Impacts of climate change and climate variability on maize yield under rainfed conditions in the sub-humid zone of Ghana: A scenario analysis using APSIM

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Abstract

Climate change and variability pose a serious threat to food production in sub-Saharan Africa. The projected changes in local spatio-temporal patterns of rainfall and temperature will likely affect the availability of water and nutrients, crop growth, and yield formation. This paper presents the simulated effects of climate change on maize (*Zea mays L.*) in Ejura in the Sekyedumase district of Ghana, one of the important food baskets of the country. Experimental data from maize grown under various nitrogen (N) and phosphorus (P) conditions in the 2008 major and minor rainy seasons at two sites in Ejura were used to parameterize and evaluate the cropping systems model APSIM. Daily climatic data for the period 2030-2050 under the scenarios A1B and B1 were obtained from the regional climate projections obtained by the mesoscale model MM5. The assessment of climate change impact on grain yield suggested a likely 6-week shift in the planting dates of the rainy season from the current (1980-2000) 3rd week of March to the 2nd week of May for the simulated period. Climate change also resulted in projected yield reduction of, on average, 19% and 14% for the Obatanpa maize variety under A1B and B1, respectively, for maize-maize continuous cropping. Likewise, the Dorke maize yield is expected to reduce by 20% and 18% for A1B and B1, respectively, with increased yield variability under both scenarios. Potential adaptation measures to climate change in the area include cropping of cowpea during the minor season or fallow rotation with other crops.

Introduction

Climate change is a threat to food security and livelihoods of the rural poor. Reported projections on climate change indicate that Africa will be the hardest hit because many smallholder farmers largely or totally rely on rain-fed agriculture and have fewer alternatives ((IPCC) 2001; Boko et al. 2007; Tesfaye et al., 2015; Abera et al., 2018), due to high levels of poverty, low levels of human and physical capital, and poor infrastructure ((IFPRI) 2009). In Sub-Saharan Africa, the agriculture sector is one of the most important sectors providing employment for about 70 % of the population of the region (World Bank 2017). Rainfed agriculture is very important in this part of the world (Ringler et al. 2010; Webber et al. 2014). The spatial and temporal variability of rainfall, which is reflected by recurrent dry spells and floods, is the most important factor affecting crop productivity, hence reducing food security (Laux et al. 2010; IPCC 2014). In addition, rainfed agriculture is dominated by smallholder farming that have limited options for investment (i.e. fertilizers, pesticides, machines) and irrigation, making it a highly vulnerable agricultural system (Roudier et al. 2011; Calzadilla et al. 2013).

It is well accepted in literature that inter- and intra-seasonal rainfall variability are the major causes for crop failure (e.g. Usman et al. 2005; Mishra et al. 2008; Laux et al. 2008, Laux et al. 2009; Waongo et al. 2014; Kyei-Mensah et al., 2019). Thus, the amount and distribution of rainfall within the cropping season is very important for crop growth, crop

development and yield formation. In the semi-arid regions of Africa, Agricultural systems reliant on rainfall as a sole source of moisture for crop production inevitably experience highly variable production levels and risks due to seasonal rainfall variability. This phenomenon is gradually shifting to the sub-humid regions, where increasing variability in seasonal rainfall totals and distribution is occurring more frequently (Cooper et al. 2006). While total seasonal rainfall and the season-to-season variability are themselves important (Siegmund et al. 2015), the nature of the within-season variability can also have a major effect on crop productivity, especially at certain critical stages (flowering and grain filling stage) of the crop. The onset of the season is another important variable that affects crop production (Ingram et al. 2002; Ziervogel and Calder 2003), particularly if the end of this season does not shift concomitantly as plant available water depends on the onset and the length of the season.

Thus, climate change and variability are expected to have significant negative impacts on crop growth and developmental processes although the extent of these effects are known to be dependent on the nutrient status of the soil. Kimball (1983) stated that photosynthetic rate of plants can be affected by an increase in carbon dioxide (CO_2) which will in some cases lead to higher yield. Similarly, changes in temperature and precipitation will affect crop photosynthesis, crop development rates, as well as water and nutrient availability to crops (Long 1991). IPCC (2014) indicates that an increase in temperature of 2º C or more in the late 20th century is expected to negatively affect major crops (i.e. wheat, rice, and maize) in both temperate and tropical regions.

Climate impacts, however, are expected to differ depending on the geographical location. For example, in the temperate regions where temperatures affect the length of the growing season, crops may benefit from warmer conditions resulting in longer seasons and higher yields. On the other hand, tropical regions like West Africa which already have a warm climate, are likely to have yield reduction and or crop failure with the increase in temperature, evapotranspiration and reduction in precipitation (Challinor et al. 2007; Barimah, et al., 2014). Lobell et al. (2011) reported that each degree-day temperature above 30º C reduces crop yield by 1% under optimal rainfed conditions and by 1.7% under drought conditions in Africa. In Southern Africa and across SSA, respectively, crop yields are expected to decrease averagely by 18% and 22% by mid-21st century (IPCC 2014). Similarly, simulation results of climate change scenarios by Thornton et al. (2010) indicate that maize yield is expected to decrease by more than 5% by 2050 in the northern part of East Africa. For the 2020s, however, yields are likely to benefit from the CO_2 fertilization effect. An algorithm to adapt the planting dates in order to increase the attainable yields and reduce its variability at the same time was introduced as a potential adaptation measure to reduce the negative impacts on crop productivity. A similar algorithm on a larger scale (grid scale) was applied for maize production in Burkina Faso (Waongo et al. 2014), and was evaluated for the same region using an ensemble of regional climate projections (Waongo et al. 2015).

The sub-humid region of Ghana is one of the most productive areas of the country, with maize being the dominant cereal crop. Over the years there has been a decreasing trend of yield due to a decline in soil fertility,

due especially to lack in nitrogen (N) and phosphorus (P) (Wopereis et al., 2006). As farmers try to increase their productivity under low soil fertility conditions, climate change and variability is compounding the existing challenges greatly affecting maize yield, and hence the livelihoods of the rural poor population.

As there are little climate change impact assessments for maize yield estimations in the area, this paper seeks to investigate the impacts of climate change on maize yield under rainfed conditions in Ejura in the Sekyedumase district which falls within sub-humid Ghana. Ejura is known to be one of the highest maize producing areas in Ghana. The objectives of the paper is to access the impact of climate change and variability on maize production and effects of agricultural options such as fertilization management and the use of different varieties. To account for spatially explicit management information, the field scale crop model *Agriculture System Simulator Model* (APSIM) is a particularly suitable tool because it has the ability to simulate long-term dynamics of soil resources (soil nutrients especially phosphorus) while recognizing the limited sensitivity of their generic crop models to weather input. It is effective in analyzing the complex relationship between climate, management options, and crop productivity (e.g., Fosu-Mensah et al. 2012; Andrea et al., 2016; Chisanga et al., 2017; Gaydon, et al, 2017; Peng et al., 2018). The capability for simulating crop growth in response to soil phosphorus makes it suitable for analyzing crop production in West Africa, where crop yield and N use efficiency of applied mineral fertilizers are greatly affected by low soil P (Fosu-Mensah et al. 2012; Chisanga et al., 2017).

Material and methods

Study area

The study was conducted in Ejura, in the Sekyedumase District of the Ashanti Region of Ghana. Ejura is located in the southern fringes of the Volta Basin in a slightly hilly terrain (150 – 250 meters above sea level). It lies in the sub-humid agro ecological zone, with the moist forest zone in the south and the Guinea savannah zone to the north at a latitude of 7°22' N and a longitude of 1°21' W as

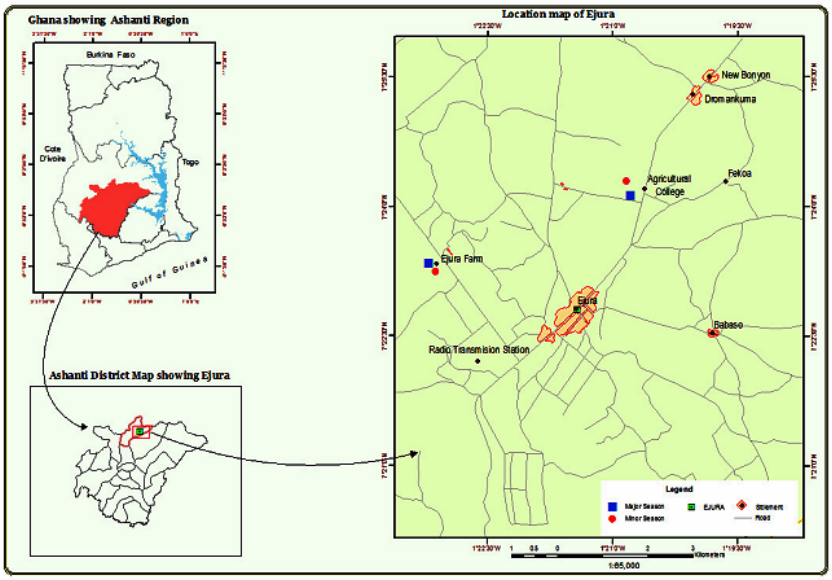

Figure 1: Map of the study area

shown in figure 1. This zone is characterized by a bimodal rainfall regime (major and minor seasonal rainfall) with mean annual rainfall of about 1400 mm. The soils in the study area are Haplic Lexisol and Plinthosol (FAO classification). These soil types have high sand content, are acidic and generally low in nitrogen and organic carbon.

APSIM crop simulation model overview

Crop simulation models are state-of the-art technology that enable users or researchers to estimate the growth, development and yield of crops using management strategies and environmental factors as input parameters (Mavromatis et al. 2001). A framework is provided by the model that uses a range of component modules. These modules, which are plugged into one main model (e.g., APSIM, CropSyst, CERES and DSSAT) engine, can be managerial or biological, environmental and economic (Jones et al. 2001; Keating et al. 2003). The models are developed such that they use in-built algorithms that express the correlation between plant growth processes (transpiration, photosynthesis, physiological development, biomass growth and partitioning, and nutrient and water uptake) and environmental driving forces (e.g., daily temperature, photoperiod and available soil water). In the APSIM model, there is integration of cultivar-specific genetic coefficients which estimate growth and development on a daily basis and response of plants to environmental factors such as weather, soil and management practices (Boote et al. 1998). The Maize module has 11 crop stages and nine phases (time between stages). The commencement of each stage is determined by accumulation of thermal time except during the sowing to germination period which is driven by soil moisture. The phase between emergence and floral initiation is composed of a cultivar-specific period of fixed thermal time, commonly called the basic vegetative or juvenile phase. Between the end of the juvenile phase and floral initiation, the thermal development rate is sensitive if the cultivar is photoperiod sensitive.

Crop simulation models have the ability to simulate yields of a range of crops in response to nutrients and crop rotation sequence. For example, they have been used in Zimbabwe and Kenya to simulate the effect of P on maize and bean production and N use efficiency (Whitbread et al. 2004; Delve et al. 2009), climate forecast applications (Meinke et al. 1996; Chen et al. 2010; Andrea et al., 2016; Chisanga et al., 2017; Peng et al., 2018), simulate water and nutrient dynamics in fallows systems (Probert et al. 1998; Asseng et al. 2000) on a short- and long-term basis, thereby providing insights into the impact of management strategies on the productivity due to soil fertility losses and erosion (Malone et al. 2007).

A flexible working environment is provided by the APSIM model which enables users to choose from a set of modules from a suite of crop, soil and utility modules to configure specific model (Table 1). Thus the APSIM model has the ability to capture intricate detail and subtleties of management practices of farmers through a highly flexible 'Manager' Module allowing the user to specify detailed farmer decision making in a simple 'if-then-else' logic (Holzworth et al., 2014).

The strengths (crop yield in relation to management factors) and weaknesses (system aspect of cropping) of earlier models such as Crop Estimation through Resource and Environment Synthesis (CERES, (Godwin and

Singh 1998; Ritchie et al. 1998)) and Decision Support System for Agro-technology Transfer (DSSAT) were considered in the building of the APSIM model. The model relied on other models such as; Erosion Productivity Impact Calculator ((EPIC) (Williams 1983) and NTRM (Shaffer et al. 1983), for long-term dynamics of soil resources while recognizing the limited sensitivity of their generic crop models to weather input (Steiner et al. 1987).

The important modules in APSIM are the soilP, soilN, and soilWAT modules. The SoilP module describes the availability of P in the soil in terms of labile P pool and fluxes into and out of this pool. SoilN deals with the dynamics and transformation of both carbon (C) and N on layer basis in the soil. Soil organic C is differentiated in two pools, "biom" the more labile and "hum" the less labile form. Flows between pools are calculated in terms of C, while the corresponding N is determined by the CN ratio of the receiving pool. The water balance and solute movements within APSIM model is handled by the soil WAT. It is a cascading layer model, which owes much of its precursors to CERES (Littleboy et al. 1992) as well as to the algorithms for redistributing water within the soil profile. It simulates on a daily time basis and water characteristics specified in terms of wilting point (LL), drained upper limit (DUL) and saturated (SAT) volumetric water contents of each soil layer. Processes adopted from PERFECT include the influence of crop residues and crop cover on runoff and potential evaporation. The motivating factor for the incorporation of a P routine in crop modules was as a result of many soils on which subsistence crops grown are deficient in both N and P, with potential sources of N and P being manure and compost. For models to be useful in these environments, the supply of both N and P is crucial. A routine was therefore incorporated into the crop modules that limit growth and development of crop under P-limiting conditions with a soil P module specifying P supply from the soil. Details of the module is reported in Keating et al. (2003).

TABLE 1
Soil properties used for modelling maize yield in the study area

Soil layer	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Layer thickness (mm)	150	150	150	150	150	150	150	150	150
Soil parameters									
Haplic Lixisol (Expt. 1 and 3)									
BD (g cm^{-3})	1.50	1.55	1.54	1.54	1.44	1.50	1.40	1.40	1.40
SAT (cm cm^{-1})	0.401	0.388	0.387	0.394	0.398	0.409	0.457	0.457	0.461
DUL (cm cm^{-1})	0.310	0.318	0.311	0.308	0.344	0.359	0.407	0.407	0.407
LL (cm cm^{-1})	0.106	0.167	0.228	0.280	0.281	0.283	0.283	0.283	0.283
Soil C parameters									
Organic C (%)	1.10	0.68	0.51	0.46	0.42	0.38	0.28	0.28	0.28
finert[a]	0.30	0.50	0.60	0.75	0.90	0.99	0.99	0.99	0.99
fbiom[b]	0.035	0.025	0.015	0.01	0.01	0.01	0.01	0.01	0.01
Soil P parameters									
Labile P (mg/kg)	12.7	6.5	3.4	2.0	1.7	1.5	0.9	0.9	0.9
P sorption[c] (mg/kg)	50	125	150	200	200	200	200	200	200

BD: Bulk density, SAT: volumetric water content at saturation, DUL: drained upper limit, [a]Finert defines the proportion of the soil organic matter that is not susceptible to decomposition; [b]Fbiom is the proportion of the decomposable soil organic matter that is initially present in the more rapidly decomposing pool. [c]Sorption is the P sorbed at a concentration in solution of 0.2 mg l-1

Parameterisation and evaluation of APSIM

Four modules – maize crop module (APSIM-maize 6.1), a soil water module (Soilwat2), the soil nitrogen (Soiln2), and soil P modules – were linked within the APSIM crop simulation model to simulate cases described in this paper. Input data required by the APSIM model are related to the soil chemical and physical properties, crop genetic characteristics, crop management (sowing, soil amendments, etc.) and climate data (Table 2).

The SOILWAT2 module is a cascading soil water balance model which works on a daily resolution to simulate the soil water balance. This is specified by the drained upper limit (DUL), lower limit of plant extractable water (LL15) and saturated water content (SAT). The measurement of soil water content before sowing defined the initial soil water content of the soil. All soil water characteristics were measured from the study site using neutron probes. Data on soil water dynamics were used to parameterize the model. The detailed description of the model parameterization and evaluation are given in Fosu-Mensah et al. (2012).

TABLE 2

Genetic parameters for the maize cultivars Obatanpa and Dorke used in APSIM

Parameters	Value	Units
Obatanpa cultivar		
Thermal time accumulation		
Duration from emergence to end of juvenile	300	°C day
Duration – end of juvenile to flowering initiation	20	°C day
Duration – flag leaf to flowering stage	10	°C day
Duration - flowering to start of grain filling	170	°C day
Duration, flowering to maturity	830	°C day
Duration – maturity to seed ripening	1	°C day
Photoperiod		
Day length photoperiod to inhibit flowering	12.5	H
Day length photoperiod for insensitivity	24.0	H
Photoperiod slope	23.0	°C /H
Grain maximum number per head	520	
Grain growth rate	8	mg/day
Base temperature	8	°C day
Dorke cultivar		
Duration from emergence to end of juvenile	285	°C day
Duration – end of juvenile to flowering initiation	20	°C day
Duration – flag leaf to flowering stage	10	°C day
Duration - flowering to start of grain filling	170	°C day
Duration, flowering to maturity	700	°C day
Duration – maturity to seed ripening	1	°C day
Photoperiod		
Day length photoperiod to inhibit flowering	12.5	H
Day length photoperiod for insensitivity	24.0	H
Photoperiod slope	10.0	°C /H
Grain maximum number per head	420	
Grain growth rate	8	mg/day
Base temperature	8	°C day

The crop genetic characteristics used in this study are the Obatanpa and Dorke varieties (Fosu-Mensah et al. 2012), that are common in the region. To evaluate the APSIM model, data from four experiments conducted during the major and minor rainy seasons of 2008 (from Ejura farms and Ejura Agricultural College in Ejura) were used. Four concentrations of N (0, 40, 80, and 120 kg ha^{-1}) in the form of ammonium sulphate and three concentrations of P (0, 30, 60 kg ha^{-1}) in the form of triple super phosphate were applied in a factorial combination. Treatments were replicated three times in each experiment. Details of the experiment and types of soil used are described in Fosu-Mensah et al. (2012). Initial soil chemical and physical parameterization were obtained from previous soil samples (Fosu-Mensah et al. 2012).

Regional climate scenarios for assessing the impacts of climate change on maize

The daily climatic data for the period 2030-2050 under the emission scenarios A1B and B1 (IPCC 2007) were obtained from the regional fifth generation mesoscale model ((MM5) (Penn State/NCAR Mesoscale Model, Dudhia (2000)as applied in the Adaptation of Landuse to Climate Change in Sub-Saharan Africa (ALUCCSA) project (Knoche 2015).

The A1B scenario foresees a future world of very rapid economic growth, with a global population that peaks in mid-century and declines thereafter, with a rapid introduction of new and more efficient technologies without relying too heavily on one particular source of energy. The B1 storyline sees a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 scenario, but with a rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies.

Compared to observed historical precipitation data (L'Hote and Mahé 1995), the seasonal characteristics of precipitation, as well as the spatial patterns, are accurately represented by the MM5 simulations for the West African domain during the baseline period 1980-2000, providing credibility to the use of the downscaled future climate projections for subsequent impact modeling (e.g. Wood et al. 1997), i.e. the crop yields projections. The regional climate projections for the period 2030-2050 in general showed an increase in temperature and decrease in precipitation with relatively small differences between the emission scenarios. For the selected locations in Ghana (Ejura), both A1B and B1 scenarios show an increase in mean temperatures of 1.6ºC and 1.3ºC, respectively, compared to the 1980-2000 period. Precipitation was projected to decrease by about 20% and 21% under A1B and B1 scenarios, respectively.

The impact of climate change on maize yield was simulated by considering (i) continuous maize cultivation (only maize during both the major and minor seasons), (ii) Maize-cowpea simulation (simulation of maize during major season and cowpea during minor season) for 21 years, (iii) Maize-fallow rotation (maize during major season and fallow during minor season). The sowing window of 15 March to 10 May was used, planting was done when a cumulative rainfall amount of 20 mm was attained within five days and sowing was at soil depth of 50 mm. Two maize varieties (Obatanpa and Dorke) were used in the experiment and for the simulation with the application of 40 and 80 kg N ha^{-1} with 30 kg P ha^{-1}. Only results of the major season (maize)

are presented.

Statistical analysis

The performance of the model in predicting the grain yield, total biomass, N and P uptake of maize were evaluated using the coefficient of determination (R2) as well as the root mean square error (RMSE):

$$\text{RMSE} = [n^{-1} \sum (yield_{sim} - yield_{meas})^2]^{0.5}$$

Where n is the number of replications, sim and meas denote simulated and measured total biomass, grain yield, N and P uptake for each replicate.

Results

Evaluation of model performance

Statistical analysis indicated that the APSIM simulated number of days to tasseling of both cultivars, in response to inorganic fertilization, was well comparable to the measured number of days to tasselling, with an overall RMSE of 1.5 and 1.4 days for Obatanpa and Dorke, respectively. In general, the model simulated crop duration adequately, with RMSE values of 4.7 and 2.9 days for Obatanpa and Dorke, respectively. Fosu-Mensah et al. (2012) reported that the APSIM-maize model captured leaf area index response to N and P application, with coefficient of determinations (R^2) of 0.91 (Obatanpa) and 0.94 (Dorke). Simulated in-season biomass accumulations were also in good agreement (R2 of 0.89 for Obatanpa and 0.91 for Dorke) with measured data. The dynamics of soil moisture were reasonably predicted by the model (Figure 2). Fluctuations in soil moisture content were well represented. The model also captured the higher fluctuations in the 0-15 cm soil layer as compared to the 15-30 cm.

The RMSE values for grain yield ranged from 261 kg ha^{-1} to 671 kg ha^{-1} with modified coefficient of efficiency (E1) of 0.63 and 0.62 for Obatanpa and Dorke, respectively. Other studies, including, Fosu-Mensah et al. (2012); Whiebread et al., 2010; Hochman et al., 2014; and Waha, et al., 2015; have reported that the response of grain yield to different applications of inorganic N and P fertilizer were well simulated by the model.

Impact of climate change on onset of the rainy season

Outputs from the regional climate simulations indicate that climate change is expected to result in a shift in the onset of the rainy season and thus the planting dates. Under both climate change scenarios considered in this study, about 60% of the years under simulation will receive an agronomic relevant amount of rainfall for planting (Sivakumar 1988) i.e., 20 mm in five consecutive days in the 2nd week of May (Figure 3) as compared to historical planting in the 3rd week of March; thus a 6-week delay in planting or sowing due to climate change by the year 2050. The predicted delay in the onset of the rainy season as a result of climate change delays the planting period and narrows the planting window, hence, planting long duration cultivars will result in harvesting operations entering the minor season and interfering with planting in the minor season. Simulations for the minor season indicate that climate change will possibly result in a shift in the planting date to the 3rd and 4th week of September (Fig. 4b and 4c) under A1B and B1 scenario compared to the 4th week of July and 3rd week of August based on historical data (4a).

The response to increased application of

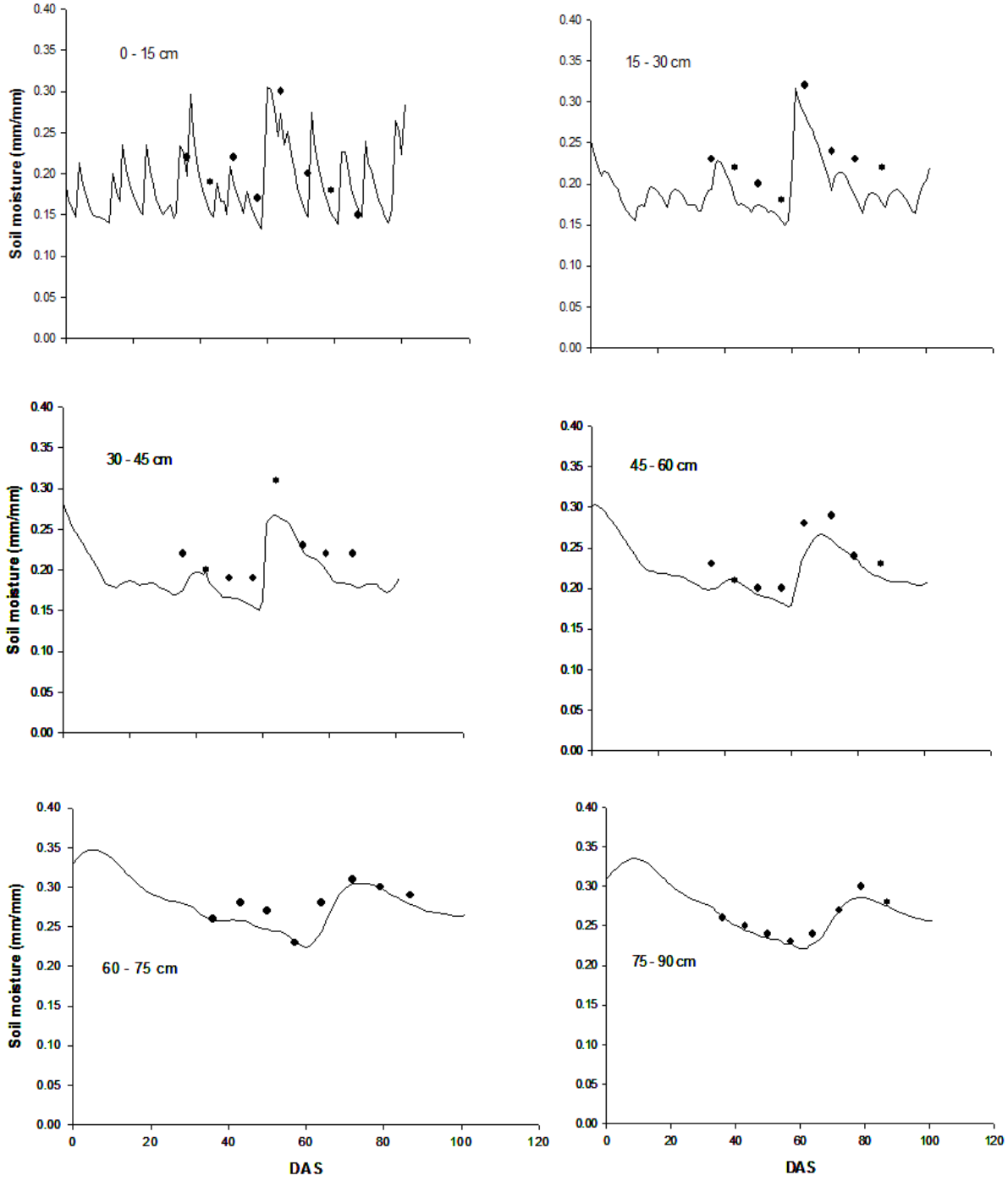

Figure 2: Comparison of observed (symbol) and simulated (line) time series soil moisture on Haplic Lixisol at the Ejura farm in 120 kg N ha^{-1} and 60 kg P ha^{-1} plots from sowing to maturity

fertilizer by crops was reduced under both A1B and B1 climate change scenarios. As seen in Figures 4 - 6, the application of 80 kg N ha-1 gave vary similar yields as those of 40 kg N ha^{-1} under both scenarios. Substantial increases in yields were, however, obtained with an increase in N level from 40 to 80 kg ha^{-1} in historical weather.

Discussion

Impact of climate change on the onset of the rainy season

Using the process-based crop model, ASPSIM in combination with regional climate change scenarios derived from MM5 downscaling revealed that a 6-week delay and contraction

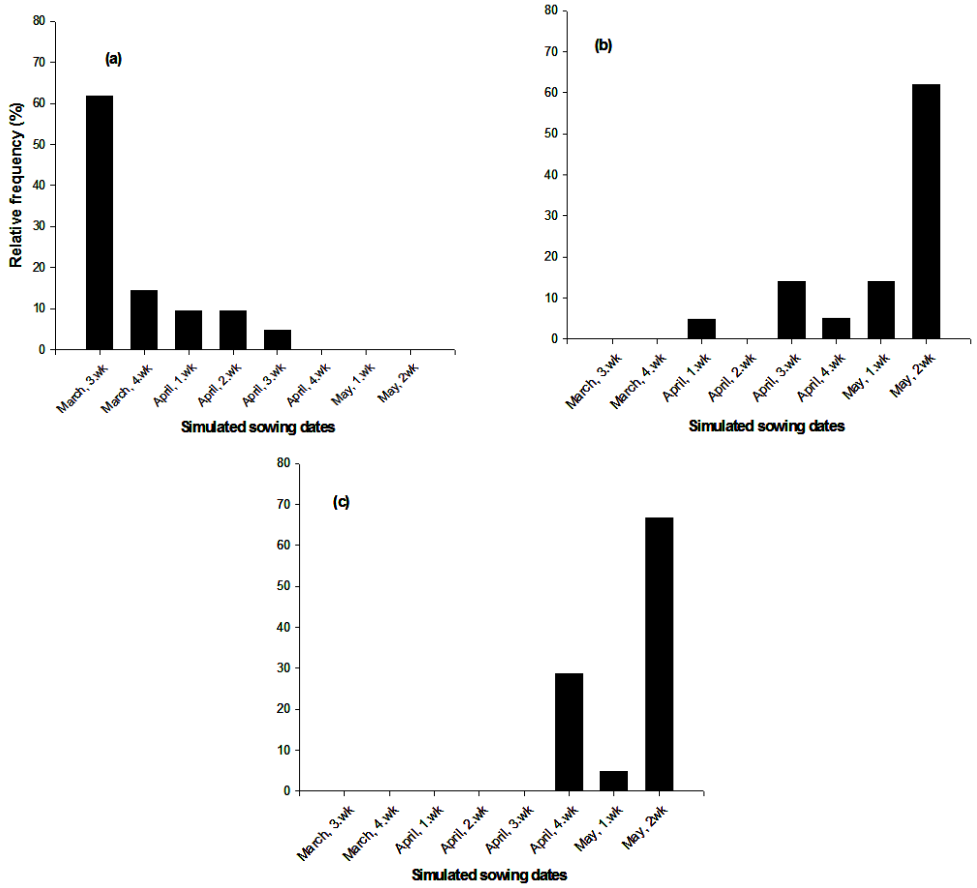

Figure 3: Relative frequency (%) of simulated maize sowing dates during the major season on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000). (a) projected climate change (2030-2050) for scenario A1B (b) and B1 (c)

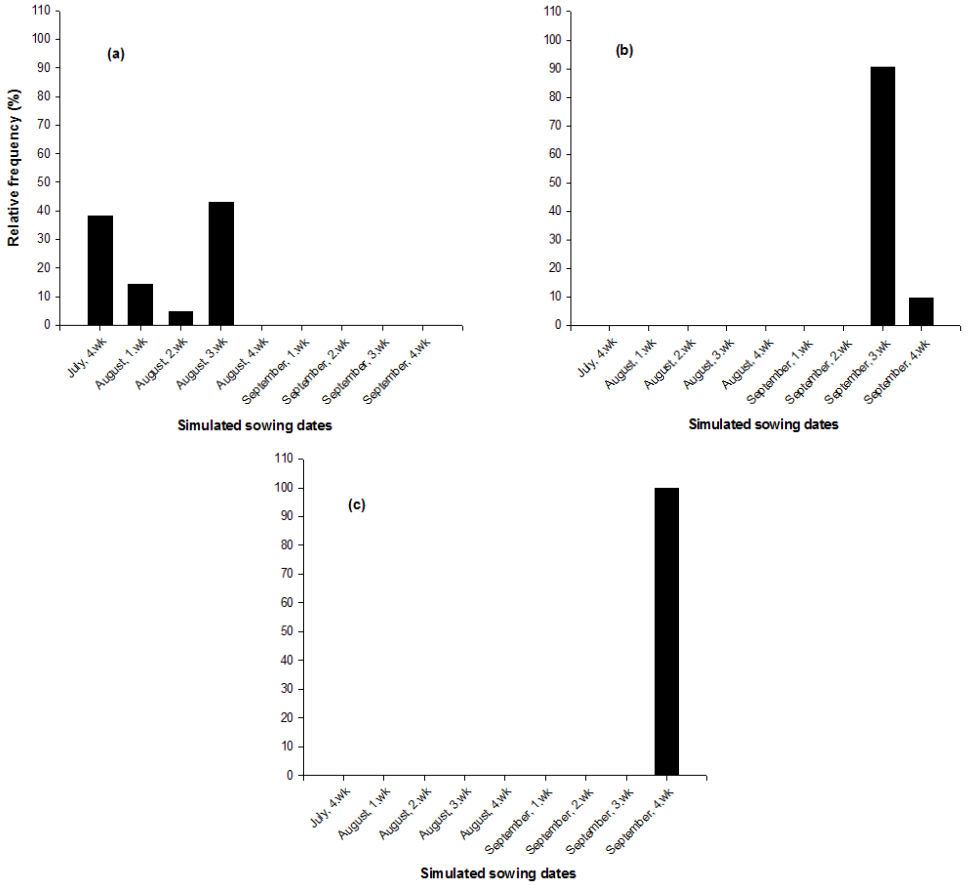

Figure 4: Relative frequency (%) of simulated maize sowing dates during the minor season on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1(c)

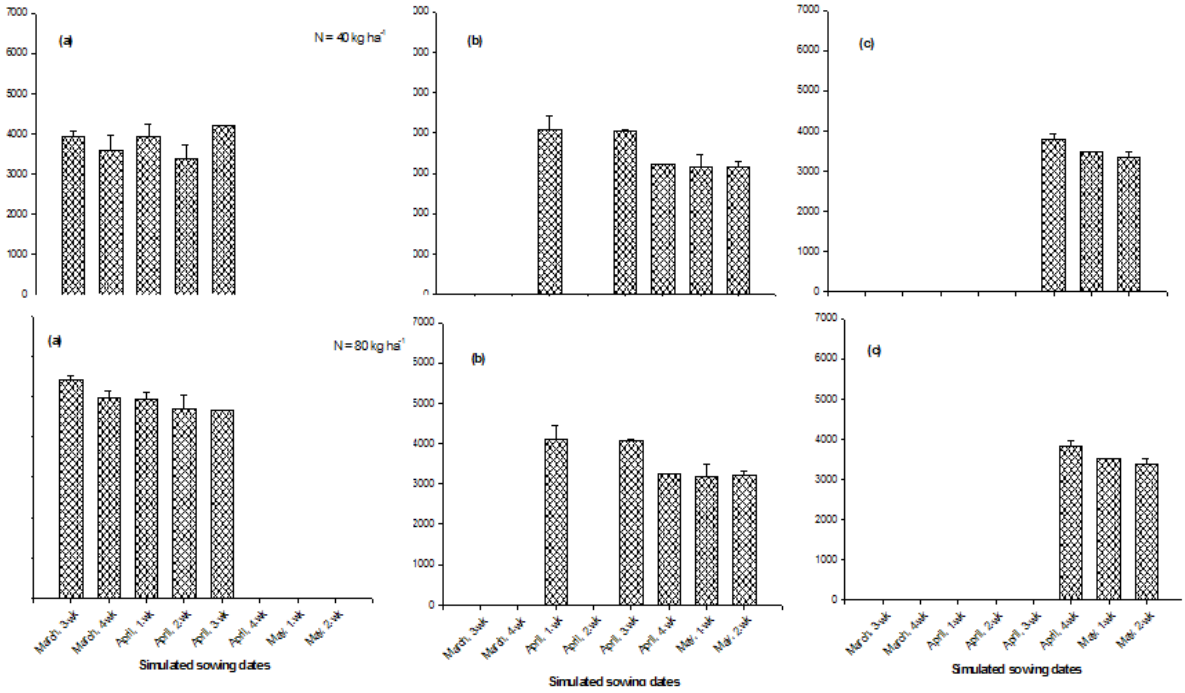

Figure 5: Simulated maize (var Obatanpa) – maize (var Obatanpa) grain yield (kg/ha^{-1}) rotation on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1(c) with 40 and 80 kg N ha^{-1} and 30 kg P ha^{-1}

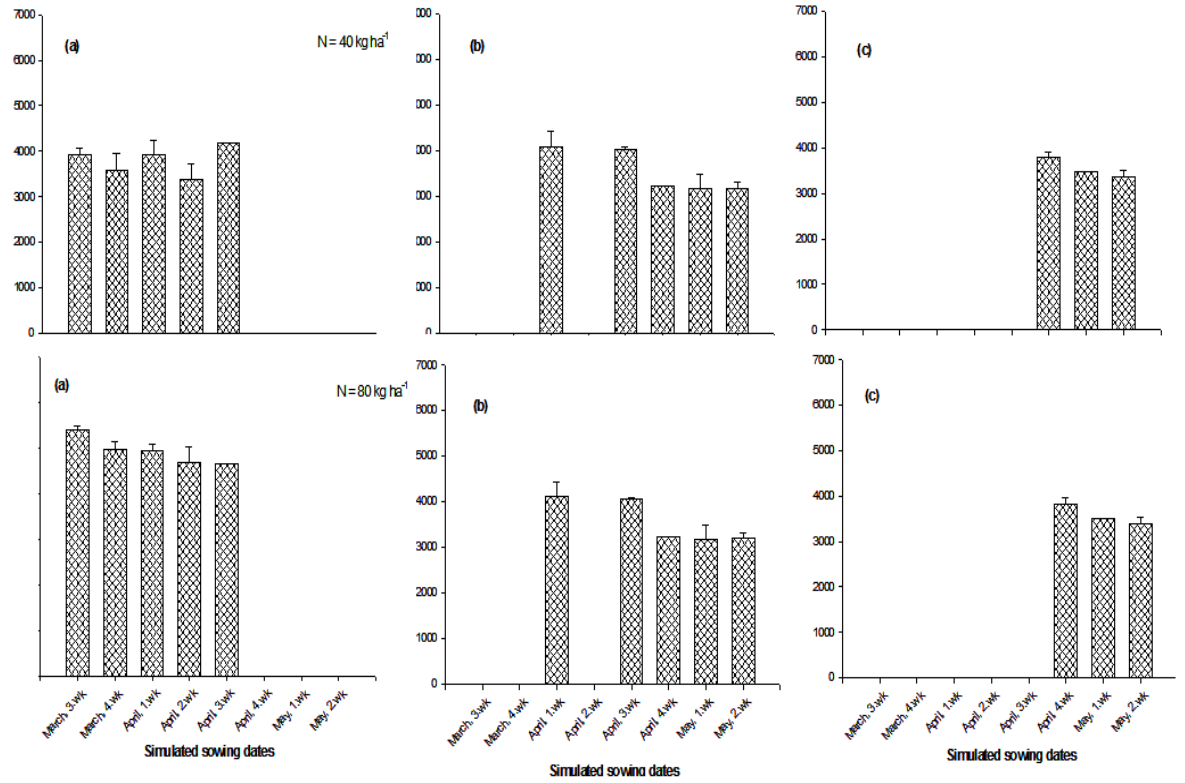

Figure 6: Simulated maize (var Obatanpa) – cowpea (Malam yaya) grain yield (kg/ha^{-1}) rotation on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1(c) with 40 and 80 kg N ha^{-1} and 30 kg P ha^{-1}

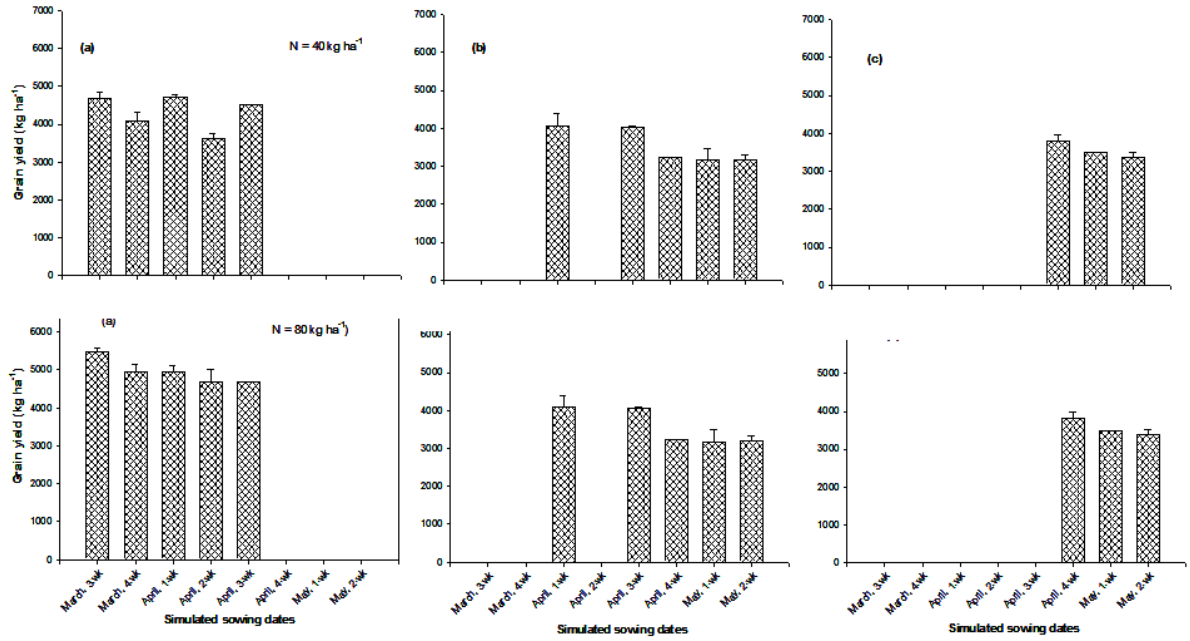

Figure 7: Simulated maize (var Obatanpa) grain yield (kg/ha-1) – fallow rotation on Haplic Lixisol at Ejura, Ghana, from historical weather data (1980-2000) (a), projected climate change (2030-2050) for scenarios A1B (b) and B1(c) with 40 and 80 kg N ha^{-1} and 30 kg P ha^{-1}

of the rainy season will negatively affect attainable maize yield in the later part of this century. This delay will narrow the window for planting and, hence planting long season varieties will interfere with planting in the minor season with harvesting operations of the major season crops. Similar findings on the impacts of climate change on rice were reported by Lansigan et al. (2000) in the Philippines, where sowing in normal years is commonly done on the 173rd day of the year (DOY), but in El Niño years sowing may have to be delayed until 229 DOY. Similarly, Fiwa et al., 2014 reported a shorter growing period, as a result of delayed onset and early cessation of the growing period in Cameroon. In addition, Myoung et al. (2015) reported that the change in planting date affected the yield of maize in mountainous areas with higher yields observed in early planting of maize.

The onset of the rainy season is an important variable for agricultural management practices (Ingram et al. 2002; Ziervogel and Calder 2003; Laux et al. 2010; Fiwa et al., 2014). Similarly, Waongo et al. (2014) indicated that the effective optimization of planting dates has the potential to increase crop production in SSA. Time of sowing affects crop growth, development and hence yields especially in rain-fed systems in sub-Saharan Africa (Kumar 1998).

Impact of climate change on maize yield

There were clear differences in terms of grain yield between historical yields and yields as a result of impact of climate change (Special Report on Emission Scenario (SRES) A1B and B1). The higher impact of A1B can be attributed to higher projected increase in temperature (1.6°C) compared to the 1.3°C for the B1 scenario. The study region already experiences high temperatures; hence, a further increase in temperature is expected to have a negative impact on yield. Boote

and Sinclair (2006) indicated that moderately cool temperatures favour high yields, as they allow the crop to progress slowly through the season so as to maximize the time for light capturing and carbon assimilation, as well as for partitioning assimilates to reproductive structures. A region like sub-humid Ghana, which has relatively high temperatures (mean temperature ranging from 26-30ºC), is expected to experience decreased yield with further increase in temperature. Lobell et al. (2011) found that for each degree-day above 30ºC, crop yields reduced by 1% under optimal rainfed conditions and by 1.7% under drought conditions in Africa.

The increase in temperature will result in a reduction in grain yield by 19 and 14 % under A1B and B1 scenarios, respectively. Waongo et al. (2015), for example, used different RCMs and found evidence for decrease in maize yield across Burkina Faso of −3.4% on average for the RCP4.5 and −8.3% on average for RCP8.5. Mati (2000) used two different GCMs, i.e. the GFDL and the CCCM model, and projected a temperature increase of 2.9 and 2.3°C, respectively for the semi-humid and semi-arid areas of Kenya. She concluded that the planting date has a profound influence on maize yields and that early maturing cultivars and early planting practice were necessary to counter the adverse effects of climate change in maize production in these agro-ecologies.

In this study, lower yield reductions were projected for crops planted earlier compared to those planted late. This could be attributed to higher moisture levels in the soil during the grain filling stage of the crop. Fosu-Mensah et al. (2012) reported that water stress during the flowering and grain filling stage of maize crop in both major and minor seasons resulted in low yields. Results of a simulation by Travasso et al. (2008) using HadCM3 climatic projections for the year 2080 under A2 scenario showed that increases in temperatures reduced the growing season of maize crops in southeastern South America by 27 days and consequently reduced yields. Even with non-limiting water supply and considering CO_2 fertilization, maize crops could still experience reduced grain yields with temperature increases greater than 1°C (Magrin and Travasso 2002). Similarly, Waha, et al., 2015 reported the well response of APSIM to farmers management practices and uncertainty in West Africa. Additionally, Meza et al. (2008) reported that under climate change, a high yielding maize cultivar DK 647 in Chile showed a yield reduction of between 15 and 28%. The reduction in yield was attributed to the shortening of the growth period of maize by up to as much as 40 and 28 days for the A1F1 and B2B scenario, respectively. Similarly, Kim et al. 2015 reported a change in maize yield as a results of change in minimum and maximum temperature in Southern United State of America. Early sowing and the reduction of fertilizer use were recommended as an adaptation measure under the B2B scenario.

Increased variability in rainfall distribution, which usually reflects in the high variability in grain yield, is another factor leading to the reduction of yields (Fosu-Mensah et al. 2012). Wheeler et al. (2007) simulated the effect of even and uneven intra-annual rainfall distribution on crop yield, independently of the total annual amount. Soil moisture stress at an important developmental stage (grain filling) of the plant development had a serious effect on grain size and weight and hence on yields (Fosu-Mensah et al. 2012). Similar findings were reported by Usman et al. (2005); Mishra et al. (2008) and Myoung et al. (2015)

who stated that the within and between season variability of rainfall is one of the major causes of yield reduction and or crop failure in sub-Sahara Africa. From the results obtained, the application 80 kg N ha^{-1} did not result in substantial increase in yield under either of the climate change scenarios. This may be attributed to water stress condition within the season as plant nutrient are transported through soil moisture. Moisture stress will result indirectly in nitrogen stress as water is needed for nutrient uptake.

The introduction of cowpea into the cropping system saw an increase in yield compared to maize-maize under climate change.

Conclusion

Simulation results of the climate change scenarios indicated a 6 week delay in sowing as a result of the delay in the onset of the rains. This will result in delayed planting and hence reduced maize yields. The increase in temperatures in the region by 1.6 °C and 1.3°C by 2050 under scenario A1B and B1, respectively, will have an effect on soil moisture and hence crop water availability.

Using historical yield data as a baseline, the average yield of maize by 2050 is likely to decrease by 19 and 14% in continuous maize-maize cropping system under A1B and B1 scenarios respectively. Furthermore, the inter-seasonal variability in maize yields is likely to increase significantly. The introduction of some adaptive measures, such as cropping of cowpea or fallowing the land during the minor season would likely increase yield by 3.4 and 0.5% under A1B and B1 scenario, respectively compared with maize-maize under climate change. Early sowing as soon as the season start will, however, reduce the adverse effect of climate change on yield. Depending on the onset of the rainy season, farmers would need to have access to suitable maize varieties in order to avoid significant yield losses in case of delayed planting, and capitalize on favorable conditions in good seasons. This will require development and availability of locally-adapted maize varieties with different maturity periods. Under both scenarios, the most effective adaptation measure would be early planting as soon as the season starts or conditions are favorable and cultivation of cowpea in the minor season. This requires climate or weather forecast information on the onset of the season. The government may need to do feasibility studies on irrigation systems as a means to extend the growing season for maize in the future.

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