African Crop Science Journal, Vol. 20, Issue Supplement s2, pp. 243 - 259 ISSN 1021-9730/2012 $4.00

IMPACT OF CLIMATE CHANGE ON SORGHUM PRODUCTION UNDER DIFFERENT NUTRIENT AND CROP RESIDUE MANAGEMENT IN SEMI-ARID REGION OF GHANA: A MODELING PERSPECTIVE

D.S. MACCARTHY and P.L.G. VLEK[1]
University of Ghana, College of Agriculture and Consumer Sciences, Institute of Agricultural Research, Soil and Irrigation Research Centre, Kpong, P. O. Box LG 68, Legon, Accra, Ghana
[1]Center for Development Research (ZEF), University of Bonn, Walter Flex Strasse 3, 53113, Bonn, Germany
Corresponding author: kpongor@yahoo.com

ABSTRACT

This study evaluates the potential impact of climate change on sorghum (*Sorghum bicolor* (L.) Moench) grain yield under different crop residue and nutrient management systems in a smallholder farming system. The Agricultural Production Systems Simulator (APSIM) was used in this scenario analysis. Two crop residue management types (crop residue retention in soil and crop residue removal) and fertiliser management (no fertilisation and application of 40, 30 kg P ha^{-1}) were the scenarios analysed using climate change (CCD) and historical (HD) weather data to simulate sorghum yield. Comparing grain yield under the two weather conditions, there was a 20% reduction in grain yield as a result of climate change when no fertiliser was applied compared with a yield increase of 4% with the application of 40 kg N, 30 kg P ha^{-1}. The impact of crop residue management on grain yield was lower under climate change weather conditions than under historical weather conditions. This can be attributed to higher soil moisture stress which also contributed to lower rate of soil carbon decomposition in the top soil. Instability (inter-annual standard deviation) in grain yield was higher under climate change (0.13 to 0.21) weather conditions than under historical (0.04 to 0.11) weather conditions. This was reflected in higher change in yield, thus, making sorghum production under rain-fed agriculture more risky, particularly to the smallholder (low input) farmers.

Key Words: APSIM, phosphorus, rain-fed, *Sorghum bicolor*

RÉSUMÉ

Cette étude évalue l'impact potentiel du changement climatique sur le rendement en grain du sorgho (Sorghum bicolor (L.) Moench) sous différents systèmes de gestion des résidus des cultures et des éléments minéraux dans le system de petites exploitations agricoles. Le Simulateur des Systèmes de Production Agricole (APSIM) était utilisé dans cette analyse de scénario. Deux types de gestion de résidus des cultures (maintien de résidus des cultures dans le sol et l'enlèvement des résidus) et la gestion des fertilisants (pas de fertilisation et application de 40 kg N, 30kg P kg^{-1}) étaient des scenarios analysés en utilisant des données de changement climatiques et des données climatiques historiques pour simuler le rendement du sorgho. En comparant le rendement en grain sous les deux conditions climatiques, une réduction de 20% du rendement en grain était observée en condition de sol non fertilisé ainsi qu'une augmentation du rendement de 4% induite par l'application de 40kg N et 30 kg P ha^{-1}. L'impact de la gestion des résidus des cultures sur le rendement en grain était plus bas sous condition de changement climatique que sous condition de climat historique. Ceci peut être attribuée au stress liée à une humidité plus élevée qui, avait aussi contribué à réduire le taux de décomposition du carbone du sol dans la couche superficielle du sol. L'instabilité (déviation standard inter-annuelle) dans le rendement en grain était plus élevée en condition du changement climatique (0.13 à 0.21) qu'en condition du climat historique (0.04-0.11) Ceci s'était manifesté dans le changement notable du rendement, ainsi, faisant que la production du sorgho en condition pluviale soit une activité à risque, particulièrement chez les petits exploitants.

Mots Clés: APSIM, phosphore, pluviale, *Sorghum bicolor*

INTRODUCTION

Climate change (CC) and its potential long-term impact on crop production is a topical issue worldwide. Its long-term impact on food security and environmental sustainability are continuously gaining attention, particularly in Sub-Saharan Africa (SSA). This is partly because the potential impacts of CC on agriculture are highly uncertain. Additionally, changes in climate can potentially impact on weather and soil, which are two very important factors that influence crop production. Crop production in SSA, and for that matter Ghana, is based on rain-fed agriculture, largely at a subsistence level and the use of external inputs is low. Hence, deterioration in weather patterns, particularly rainfall amounts and distribution, could be devastating to food production. Additionally, the sub-region is saddled with nutrient export, both nationally and internationally, resulting in soil fertility decline (Breman *et al.,* 2008).

In spite of the contributions of mineral fertilisers to food production world-wide, their use in the SSA region is still very low (around 10 kg ha^{-1}) Fosu *et al.* (2010) and this has been attributed to high prices and the variable yield response due to erratic seasonal rainfall amounts and distribution.

To access the potential impacts of climate change on food production, a crop simulation model (CSM), together with predicted parameters for future weather (Jung, 2006), as projected using LARS weather generator over a 40-year period (Semenov and Brooks, 1999) was used in the present study. CSMs have been used for many different applications in various countries around the world (Asseng *et al.,* 2011; Bell *et al.,* 2011; Thorburn *et al.,* 2011). It is a suite of simulation model that can make a valuable contribution to the understanding of the processes that determine crop responses and can predict crop performance, resource use and environmental impacts for different environments and scenarios. This is achieved by capturing the interactive effect of soil-atmosphere on crop yield. The Agricultural Production Systems sIMulator (APSIM) (Keating *et al.,* 2003) was the CSM used in this study. It is a framework that allows individual modules that are key components of the farming system (as selected or described by model user) to be 'plugged in' (McCown *et al*., 1996). The result is a farming system simulator that possesses the ability to combine accurate crop yield estimation in response to management practices with the long-term consequences of management practices on the soil resource base (Keating *et al*., 2003). Examples are the simulation of soil P impact on grain yield, or the long-term soil organic dynamics in response to management practices and weather.

This study aimed at assessing the potential impacts of projected climate change on sorghum production in the sub-region of Ghana.

METHODOLOGY

Study area. The study was conducted in the semi-arid part of the Volta Basin in Ghana, falling in the transitional zone of Guinea and Sudan savannah agro-ecological zones. It is bordered by latitude 10° 15" and 11° 10" N and 0° and 1° 0" W. The area is characterised by a unimodal rainfall pattern with an annual average rainfall of about 950 mm. Soils used in the study are classified as Endoeutric-stagnic Plinthosol and Eutric Gleyic Regosol (FAO classification). They are very low in organic matter and are characterised by annual burning of vegetation. The vegetation comprises of scattered trees and shrubs with grass under growths.

APSIM model evaluation. In order to ensure that the model simulations were comparable to the agronomic reality in the study area, APSIM model outputs were tested against data collected from rain-fed experiments. These were conducted at two different sites at Navrongo in Ghana in the year 2005 cropping season. The experiment combined 3 levels of P (0, 30 and 60 kg ha^{-1}) and 4 levels of N (0, 40, 80, 120 kg ha^{-1}) in a randomised complete block design. Details of the APSIM evaluation to simulate grain yield response to nutrient management are available in MacCarthy *et al.* (2009). Soil water content in the top soil (0-150 mm) was monitored during the growing season buy collecting soil samples using core sampler with known volume. Soil samples were oven-dried at a constant temperature of 105 ^{o}C till constant weight was attained. Soil water content of the various samples was determined using the volumetric method as described in Hoogenboom *et al*. (1999).

Simulation experiments. Five different modules in the APSIM model; a specific sorghum crop module (APSIM-sorghum 4.2), soil nitrogen (soiln2), soil P module (soilP), soil water (soilwat2) and residue (residue2) modules were linked within the APSIM 4.2 model, to simulate sorghum yield. Input data included soil chemical and physical properties, crop management data, (dates of sowing, amount and types of fertilisers applied etc.), crop genetic characteristics and weather data (daily values of solar radiation, maximum and minimum temperature and total rainfall amount).

A sowing window of between 15th May and 30th June was given for the model to sow after cumulative rainfall amount of 15 mm occurred. This was achieved by introducing this condition in the sowing rule in the manager file of the model. Sorghum was sown at a planting density of 12 plants m^{-2}. Soil properties used to initialise simulations of the various management scenarios under both weather conditions are presented in Table 3. Additionally, data from published results of previous works (MacCarthy *et al*., 2009) on APSIM evaluation were used. Historical (HD) and climate change (CCD) weather data were used to simulate grain yield. Farm management scenarios used in the simulation experiments were:

(i) Continuous removal of crop residues with no fertiliser inputs;
(ii) Continuous removal of crop residues with 40 kg N, 30 kg P ha^{-1}applied;
(iii) Continuous retention of crop residues with no fertiliser inputs; and
(iv) Continuous retention of crop residues with 40 kg N, 30 kg P ha^{-1}applied.

Crop simulation model-APSIM (Agricultural Production Systems sIMulator), which had been calibrated and evaluated (MacCarthy *et al*., 2009) for the study area was used for the simulation experiment.

Weather data. The base weather data used were an output of the coupled Atmosphere-Ocean Global Circulation Model (AOGCM) ECHAM4/OPYC that were downscaled dynamically with the meso-scale meteorological model MM5, and coupled to the hydrological model, WaSiM to assess the impact of a globally changing climate on regional climate and hydrology and stored in grid format. Details of these models, procedures and outputs are described in Jung (2006).

The simulated weather data used were over the time slices 1991-2000 and 2030-2039 for the study site, which were extracted from the main data base (GLOWA-Volta website). The LARS-WG (Semenov and Brooks, 1999) was used to project both time slices to 30 years period each. These weather data was then fed into a crop simulation model – APSIM 4.2 and used in running simulations.

Agro-climatic risk indicators. Two agro-climatic indices were computed, namely inter annual standard deviation of yield and sustainability of grain yield. Inter annual standard deviation (INST) of grain yield (modified from Akponikpe *et al*. (2010)) for the various management scenarios were calculated under both weather conditions as:

$$INST = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}(Y_{jk} - Y_j)^2}$$

Where Y_{jk} is grain yield per year, Y_j is average grain yield over the number of cropping years. The lower the value, the more stable grain yield; hence, the less risks of attaining lower yields over the period. The sustainability or yield stability of each of the scenarios were analysed using;

$$SYI = \frac{(Y_a - stdev)}{Y_m}$$

Where: Y_a is the mean yield, stdev the standard deviation, and Y_m is the maximum yield obtained under each set of management system.

Statistical analysis. Paired t-test procedure was used to differentiate between scenarios for significant differences at P = 0.05. Coefficient of variation (CV) was used to assess the variability in data sets. Signal to noise ratio was used to assess the significance of differences between present and future weather parameters.

$$SN = \frac{|Xfut - Xpres|}{stdev}$$

Where: SN is signal to noise ratio, Xfut and Xpres are mean future and present values, respectively. SN > 1 indicates a detected change in the variable in question over present values. The performance of the model in simulating observed grain yield, N and P uptake, and water dynamics were assessed using the root mean square error (RMSE) and index of agreement (d) (Willmott *et al*. 1985). RMSE is defined as:

$$RMSE = [n^{-1} \sum (Yield_{Simulated} - Yield_{Observed})^2]^{0.5}$$

$$d = 1- \left[\frac{\sum_{i=1}^{n}(S_i - O_i)(S_i - O_i)}{\sum_{i=1}^{n}(|S_i - M_i| + |O_i - M_i|)}\right]$$

where: Si and Oi are the simulated and the observed values, n the number of observations, and *M* the mean of the observed value. Good simulations have values of RMSE and *d* as close as possible to 0 and 1 respectively. High values of *d* close to 1 indicate good model performance and better relation of observed verses simulated.

RESULTS

APSIM model performance. Crop phenology, grain and biomass yields collected from two management zones and soils, were adequately predicted by the model (MacCarthy *et al*., 2009). The RMSE represented between 11 and 30% of mean yield for the different management zones and soils. This falls within the upper limit reported for similar environments in farmers fields in Sahelian Niger (Brouwer *et al*., 1993; Akponikpe *et al*., 2010). Predictions of soil moisture dynamics were close to observed data (Fig. 1) with low RMSE of 0.014 mm mm^{-3} and high d value of 0.87. The model also adequately reproduced the trend of sorghum grain and biomass yield in response to N and P fertilisation. The model was able to represent grain yield under no input system which is characteristic of the study area. Nitrogen and P uptake by plants were also reasonably well predicted by the model. Details of model performance are available in MacCarthy *et al*. (2009).

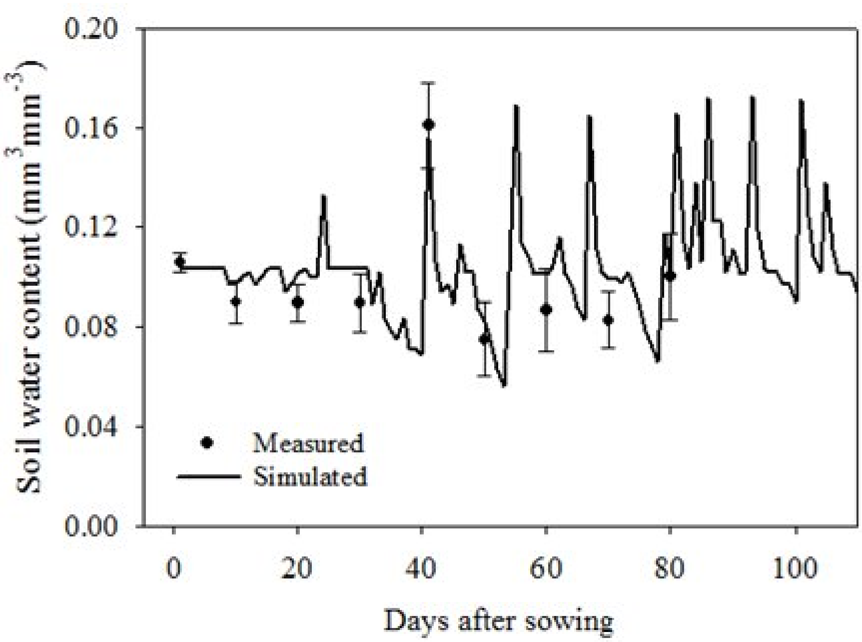

Figure 1. Simulated and measure soil water content in soil profile (0 - 150 mm depth) during the growing season of sorghum sown on the 12th June 2005. RMSE is 0.014 mm mm^{-3} and Willmot (1985) index of agreement (d-value) of 0.73

Precipitation. The peak of the rainy season for the present time slice occurred in July, but a shift in the rainfall peak toward August was projected for the future time slice. Significant increases in monthly rainfall figures were projected in the future for the months of August, October and November. August recorded the highest increase in precipitation (Table 1). Since sandy soils normally dry out quickly due to their relatively low permanent wilting point, available water and water holding capacity, they depend highly on well distributed rainfall pattern for good crop yields.

Temperature. Mean annual temperature increased from 31.6 for the recent time slice to 33.1 projected for the period 2030-2039. The annual temperature cycle shows a clear increase for the study region, ranging from an absolute value of 0.5 °C for the month of September to 2.7 °C for the month of May. The increases in temperature were obvious in the mean annual value, and more importantly, during the growing season (Table 2). This phenomenon has the potential of shortening the growth cycle of the sorghum variety used in this study (ICSV III) as its growth duration is controlled by accumulated thermal degree days (Murty *et al*., 1998). This was reported to be the case for maize by Tachie-Obeng *et al.* (2010) using projected climate change scenarios with projected increases of between 2.0 and 4.0 °C in temperature. This was, however,

TABLE 1. Analysis of present and future precipitation for Navrongo, Ghana (HD is historical weather data and CCD is climate change data)

Month	HD (mm)	CCD (mm)	Stdev-(HD) (mm)	Diff	SN
January	0	0.0	0	0	0
February	0.5	0.0	1.2	0.5	0.4
March	6.1	2.2	8.1	3.9	0.5
April	45.1	34.9	12.8	10.2	0.8
May	162.4	147.3	82.9	15.1	0.2
June	168.7	173.4	86.7	4.7	0.1
July	225.2	205.6	92.1	19.7	0.2
August	194.7	304.6	60.5	109.8	1.8
September	155.8	203.7	58.3	47.9	0.8
October	43.3	76.3	8.3	32.9	4.0
November	1.5	4.3	2.5	2.8	1.1
December	0	0	0	0	0

TABLE 2. Analysis of present and future temperature for Navrongo, Ghana (HD is historical weather data and CCD is climate change data)

Month	HD(°C)	CCD (°C)	Stdev-(HD)	Diff	SN
January	29.4	30.5	1.0	1.0	1.0
February	31.8	32.9	1.2	1.1	0.9
March	34.9	36.0	1.1	1.0	0.9
April	35.7	38.1	1.0	2.5	2.4
May	32.0	34.7	1.4	2.7	2.0
June	30.2	31.7	1.2	1.5	1.3
July	29.4	30.9	0.9	1.6	1.7
August	29.2	30.3	0.6	1.0	1.7
September	30.4	30.9	1.1	0.5	0.5
October	33.9	34.7	1.1	0.8	0.7
November	32.4	34.3	0.7	1.9	2.6
December	29.7	31.6	0.9	1.9	2.1

not evident in this study, probably because of the effect of moisture stress in prolonging crop phenology.

Sowing dates. Increases in rainfall in the middle and tail portion of the growing season (especially August, October and November (Table 1) observed for projected climate change scenarios could result in favourable conditions for late planting of sorghum in this region. There was a general shift in the start of the season; hence, the planting window for the climate change scenarios was extended by 30 days. Maintaining the planting window for the historic weather data resulted in total loss of crops in a number of years. This was due to crop failure as a result of prolonged drought and inadequate moisture for seeds to emerge. The extension in the planting window also allowed crops to benefit from increased rainfall amounts for the months of October and November. Time taken for crop to mature was significantly increased in the climate change scenarios (10 and 15 days for fertiliser application and no fertilisation, respectively). Variations in maturity dates were higher in the climate change scenarios (10 and 5% for unfertilised and fertilised, respectively) than those with historical data (7 and 2% for unfertilised and fertilised, respectively). These variations were, however, lower with the application of fertiliser.

Soil productivity. Sorghum grain varied from 0.59 to 1.32 t ha^{-1}, when historic weather data was used, and no fertiliser was applied and crop residues were removed from fields. Using climate change scenario weather data under similar fertiliser and residue management, grain yield varied between 0.44 and 1.7 t ha^{-1}. Retaining crop residues into the soils without mineral fertiliser application resulted in yield levels increasing (1.06 to 1.99 t ha^{-1}) with the historic weather data. Under the climate change scenario, grain yield varied from 0.32 to 1.78 t ha^{-1}. Crop residue retention in the soil yielded higher returns under the simulations with historic weather data than the simulations with climate change scenario data. This is evident in the higher average grain yield obtained with the historic weather data. Significant differences in grain yields existed between scenarios with historical and climate change scenario weather data irrespective of type of residue management. Fractional change in grain yield was generally higher with the climate change scenario data than for the historical data (Figs. 2 - 5). Removal of crop residue resulted in an increase in the percentage loss in yield for both historic and climate change scenario data.

With the application of 40 kg N, 30 kg P ha^{-1}, and removal of crop residues from the fields, grain yield varied between 2.11 and 2.84 t ha^{-1} with an average of 2.4 t ha^{-1} under historical weather condition. Under climate change weather conditions, grain yield varied between 1.78 to 3.50 t ha^{-1} with an average of 2.68 t ha^{-1}. With the retention of crop residues on the fields and similar fertiliser management, grain yield varied between 2.29 and 3.28 t ha^{-1} with an average yield of 2.83 t ha^{-1} under historical weather condition. Under the climate change scenario weather condition with similar fertiliser and crop residue management, grain yield varied between 1.94 and 3.65 t ha^{-1} with an average yield of 2.76 t ha^{-1}.

There was no added value from crop residue in terms of improving yield sustainability index under both weather conditions when 40 kg N, 30 kg P ha^{-1} were applied. The inter-annual instability (standard deviation) in grain yield ranged from 0.04 to 0.26 in the unfertilised system under the historical weather conditions and fertilised climate change weather condition, respectively. Scenarios with historical weather data with fertiliser application were the most sustainable for sorghum grain production (Table 4). The least sustainable system occurred without fertiliser and when crop residues were removed under the climate change scenario weather data. In the no input (non-fertilised) system, retaining crop residue in the soil resulted in higher sustainability index. On the contrary, the impact of crop residue retention in the fertilised systems was masked by the application of 40 kg N, 30 kg P ha^{-1} thus, not impacting on the sustainability index. The relationship between INST (instability index) and SYI were statistically significant with a negative slope (-0.12) and R^2 value of 0.12. Generally, INST indices decreased with increasing values of SYI. This reveals that, that inter annual grain yield tended to decrease with increasing sustainability of grain yield.

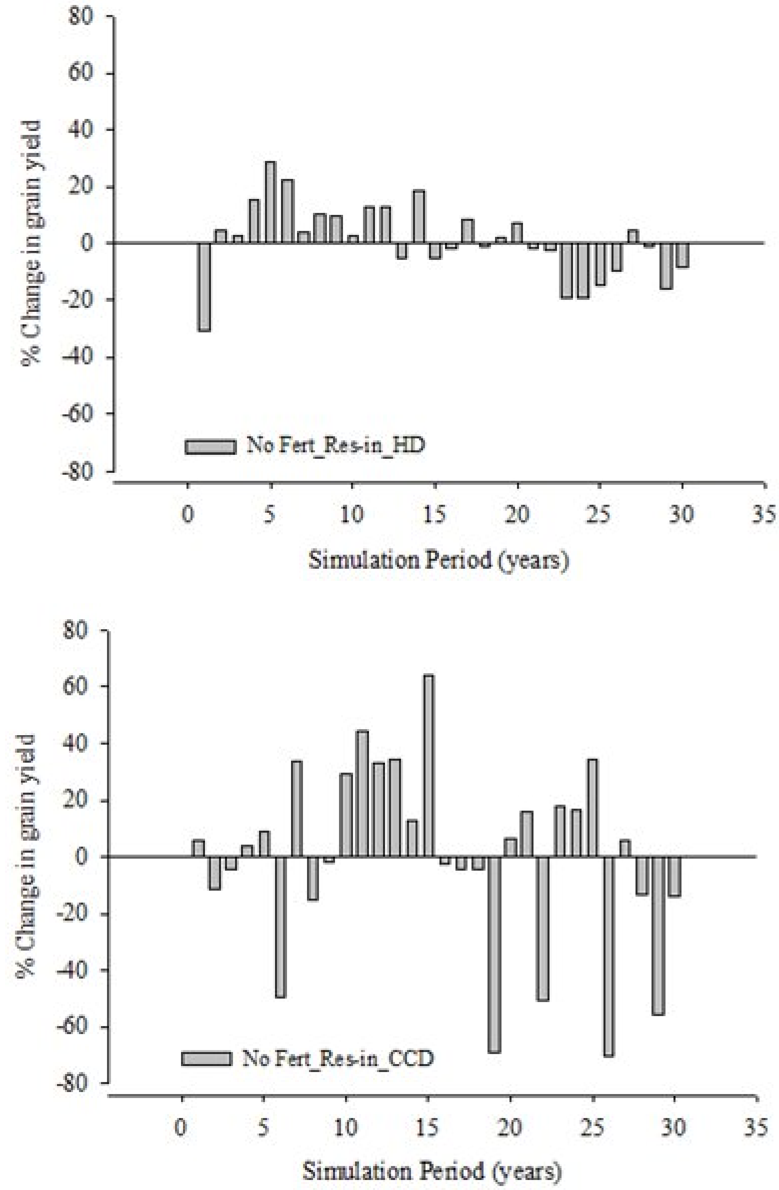

Figure 2. Simulated relative change (%) in sorghum grain yield under unfertilized management system with residue retention using both historical (HD) and climate change (CCD) data for Navrongo, Ghana.

Harvest index was generally higher under HD weather conditions (0.25 to 0.29) than under CCD weather conditions (0.23 to 0.28) with variability consistently lower with the HD (3 – 11%) than those under CCD (6-15%). Total N available in biomass was 56 compared to 46 kg ha^{-1} with the application of 40 kg N ha^{-1} for the CCD and HD, respectively. This was more stable under HD than under CCD. With no fertilisation, difference in total N available in biomass was not significant (13 and 14 kg N ha^{-1} CCD and HD, respectively).

DISCUSSION

Variation in grain yield over the simulation period was generally high (CV from 10 to 42%). Under all management scenarios, variability in grain yield was higher under the climate change scenario

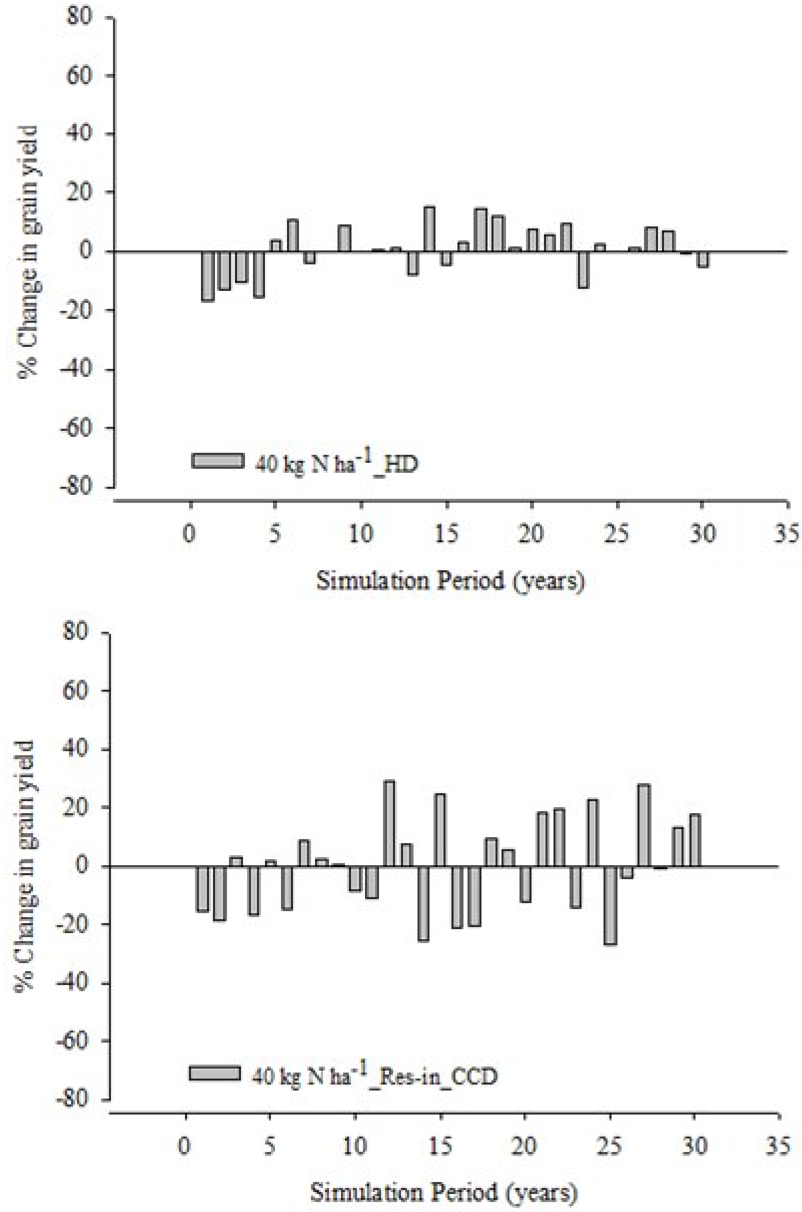

Figure 3. Simulated relative change (%) in sorghum grain yield under fertilized (40 kg N, 30 kg P ha^{-1}) management system with residue retention using both historical (HD) and climate change (CCD) data for Navrongo, Ghana.

weather data compared with yields obtained under the historical weather data (Table 4). Grain yield was particularly variable with fertiliser application under the climate change weather data. High variability in crop yield was observed over the 30-year simulation period for all four crop production management scenarios, with the scenarios without fertiliser experiencing a decreasing trend. This variability can be attributed to a large extent to rainfall amounts and distributions considering the fact that it was the most variable weather parameter recording a coefficient of variation of 18%. In scenarios where no fertiliser was used and crop residues were

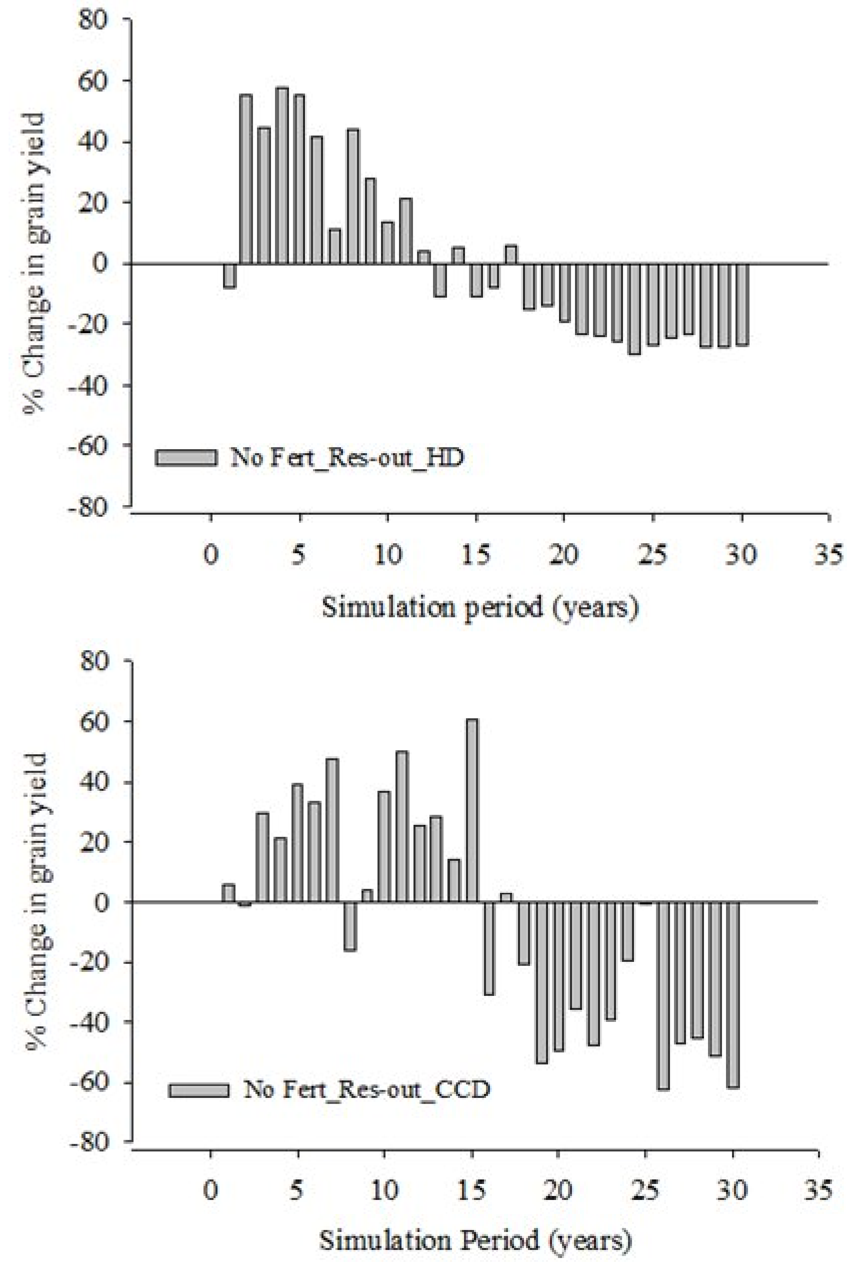

Figure 4. Simulated relative change (%) in sorghum grain yield under unfertilized management system with crop residue removal using both historical (HD) and climate change (CCD) data for Navrongo, Ghana.

removed annually, which is the usual farming practice in the study region, depletion of soil organic carbon base was another factor that played an important role in crop yield (MacCarthy *et al*., 2009). Additionally, the long-term benefit of crop residues was evident in higher yields after about 20 years of continuous cultivation. These benefits were, however, higher where no fertiliser was applied. Lithourgidis *et al*. (2006) reported similar results of stability in the long-term yield of winter wheat, which they attributed to the application of inorganic fertiliser and

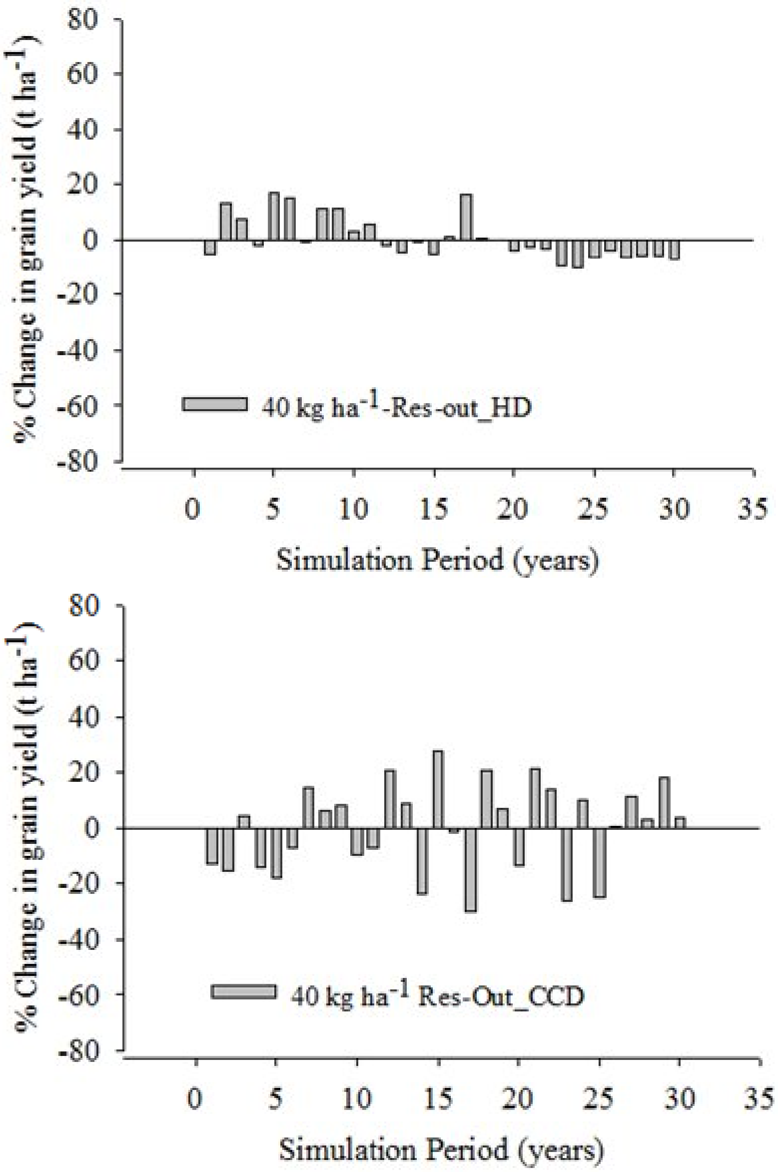

Figure 5. Simulated relative change (%) in sorghum grain yield under fertilized (40 kg N, 30 kg P ha^{-1}) management system with crop residue removed using both historical (HD) and climate change (CCD) data for Navrongo, Ghana.

incorporation of crop residue from preceding seasons.

Clear trends of decreasing grain yield with continuous cropping in the scenario with no fertilisation were observed under both weather conditions. The rate of decrease is lower with retention of crop residue. This can be attributed to the build-up of soil organic carbon as well as N input from crop residues (MacCarthy *et al.*, 2009) which would have been lost to the system. Retaining crop residues from preceding crop resulted in a reduction in crop losses (relative the means for the various scenarios). Thus, reduction in crop yield can be limited by the incorporation of crop residues. This was the case when both historical and climate change scenario weather data were used. While retaining crop residues into the soil resulted in higher stability in grain yield over the period for the unfertilised systems, the impact of residue retention in the

TABLE 3. Soil properties used for modeling sorghum yield in the study area

Layer	1	2	3	4	5
Layer thickness (mm)	150	150	200	250	250
Soil water parameters					
BD (g cm^{-3})	1.52	1.50	1.51	1.62	1.56
SAT [cm cm^{-1}]	0.291	0.321	0.320	0.222	0.246
LL [cm cm^{-1}]	0.073	0.105	0.152	0.149	0.145
DUL [cm cm^{-1}]	0.163	0.241	0.262	0.219	0.159
Soil-C parameters					
Organic C (g $100g^{-1}$)	0.47	0.40	0.32	0.37	0.32
pH	6.90	5.30	5.20	5.60	5.90
finert [a]	0.35	0.40	0.50	0.80	0.80
fbiom [b]	0.02	0.02	0.01	0.01	0.01
Soil P parameter					
Labile P (mg kg^{-1})	15.0	6.2	5.0	2.0	1
P sorption (mg kg^{-1})	50	90	150	180	200

[a] Proportion of soil carbon assumed not to decompose. [b] Proportion of decomposable soil carbon in the more labile soil organic matter pool BD: bulk density, SAT: volumetric water content at saturation, LL: wilting point, DUL: field capacity

TABLE 4. Average grain yield and CV and selected statistics and agro-climatic indices for different residue and nutrient management under historical and climate change weather data

Scenario	Mean grain yield (t ha^{-1})	CV(%)	Max (t ha^{-1})	Min (t ha^{-1})	SYI	INST
0 N Res out HD	1.03	33	1.32	0.59	0.48	0.11
0 N Res in HD	1.55	14	1.99	1.06	0.67	0.04
0 N Res out CC	0.92	42	1.70	0.44	0.31	0.15
0 N Res in CC	1.08	33	1.78	0.32	0.40	0.13
40 N Res out HD	2.40	9	2.84	2.11	0.79	0.05
40 N Res in HD	2.83	10	3.28	2.29	0.79	0.07
40 N Res out CC	2.68	18	3.50	1.78	0.66	0.19
40 N Res in CC	2.76	19	3.65	1.94	0.67	0.21

fertilised systems were not visible in grain yield. The magnitude of grain losses were, however, higher with the climate change scenarios in both the no input system as well as when 40 kg N ha^{-1} was used. This is probably due to the differences in temperature and in rainfall distribution and amount. Comparing average grain yield between historical and climate change data indicates an average loss in grain yield of 22% for no fertiliser application and yield increase of 4% when fertiliser was applied over the simulation period.

Using the two time slices (historical and future) weather data showed significant differences in soil organic carbon dynamics under the same crop production management scenarios (Fig. 7). Depleting SOC as result of removal of crop residue is evident in both time slices.

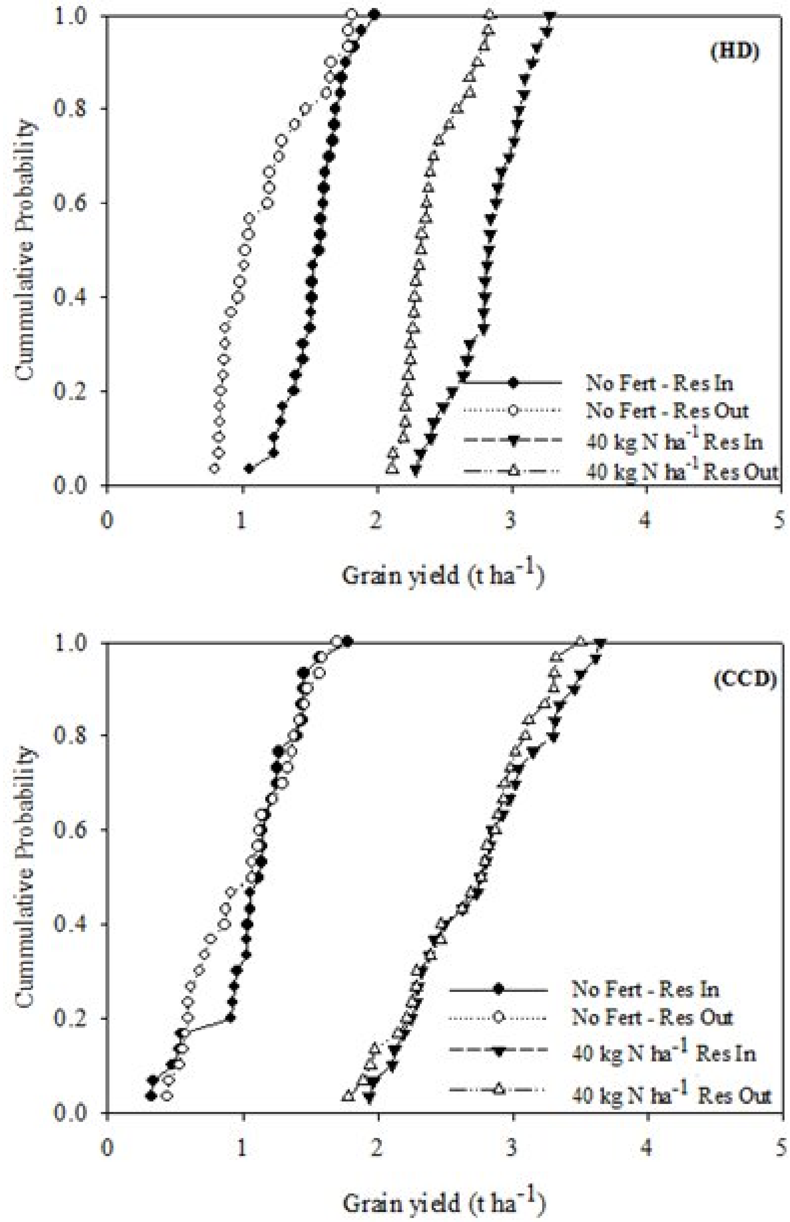

Figure 6. Comparison of the cumulative probability of simulated grain yield of sorghum under different management scenarios using historical (HD) and climate change (CCD) data generated by the MM5 that has been projected into a number of years by the LARS weather generator for Navrongo area.

However, the rates of SOC decline were lower under future climate scenarios than those under historical weather data. The decomposition of SOC depends on available soil moisture, soil temperature and C: N ratio of organic material. Given that soil moisture stress was higher (Fig. 8) in the climate change scenario compared to that of historic weather data, the rate of decomposition was probably constrained. The lowest soil water content for the historic weather condition was 0.048 mm^3 mm^{-3} compared to 0.022 mm^3 mm^{-3} for the climate change conditions. This resulted in the lower rate of decline in SOC with the removal of crop residues, and a higher rate of

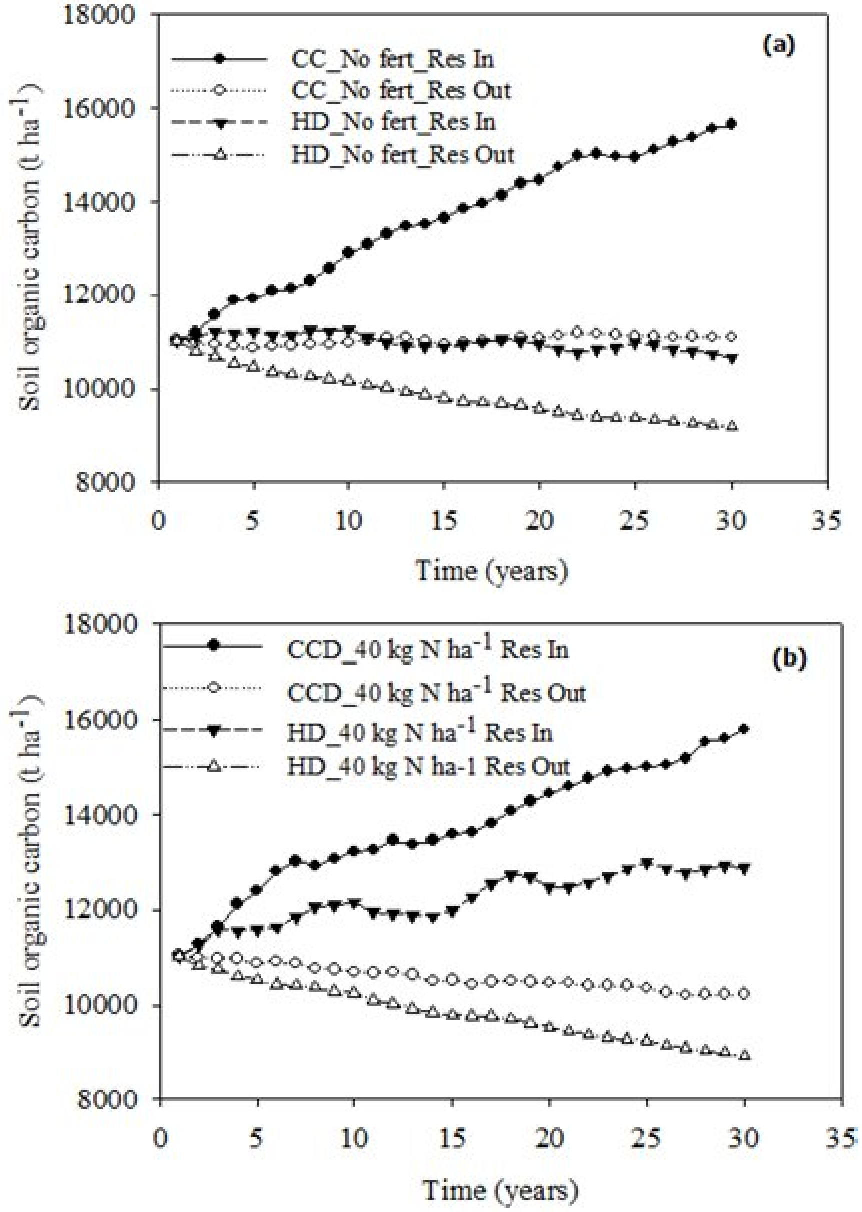

Figure 7. Simulated Soil Organic Carbon dynamics under continuous cultivation for the various management scenarios (a) No fertilizer input and (b) 40 kg N, 30 kg P ha^{-1} using both historical (HD) and climate change data (CCD) weather parameters as per MM5 weather predictions.

SOC build up with crop residue retention in the climate change scenario in spite of the higher temperature. Additionally, biomass yield was generally higher under climate change scenario, thus, more organic carbon was available for decomposition. The harvest indices were; however, lower under climate change weather conditions for all management scenarios. Reduction in the long-term grain yield can also be attributed to reduction in SOC, which is needed to improve the buffering capacity of the soil, particularly when no fertiliser was applied.

Impact of crop residue on the stability of grain yield is prominent without fertiliser application

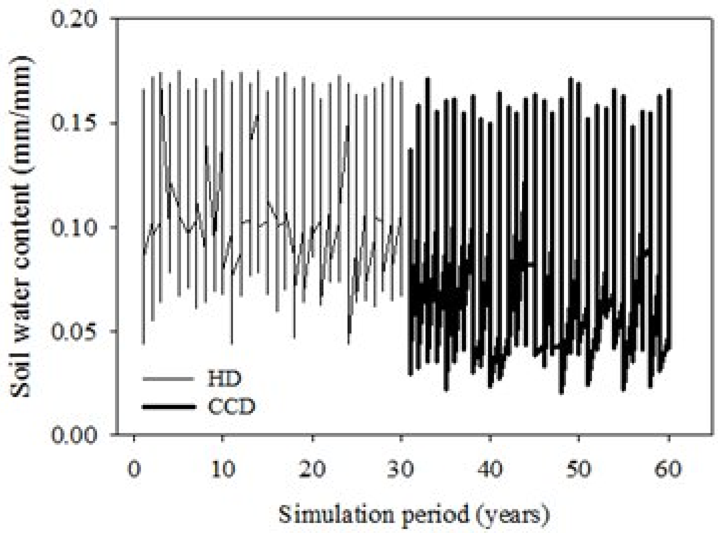

Figure 8. Simulated soil water (0 – 150 mm layer) dynamics under sorghum production at Navrongo under both historical (HD) and climate change data (CCD) weather conditions parameters as per MM5 weather predictions.

under both weather conditions. The cumulative distribution functions (CDF) of grain yield are illustrated in Fig. 6. Based on the paired T test, there were significant differences between CDFs for fertilised and unfertilised management scenarios. Effect of crop residues on grain yield under historical weather conditions were also significant ($P<0.05$) using the paired T-test. The significant impact of crop residues under HD weather conditions is illustrated by clear differences in grain yield between the two residue management types under both types of fertiliser management. When no fertiliser were applied, there was a 50% probability of attaining grain yields of 1.0 and 1.5 t ha^{-1} (removing and retaining crop residue respectively) in HD weather conditions compared with 1.0 t ha^{-1} in the CCD weather condition irrespective of type of crop residue management. A similar trend was observed with the application of 40 kg N and 30 kg P ha^{-1}. The lack of impact of crop residue under CCD weather condition could probably be attributed to soil moisture stress. Thus, soil moisture becomes the factor limiting crop productivity, as moisture is needed for nutrient uptake from the soil and other soil and plant metabolic processes. The cumulative probability of grain yield for the unfertilised systems tends towards lesser yields in the CCD weather condition than those under HD weather conditions (Fig. 6). This poses serious concern for crop production in this sub region as most of the smallholder farmers use very little or no fertilisers. Average grain yield of sorghum estimated over 6 years (2001 to 2006) period was 0.96 t ha^{-1} (Fosu *et al*., 2010) mainly under very limited or no fertilisation. This level of grain production is always accompanied by annual food shortages for between 3 and 5 months as it does not suffice households till the next crop harvest. Assuming then, that yields below 0.96 t ha^{-1} will result in food shortages, there would be a 38% probability for yields to drop below this threshold when crop residues are removed under HD weather condition, while no food shortage would occur when crop residues are retained in the soil. In contrast, in the CCD weather condition; there would be a 41% chance of food shortage occurring with the removal of crop residues while retaining crop residues would reduce chance of food shortage to 21%.

Data on temperature (CCD) showed an increasing trend over the years (Jung, 2006). Given that increases in temperature will reduce phenology and hence reduction in the time to capture light and water use (Anwar *et al*., 2007), reduction in grain yield was only evident in treatments with no fertiliser application. Yield reduction was not observed in treatments with fertiliser application. Additionally, increased carbon dioxide as is associated with climate change is expected to create an initial increase in yield, because of increased use efficiency of solar radiation, water, nitrogen and other minerals (Drake *et al*., 1997; Barrett and Gifford, 1999; Gifford *et al*., 2000; Anwar *et al*., 2007). The shortened growth periods due to accelerated phenology will reduce yields (Anwar *et al*., 2007). The CO_2 fertilisation which is expected under climate change in C 4 plants will result in increase CO_2 fixation capacity of plants and decrease in water used rate as stomata partially close under increased CO_2 conditions. These gains in plant growth and soil water saving tend to be completely offset by increases in air temperature, which will result in increased evapo-transpiration and plant respiration (Laryea *et al*., 2010). In dry environments, where nutrient limitations are prominent, such as in this study, the C-fertiliser effect will be negligible (Amthor, 2001). Some factors, such as plant adaptation to CO_2, source-sink relationships, pest-crop interactions, and site-specific characteristics, such as soil structure, which are reported to be associated with climate change (Patterson and Flint, 1990), were not included in the simulation. This could have resulted in more negative yield results in response to climate change (Mearns *et al*., 1992; Amthor, 2001; Van Ittersum *et al*., 2003). Howden and Jones (2001), however, argued that adherence to appropriate adaptation strategies could enhance production (up to 8% increase in mean production) in humid regions.

CONCLUSION

Significant increases in both temperature and solar radiation are predicted. No significant change in total precipitation amount is evident except for the month of August which is normally the peak of the rains in the growing season. The impact of crop residue retention into soil on grain yield is more pronounced under historical weather conditions than under climate change weather conditions. This is mainly due to the higher moisture stress associated with climate change over simulation period. The rate of soil organic carbon decomposition was slower under climate change weather than under historical weather conditions. The percentage change in grain yield will be higher under climate change weather conditions. Additionally, when no fertiliser is applied, percentage changes in grain yield will be higher than when fertiliser is applied under both weather conditions. Climate change poses a potential risk more to low input smallholder farmers who provide a significant proportion of crop produce, hence, a potential threat to food security in the study region.

REFERENCES

Akponikpe, P., Gérard, B., Michels, K. and Bielders, C. 2010. Use of the APSIM model in long term simulation to support decision making regarding nitrogen management for pearl millet in the Sahel. *European Journal of Agronomy* 32:144-154.

Amthor, J.S. 2001. Effects of atmospheric CO_2 concentration on wheat yield: Review of results from experiments using various approaches to control CO_2 concentration. *Field Crops Research* 73:1-34.

Anwar, M.R., O'Leary, G., McNeil, D., Hossain, H. and Nelson, R. 2007. Climate change impact on rain-fed wheat in south-eastern Australia. *Field Crops Research* 104:139-147.

Asseng, S., Foster, I. and Turner, N.C. 2011. The impact of temperature variability on wheat yields. *Global Change Biology* 17:997-1012.

Barrett, D.J. and Gifford, R.M. 1999. Increased C-gain by an endemic Australian pasture grass at elevated atmospheric CO2 concentration when supplied with non-labile inorganic phosphorous. *Australian Journal of Plant Physiology* 26:443-451.

Bell, L.W., Kirkegaard, J.A., Swan, A., Hunt, J.R., Huth, N.I. and Fettell, N.A. 2011. Impacts of soil damage by grazing livestock on crop productivity. *Soil and Tillage Research* 113:19-29.

Breman, H., Fofana, B. and Mando, A. 2008. The lesson of Drentes "Essen": Soil nutrient depletion in sub-saharan Africa and management strategies for soil replenishment. In: Braimoh, A.K. and Vlek, P.L.G. (Eds.). Land use and soil resources. Springer, The Netherlands.

Brouwer, J., Fussell, L.K. and Herrmann, L. 1993. Soil and crop growth micro variability in the West-African semiarid tropics - A possible risk-reducing factor for subsistence farmers. *Agriculture, Ecosystem and Environment*. 45:229-238.

Drake, B.G., Gonzales-Meler, M.A. and Long, S.P. 1997. More efficient plants: A consequence of rising atmospheric CO2? *Annual Review of Plant Physiology and Moecular Biology*. 48:609-939.

Fosu, M., Tetteh, F. and Bediako, J. 2010. A review of Soil health status in Ghana. Report to Alliance for Green Revolotion in Africa (AGRA). 52pp.

Gifford, R.M., Barrett, D.L. and Lutze , J.L. 2000. The efects of elevated CO2 on the C:N and C:P mass ratios of plant tissues. *Plant and Soil* 224:1-14.

Hoogenboom, G., Wilkens, P.W., Tsuji, G.Y. (Eds.). 1999. DSSAT V3, Vol. 4. University of Hawaii, Honolulu, HI, USA. pp. 234-235.

Howden, S.M. and Jones, R.N. 2001. Howden, SM & Jones, RN 2001, 'Costs and benefits of CO_2 increase and climate change on the Australian wheat industry', Report to the Australian Greenhouse Office. p. 25.

Jung, G. 2006. Regional Climate Changeand the Impact on Hydrologyin the VoltaBasin of West Africa. PhD. Dissertation, Institutf¨ur Meteorologie und Klimaforschung, University of Augsburg, Augsburg, Germany.

Kpongor, D.S. 2007. Spatially explicit Modeling of Sorghum (*Sorghum bicolor* (L.) Moench) production on complex terrain of a semi-arid region in Ghana using APSIM. PhD. Dissertation, University of Bonn, Bonn, Germany. Ecological and Development series No. 51.

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., Mclean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., 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. *European. Journal of Agronomy*18:267-288.

Laryea, K.B., Kumahor, S.K. and Adiku, S.G.K. 2010. Possible impacts of expected climate change on soil physical processes and the environment. Paper presented at Proceedings of Ghana Science Association Conference, Accra, Ghana.

Lithourgidis, A.S., Damalas, C.A. and Gagianas, A.A. 2006. Long-term yield patterns for continuous winter wheat cropping in northern Greece. *European Journal of Agronomy* 25:208-214.

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 Crops Research* 113(2):105-115.

McCown, R.L., Hammer, G.L., Hargreaves, J. N. G., Holzworth, D.P. and Freebairn, D.M. 1996. APSIM: A novel software system for model development, model testing and simulation in agricultural systems research. *Agricultural Systems* 50:255-271.

Mearns, L.O., Rosenzweig, C. and Goldberg, R. 1992. Effects of changes in inter-annual climatic variability on CERES wheat yields: sensitivity and 2 x CO_2 general circulation model studies. *Agriculture and Forest Meteorology* 62:159-189.

Murty, D.S., Nwasike, C.C. and Atokple, I.D.K. 1998. Registration of 'ICSV III' Sorghum Cultivar. *Crop Science* 38: 1716-1717.

Patterson, D.T. and Flint, E.P. 1990. Implications of increasing carbon dioxide and climate change for plant communities and competition in natural and managed ecosystems. pp. 83 - 111. In: Kimball, B.A., Rosenberg, N.J., Allen, Jr., L.H. (Eds.). Impact of Carbon Dioxide, Trace Gases, and Climate Change on Global Agriculture. ASA Special Publication 53, Madison, Wisonsin.

Semenov, M.A. and Brooks, R.J. 1999. Spatial interpolation of the LARS-WG stochastic weather generator in Great Britain. *Climate Research* 11: 137-148.

Tachie-Obeng, E., Gyasi, E., Adiku, S., Abekoe, M. and Ziervogel, G. 2010. Farmers' adaptation measures in scenarios of climate change for maize production in semi-arid zones of Ghana

2nd International Conference: Climate, Sustainability and Development in Semi-arid Regions. August 16-20, 2010, Fortaleza-Ceara, Brazil.

Thorburn, P.J., Jakku, E., Webster, A.J. and Everingham, Y.L. 2011. Agricultural decision support systems facilitating co-learning: A case study on environmental impacts of sugarcane production. *International Journal of Agricultural Sustainability* 9:322-333.

Van Ittersum, M.K., Howden, S.M. and Asseng, S. 2003. Sensitivity of productions and deep drainage of wheat cropping systems in a Mediterranean environment to changes in CO2, temperature and precipitation. *Agriculture, Ecosystem and Environment* 97(1-3):255-273.

Willmott, C.J., Ackleson, G.S., Davis, R.E., Feddema, J.J., Klink, K.M., Legates, D.R., O'donnell, J. and Rowe, C.M. 1985. Statistics for the evaluation and comparison of models. *Journal of Geophysical Research* 90:8995–9005.