPK stress),the SIMPLACE model simulations matched above ground biomass observations well at 58, 70 and 115 DOY (final harvest), but showed inconsistency in predicting above ground biomass at 82 and 100 DOY. At the early stages of growth, the model accurately predicted above ground biomass. However, as DVS continues the model under predicted above ground biomass compared to the observed data. except at the final harvest (Figure 6).

As total biomass at harvest was well predicted by the model results in Table 3 showed that simulated yield for both no heat stress and heat stress conditions fitted within the standard deviation of the observations.

In Table 3 on the one hand the model correctly simulated maize yield in SD1 and SD2 under heat stress while on the other hand the model under estimated yield under no heat stress conditions in SD3. The differences in the models performance could be attributed to the different sowing dates which experienced different climatic conditions during the different growth stages of the maize crop. In SD2, the SIMPLCACE with no heat stress module produced better yield simulations than the SIMPLACE heat stress module even though they both underestimated yield of maize whereas in SD1 both model configuration overestimated maize yield. However, in this case SIMPLACE heat stress module performed much better.

## DISCUSSION AND CONCLUDING REMARKS

The observed final harvested biomass, yield and the harvest index for Bontanga (Experiment1) 2013 dry season compared to the simulated values are presented in Table 3: to show the usefulness of the SIMPLACE predictions. Highest yields were obtained in SD3. The lowest yields obtained in SD2 is due to highest frequency of occurrence of max temp >35 °C during anthesis.

The observed mean final harvested biomass and yield and the harvest index for all the sowing dates in Table 3 showed that higher biomass was recorded for SD1 followed by SD2 and SD3, while the highest grain yield was recorded for SD3, SD1 and SD2 whereas the highest harvest index was recorded for SD3,SD1 and SD2 respectively. The method used herein for field observations relative to yield predictions was also employed by others, e.g., Paredes *et al*., (2014a). All data relative to biomass and yield from the three sowing dates (Table 3) were used to assess the model accuracy in predicting maize biomass and yield (Fig 1, to 6 and Table 3). The calibrated parameters for biomass showed different trends in biomass prediction.

### Experimental observations

Grain yield varied among sowing dates at Bontanga, averaging 810 and 1030 g $m^{-2}$ respectively. The higher yields in SD3 compared to SD2 were associated with longer growth duration because of the lower temperature.

The model adequately simulated grain yield with the HSadjusted in SD1. However, simulated yields were much lower than the corresponding observed values, especially in SD3 (Table 3). The model failed to predict accurately yield for SD2 and SD3 (Table 3).

## CONCLUSION

The SIMPLACE model was successfully parameterized and evaluated for simulating the effect of heat stress on maize yield under no nutrient and drought stress in the northern region of Ghana and can therefore be used as a research tool in the study area.. Results showed good agreement between simulated and observed maize biomass at several growth stages of the maize. The heat stress component of SIMPLACE gave a good prediction for yield under heat stress when no other stress (water, nutrients) occurred. The estimations of the final yield showed an over estimation when the model was run with no heat stress condition in the rainy season experiment in particular under nutrient stress. The overestimation of the yield could be due to the model's deficiency in simulating nitrogen and phosphorus mineralization from the soil organic matter during the rainy season, which is the main limitation for maize yields in the rainy season when no NPK fertilizer is applied. The model can be used to arrive at site and season specific adaptation measures to mitigate the impact of climate change on crops under well fertilized conditions.

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