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Comparative Assessment of Crop Cultivar and Sowing Dates as Adaptation Choice for Crop Production in Response to Climate Change in Cameroon

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ABSTRACT

The Cameroon's agricultural sector is potentially vulnerable to climate change and adaptation policies may be able to mitigate some of this vulnerability. This paper investigates some adaptation options within the context of Cameroon's food production. A methodology is applied where two atmosphere-ocean general circulation models (GISS and HadCM3), are coupled to a cropping system simulation model to simulate current and future (2020, 2080) crop yields for selected key crops (bambara, groundnut, maize, sorghum, and soybean) in eight agricultural regions of Cameroon. For the future, substantial yield increases are estimated for bambara, soybean and groundnut, while little or no change or even decreases for maize and sorghum yields, varying according to the climate scenario and the agricultural region investigated. We explored the advantages of specific adaptation strategies specifically for three crops viz. maize, sorghum and bambara groundnut, using GISS scenarios only. Changing sowing dates may be ineffective in counteracting adverse climatic effects because of the narrow rainfall window that strictly determines the timing of farm operations. In contrast, later maturing new cultivars could be extremely effective in offsetting adverse impacts, giving the highest increases in productivity under different scenario projections without management changes. Under one climate change scenario a 14.6% reduction in maize yield was converted to a 32.1% increase; a 39.9% decrease in sorghum yield was converted to a 17.6% increase. For bambara groundnut, yields were almost trebled (37.1% increase above that for sowing date alone (12.9%)) due to increase length of growing period and the positive effects of higher CO_2 concentrations. The results provide useful guidance and motivation to public authorities and development agencies interested in food security issues in Cameroon and elsewhere.

Keywords: agriculture, food security, policies

INTRODUCTION

Climate change is one of the primary concerns for humanity in the 21st century. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report concludes that there is strong evidence that human activities have influenced the world's climate over the last century and a half (IPCC 2007). Climate change effects are already being experienced (Walther *et al*. 2002) and it is predicted that some extreme events will increase in frequency as a result of a change in natural climate variability (McCarthy *et al*. 2001).

Agriculture is inherently sensitive to climate conditions, and is one of the sectors most vulnerable to the risks and impacts of global climate change (Reilly 1995; Smith and Skinner 2002). A large amount of literature shows that without adaptation, climate change will be problematic in some regions such as Cameroon (Tingem *et al.* 2008a) for agricultural production and communities. However, other studies suggest that detrimental climate impacts can be reduced and numerous opportunities can be created by changing climatic conditions (Alexandrov and Hoogenboom 2000; Salinger *et al.* 2000; Bellocchi *et al.* 2002; Carbone *et al.* 2003; Gbetibouo and Hassan 2004; Adger *et al.* 2005; Smith and Wandel 2006; Challinor *et al.* 2007a). Climate extreme events will probably be the most challenging for farmers and society in general under future climate change (Rosenzweig *et al.* 2001).

Farmers in Cameroon have traditionally used indigenous knowledge to cope with climate hazards based upon observations and interpretation of natural phenomena. For example, the height of an ant nest in trees, or colour of frogs to make forecasts of the onset and cessation of the rainy season and quantity of rain (Molua 2006; Tingem *et al.* 2008c). Crop choices, crop mixes and seasonal cropping calendars are largely based on these forecasts. Farmers' overriding concerns are meeting household needs, in particular achieving household food security. Harvesting natural products for food and income is considered a major and primary adaptation to climate hazards at the community level. However, population growth coupled with climate change pose serious challenges on future food security in Cameroon and elsewhere. These challenges point to the need to realign and adopt new policies that contribute to greater resilience of the agricultural sector.

Research in developing countries indicate that, in principle, climate change impacts on agriculture can be reduced through human adaptations such as; adjusting sowing dates, changing cropping patterns (Mendelsohn *et al.* 1994; Rosenzweig and Hillel 1998; Winters *et al.* 1998), or adopting higher-yielding and heat resistant cultivars, and improved extension services (Butt *et al*. 2005; Njie *et al.* 2006). To be effective, many of these adaptations, including spending on agricultural research and outreach programmes, and the selection and breeding of new hybrids and cultivars, would require an active role by government. It is important to recognise that changes in increasing atmospheric CO_2 concentration and global warming are likely to alter the phenological response of certain crops, thereby putting cur-

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rent crop-weather relationships in doubt (Challinor *et al.* 2007b; Tingem *et al.* 2008b).

Although the breeding of new cultivars with improved yields under future climate is a potentially crucial adaptation option, the basis on which any new cultivars are developed will depend on the nature and extent of climate change in any specific region or cropping system. Crop simulation models that include the dynamics of crop-soil-weather interactions and integrate crop resource capture principles can assist plant breeding in the evaluation of the impact of specific traits on yield across a range of climates, soil types and seasons (Asseng *et al.* 2003).

This study uses both current and future climate scenarios, the latter from general circulation model (GCM) simulations, as inputs to a cropping system simulation model (CropSyst, Stöckle *et al.* 2003). The analysis performed in this paper addresses certain aspects of Article 4.1 of the United Nations Framework Convention on climate Change (UNFCCC) which commits countries to formulate and implement measures to facilitate adequate adaptation to climate change.

The objective of this paper is to evaluate a set of adaptation options such as changes in sowing date and to investigate the importance of crop selection (maize (*Zea mays* L.), sorghum (*Sorghum bicolor* [L.] Moench) and bambara groundnut (*Vigna subterranea* [L.] Verdc) in the context of Cameroon's agricultural systems.

CAMEROON: BACKGROUND AND VULNERABILITY TO CLIMATE CHANGE

Cameroon is ranked 172 out of 229 countries in the world in terms of *per capita* income and nearly 40% of the population (6.8 million people) live on less that US$2 per day (World Bank 2007). The majority of the country's poor live in rural areas and work primarily in agriculture which is the largest sector of the economy contributing about 45% to the annual GDP (Molua and Lambi 2006). Cameroon covers an area of about 475,440 km^2 between 2° and 13° N with a population of ~17 million in 2006. The area is characterized by highly contrasting physical features including 402 km of coastline and mountain ranges punctuated by peaks over 3,000 m.

The average temperature in Cameroon is predicted to increase, i.e. the Hadley Centre's HadCM3 model (Gordon *et al.* 2000; Johns *et al.* 2003), annual temperatures in Cameroon are expected to rise by 0.7 to 0.8°C by the 2020s. The Goddard Institute for Space Studies (GISS) model (Hansen *et al.* 1998) projects double that increase in the same time period. Annual temperatures in the 2080s are projected to increase relative to the baseline scenario (1961–1990) by 2.5 to 3.5°C, and 3.1 to 4.4°C, according to the HadCM3 and GISS models respectively. Precipitation is expected to increase or decrease depending on the GCM used. For the GISS and HadCM3 GCM expected average % changes in precipitation ranged between -3.7% to 1.1% and 0.8% to 5.2%, respectively. However, the GISS model projected a distinct decreasing trend of precipitation in the 2020s and 2080s for most of the study sites (Tingem *et al.* 2008b).

Agricultural production in Cameroon is characterised by low levels of input (e.g. quality seeds, fertilizers, pesticides and herbicides) due to farmers low purchasing power and equally low levels of government subsidies (Molua and Utomakili 1998). Therefore, when considering projected climate change, one may reasonably ask whether Cameroonian farmers can continue farming in the same way that they have done for generations.

MATERIALS AND METHODS

Crop and climate models

The crop model used in this study was CropSyst (Stöckle *et al.* 2003), a multi-year, multi-crop, daily time step cropping system simulation model. The model has been applied and used extensively to simulate crop growth and yield for a range of crops such as wheat, maize, soybean, sorghum, groundnut, and forage crops in diverse environments. It has been used in detailed studies for tropical crops and has been shown to be robust and accurate for a diverse range of local environments, including those found within Cameroon (Tingem *et al.* 2008a). It is a balanced crop simulator, simulating different crops from a common set of parameters.

The model simulates the soil water budget, the soil-plant nitrogen budget, crop canopy and root growth, crop phenology, dry matter production, yield, residue production and decomposition, and erosion. The main inputs are daily weather data and the model allows the user to specify management options such as sowing date, cultivar coefficients (photoperiod sensitivity, duration of grain filling, maximum leaf area index [LAI], etc.), soil profile properties (soil texture, thickness, initial water and nitrogen content), fertilizer and irrigation management, tillage, etc. Crop growth is simulated for the whole canopy by calculating unstressed (potential) biomass based on crop potential transpiration and on crop intercepted photosynthetically active radiation. This potential growth is then corrected by water and nitrogen limitations, to determine actual daily biomass gain. The simulated grain yield is then obtained as the product between actual aboveground biomass accumulated at physiological maturity and crop-specific harvest index (harvestable yield/aboveground biomass).

The simulation of crop development is based on the thermal time required to reach specific development stages. Thermal time is calculated as growing degree days (GDD, °C-days) accumulated throughout the growing season (starting from planting until physiological maturity). Average air temperature above a base and below a cut-off temperature is considered for GDD calculations. The accumulation of thermal time may be accelerated by heat/water stress.

Water balance processes in CropSyst, includes rainfall, runoff, and interception, infiltration, redistribution in the soil profile, crop transpiration and soil evaporation. In this study, reference evapotranspiration was estimated by the Priestley and Taylor (1972) method. A finite difference solution soil water balance function, by which water moves up and down depending on the soil water potential of vertically adjacent layers, was used for the redistribution of water in the soil under non-limiting soil fertility (Richards 1931).

CropSyst has data requirements that can be reasonably met and provides support utilities to fill in missing inputs based on well established procedures (e.g. using pedo-transfer functions to derive soil hydraulic parameters). For this reason, it provides a conceptually unified modelling system for many crops, minimizing the dangers of structural uncertainty in making both cross crop and inter-spatial comparisons (Rivington *et al.* 2006). As such it is able to represent well the variation in yield determined by weather driven environmental conditions and respond to specific management regimen. However, as with all models the utility of estimates is largely determined by the quality of the model itself (structure, representation of process etc), and the data used to calibrate and validate it (details of the parameterization of CropSyst for Cameroon agricultural regions is presented in Tingem *et al.* 2008a, 2008b). Hence estimates described here are indicative rather than absolute projections, and have to be interpreted on the basis of the level of representational detail possible given the limitations of the calibration and validation data.

Daily observed values of maximum and minimum temperatures, and rainfall were obtained for 1979-2003 from the University Cooperation for Atmospheric Research (UCAR) (http://dss.ucar.edu/datasets/) for each of the eight sites used in the study. For each region, the data from one of the major weather stations was chosen as representative of the climate of that region. For the purpose of evaluating long term effects of climate change and variability on crop yields, the temporal range of the weather data for use in the crop model was expanded up to 50 years so as to allow a good estimation of the probability of extreme events using the ClimGen weather generator. Further information on ClimGen performance at Cameroon sites is documented in Tingem *et al.* (2007).

Representative soil properties (thickness and texture) for each of the simulation points were extracted from the International Soil Reference and Information Center data base (http://www.isric.nl)

Table 1 Relative change (%) in yields (kgha^{-1}) of five crops without adaptation between baseline and future climate projected under eight GCM scenarios (adapted and modified from Tingem *et al.* 2008b).

Location	Baseline	GISS				HadCM3			
		A2 2020	A2 2080	B2 2020	B2 2080	A2 2020	A2 2080	B2 2020	B2 2080
Bambara (*Vigna subterranean* L. verdc)									
Bamenda	1160	31.2	1.2	32.9	17.3	42.5	13.2	43.3	23.5
Garoua	1402	24.3	4.9	25.2	11.9	31	10.2	30.1	16.8
Maroua	1310	37.2	25.9	37.8	29.5	41.3	28.2	40.4	32.1
Ngaoundere	1571	52.5	46.8	53.4	49.1	58.3	48.7	57.1	50.5
Tiko	1184	9.3	-5.1	2	6.4	20.5	12.5	28.2	11.2
Yaounde	1193	21.5	3.9	24.6	12.8	31.6	9.6	31.6	16.8
Mean	1303	29.3	12.9	29.3	21.2	37.5	20.4	38.5	25.2
Groundnut (*Arachis hypogaea* L.)									
Bamenda	1017	-13.5	-41.6	-11.9	-30.1	1.9	-33.4	1.9	-22.7
Batouri	996	38.4	21.9	30.4	30	51.3	47.1	57.8	50.6
Garoua	995	15.7	-7.4	16.9	0.6	19.8	-1.2	23.2	6.6
Kribi	557	109	113	109	108.7	110	108.7	109.2	108.9
Maroua	1172	45.3	34.5	46	38.2	48.9	36.6	48	40.7
Ngaoundere	1197	50.3	37.2	51	41.7	57.2	40.1	57.1	44.5
Tiko	948	19	-1.8	25.6	12.1	35.2	16.8	32.3	21.5
Yaounde	1106	8.1	-12.4	11.1	-2.8	18.6	-6.3	18.6	1.8
Mean	998	34	17.9	34.8	24.8	42.9	26.1	43.5	31.5
Maize (*Zea mays* L.)									
Bamenda	1294	-24.7	-69.6	-22.9	-51.2	-6.7	-56.2	-5.9	-20.6
Batouri	1488	0.9	-33	0.2	-17.8	13.6	-22.5	14.2	-8.2
Garoua	1945	3.1	-16.1	4.1	-11	9.1	-12.1	11.2	-6.4
Kribi	1835	18.9	9.6	19.4	13.1	25.4	12.3	25.9	15.3
Maroua	2171	5.3	-10.5	6.9	-6.6	13.3	-8.1	10.6	-2.91
Ngaoundere	2318	24.6	6.2	25	17.3	27.1	13.8	26.9	22
Tiko	2447	12.6	-0.6	12.5	3.5	18.3	3.4	18.4	7.6
Yaounde	2158	18.4	-2.7	20	7.8	24.1	3.5	24.1	12.3
Mean	1957	7.4	-14.6	8.2	-5.6	15.5	-8.2	15.7	2.4
Sorghum (*Sorghum bicolour* L.)									
Garoua	1311	-8.2	-35.7	-6.1	-28.5	1.3	-32	4.4	-21.9
Maroua	1484	3.2	-20.1	6.3	-14.2	17.1	-16.2	14.6	-9.3
Ngaoundere	1280	-16.6	-63.8	-12.3	-47.8	3.8	-53.5	3.4	-40.7
Mean	1358	-7.2	-39.9	-4	-30.2	7.4	-33.9	7.5	-24
Soybean (*Glycine max* L.)									
Bamenda	572	57.6	27.9	58.5	38.8	68.7	34.2	78.9	45.5
Ngaoundere	1169	27.9	5.5	29.6	12.6	39.5	10.9	39.5	18.8
Tiko	110	126.9	130.4	127.7	134	153.6	148.2	145.5	162.4
Mean	617	70.8	54.6	71.9	61.8	87.3	64.4	88	75.6

(Batjes 1995). Agronomic data (e.g. yield, phenological observations) were obtained from the Central Bureau of Statistics published district reports (AGRISTAT 2001) and the Institute of Agricultural Research-Cameroon (through http://www.wisard.org).

The GISS model and HadCM3 model were used to simulate future climate scenarios. For the present-day (baseline) case, the weather generator ClimGen was parameterized to create a 50-year baseline climate scenario from observed data at each site of study. For the future climate simulations, coupled GCMs (GISS and HadCM3) were used to simulate changes in climate and these changes were added to the baseline values to obtain the future climatic scenarios on a daily basis. The A2 scenario is one of the most extreme scenarios, with carbon emissions rising monotonically from about 10Gt at present-day to over 25 Gt in 2100 (IPCC 2001). The A2 scenario indicates the maximum potential impacts of future climate on specific dynamics, in this case crop production in the studied area. The B2 scenario is a more optimistic (medium-low) counterpart (Houghton *et al.* 1996).

Simulations were run with sowing dates set to 15th March, corresponding to the 74th day of the year (DOY), in Bamenda, Batouri, Kribi Tiko, and Yaounde. In Garoua, Maroua and Ngaoundere, the sowing date was set to 15th May (day of year 135). The sowing date corresponds with traditional crop management in the study zones (Ndemah 1999; Molua 2003). A 1-m soil depth was considered to simulate the soil-water balance, because it corresponds to the observed maximum crop root length (Farre 1998). Forty per cent of crop residue was assumed to remain in the field after harvest for recycling purposes (Abraha and Savage 2006). No irrigation was used as this is not a common practice in Cameroon.

The effects of a CO_2-induced climate change on crop production, expressed as the relative changes in yields between baseline and future 2020s/2080s climate are presented as percentage changes in average yields from the baseline. The yields and phenological maturity dates, simulated under the alternative climate scenarios were compared using exceedence probability (*Pe*, %) distributions, following Weibull (1961):

$$Pe = \frac{m}{n+1}100$$

where m is the rank order of each yield estimate, with $m = 1$ as the largest and $m = n$ for the lowest, with n being the number of observations. The coefficients of variation (CV) values of yield, defined as the ratio of standard deviation to the mean, were computed over the entire time-series available at each site. The % CV represents a measure of the farmer's risk, low CVs indicate stable year-to-year production, while high CVs denote high inter-annual variability (Rosenzweig and Tubiello 2007).

Nearly all future climate scenarios show a general tendency towards diminishing future maize yields in all agricultural regions; ranging between +27.1 to -69.6% (**Table 1**). Taking the mean over all regions, yield varied between -14.6 and 8.1% for GISS and between -8.2 and 15.7% for the HadCM3 model.

The sorghum results appear to indicate that with the exception of the HadCM3 A2 and B2 2020s, CO_2-induced climate change will result in either a substantial decrease or no change on sorghum crop yield, variable with location and scenario.

Projections indicate substantial increases in the yield of groundnut by 21.5 to 109% from the baseline across all the scenarios in Batouri, Kribi, Maroua, Ngaoundere and Tiko. Simulated production in Bamenda decreased across all the scenarios by 11.9

to 41.6% except for HadCM3 A2 and B2 2020 where yields increase by 1.9%. Scenario A2 2080s for both GCMs produced a drop in yields at Garoua and Yaounde by 1.2 to 12.4%.

Bambara groundnut showed gains across all scenarios except for Tiko where a decrease by 5.1% was registered under GISS A2 2080s. Yield across all locations oscillated between 12.9 and 38.5%.

A substantial increase in soybean yields was generally estimated for the future. GISS and HadCM3 projected yield increases in the range 27.9 to 153.6% in 2020s and 5.5 to 162.4% in 2080s.

These changes were driven by the predicted temperature increase of the scenarios. HadCM3 scenarios were more benign than the GISS scenarios, due to a smaller increase in air temperature. Higher temperatures translate into faster crop development and earlier maturation which results in lower crop yields because the plant intercepts less cumulative solar radiation before it reaches maturity and harvest (Rawson 1992; Young *et al.* 2000; Brassard and Singh 2007). The future climate scenarios used had maximum daily temperatures >30°C on several days during the growing season especially with the GISS scenarios (Tingem *et al.* 2008b). The duration of the regular crop growing season for maize and sorghum (C4 crops) in the near future was simulated to be approximately between 2 to 29 days shorter than that under current climatic conditions resulting in a decrease in simulated grain yield for both. For groundnut, soybean and bambara groundnut (all C3 crops) the growing season was shortened by between 2 and 23 days. GISS and HadCM3 climate change scenarios projected increased yields for all the C3 crops above baseline levels across the whole country. In almost all cases, the negative effects of increased temperatures on crop duration were more than compensated by the positive effects of higher CO_2 concentrations. These findings were obtained without considering a number of possible adaptations.

Modelling framework - adaptation assessment

The GISS model projections indicate a drier future, compared to the HadCM3 model which also suggests less warming. Taking the "no regrets" principle (Hoffmann 2007) into consideration, we explore the advantages of specific adaptation strategies specifically for three crops viz. maize, sorghum and bambara groundnut, under GISS A2 and B2 marker scenarios only.

Taking the "no regrets" principle (Hoffmann 2007) into consideration, we explore the advantages of specific adaptation strategies specifically for three crops viz. maize, sorghum and bambara groundnut, under GISS A2 and B2 marker scenarios only.

Sowing dates of selected crops were shifted by either bringing forward or delaying sowing within the interval (D_{o-30}, D_{o-60}, D_{o+30}, D_{o+60}, days) with respect to the baseline case, D_o being the normal sowing date.

Using CropSyst, growth performance of hypothetical cultivars under conditions of climate change was tested by adjusting the genetic coefficients of the currently used and calibrated cultivars in such a way that they would prolong the vegetative period under climate change conditions. Within CropSyst, the principal genetic parameter in question is the number of growing degree-days (GDDs). A plant has a biological life that is determined by its GDDs or Heat Units (HUs) that it accumulates during the growing season until it reaches full maturity. GDDs are a function of daily maximum and minimum air temperatures and the crop base temperature as shown in the following equation:

$$GDD = \sum_{i=1}^{n} (T_i - T_b) \qquad T_i = \left| \begin{array}{ll} T_b & if \quad T_i < T_b \\ T_c & if \quad T_i > T_c \\ \dfrac{T_{\max} + T_{\min}}{2} & otherwise \end{array} \right.$$

where i is the i^{th} day from sowing, T_{max} and T_{min} (ºC) are, respectively, the daily maximum and minimum air temperatures, and T_b and T_c (ºC) are, respectively, crop-specific baseline and cut-off temperature for development (Ellis *et al.* 1990; McMaster and Wilhelm 1997). To analyse the impact of GDD, the total temperature sum to maturity was increased arbitrarily between 15 and 20% and its effects on the length of the growing season and crop yield were recorded. The duration of vegetative relative to grain-filling periods in the original cultivar was maintained. Thus, the life cycle in terms of vegetative-reproductive growth of the adapted crop under the warmer temperatures in both climate scenarios was comparable in length to that of the cultivars used for the baseline simulations. The use of nitrogen fertilization and irrigation are not considered in the study as these are non-limiting under all climate scenarios in studied sites.

RESULTS

In general, crop yields were increased by the range of adaptation techniques implemented in CropSyst.

Table 2a Percent change in the average of maize yields from baseline without and with adaptation (change in sowing dates) at Garoua (GAR), Maroua (MAR), Tiko (TIK) and Yaounde (YAO).

Location	**GISS without change in sowing dates**				**GISS with change in sowing dates**			
	A2 2020	**A2 2080**	**B2 2020**	**B2 2080**	**A2 2020**	**A2 2080**	**B2 2020**	**B2 2080**
	%Δ	**%Δ**	**%Δ**	**%Δ**	**%Δ**	**%Δ**	**%Δ**	**%Δ**
GAR	3.1	-16.1	4.1	-11.0	24.5	-3.8	26.6	5.7
MAR	5.3	-10.5	6.9	-6.6	27.8	1.2	29.4	-6.6
TIK	12.6	-0.6	12.5	3.5	26.4	16.3	28.8	20.1
YAO	18.4	-2.7	20.0	7.8	39.7	20.1	42.5	28.7

Table 2b Percent change in the average of sorghum yields from baseline without and with adaptation (change in sowing dates) at Garoua (GAR) and Maroua (MAR).

Location	**GISS without change in sowing dates**				**GISS with change in sowing dates**			
	A2 2020	**A2 2080**	**B2 2020**	**B2 2080**	**A2 2020**	**A2 2080**	**B2 2020**	**B2 2080**
	%Δ	**%Δ**	**%Δ**	**%Δ**	**%Δ**	**%Δ**	**%Δ**	**%Δ**
GAR	-8.2	-35.7	-6.1	-28.5	39.9	-17.3	40.8	2.5
MAR	3.2	-20.1	6.3	-14.2	48.0	-7.5	51.5	-14.2

Table 2c Percent change in the average of bambara yields from baseline without and with adaptation (change in sowing dates) at Garoua (GAR), Maroua (MAR), Tiko (TIK) and Yaounde (YAO).

Location	**GISS without change in sowing dates**				**GISS with change in sowing dates**			
	A2 2020	**A2 2080**	**B2 2020**	**B2 2080**	**A2 2020**	**A2 2080**	**B2 2020**	**B2 2080**
	%Δ	**%Δ**	**%Δ**	**%Δ**	**%Δ**	**%Δ**	**%Δ**	**%Δ**
GAR	24.3	4.9	25.2	11.9	46.6	24.1	47.8	34.4
MAR	37.2	25.9	37.8	29.5	48.1	39.3	48.3	29.5
TIK	9.3	-5.1	2	6.4	43.5	28.9	46.3	37.2
YAO	21.5	3.9	24.6	12.8	37.9	19.7	41.7	28.9

Sowing dates

Advancing or delaying sowing dates led to increased yields (**Tables 2a-c**) at Garoua, Maroua, Tiko and Yaounde. In Garoua and Maroua delaying sowing date resulted in better yields occurring on the 196th day of the year (DOY 196), corresponding to 15th July. For Yaounde and Tiko sowing date was advanced to 15th February (DOY 46).

Maize yields (**Table 2a**), under both GISS A2 and B2 scenarios increased up to 39.7%, except for Maroua where yield was unchanged under B2 2080 and in Garoua under scenario GISS A2 2080. In the latter, yields are 3.8% lower from the base case.

Adverse climate change impacts on sorghum yields (**Table 2b**) are attenuated or even reversed at Garoua and Maroua when planting date was shifted from DOY D1 (May 15) to DOY D2 (July 15). While these adjustments increased yields by up to 48.0%, however, average yield was still 17.3% and 7.5% lower from the base case at Garoua and Maroua under GISS A2 2080. Under GISS B2 2080 at Garoua, yields were still 14.2% lower from the baseline.

Bambara groundnut (**Table 2c**), which was least affected by increasing temperatures, also responded positively to delayed dates, showing 19.7% to 48.3% increase in crop yields from the base case.

Change in crop cultivar

Adjusting GDDs of bambara groundnut, maize and sorghum for hypothetical cultivars point to unequivocal gains in crop yields under different climate change scenarios across the entire country (**Table 3**).

Maize

Average maize yields across the country increase, ranging from 32.1% to 62.3% (**Table 3**) with decreasing CVs ranging between 3.9 and 17.5% (**Table 4**). In Bamenda, yields

Table 3 Yield changes for maize, sorghum and bambara groundnut without and with new cultivar (% change from base).

	Baseline yield (kgha^{-1})	GISS without adaptation				GISS with adaptation			
		A2 2020	**A2 2080**	**B2 2020**	**B2 2080**	**A2 2020**	**A2 2080**	**B2 2020**	**B2 2080**
Maize									
Bamenda	1294	-24.7	-69.6	-22.9	-51.2	93.2	22.3	95.9	59.6
Batouri	1488	0.9	-33	0.2	-17.8	62.9	23.4	61.8	42.3
Garoua	1945	3.1	-16.1	4.1	-11	49.8	22.5	52.9	30.5
Kribi	1835	18.9	9.6	19.4	13.1	61.4	49.8	62.4	53.9
Maroua	2171	5.3	-10.5	6.9	-6.6	51	28.6	52.2	34.7
Ngaoundere	2318	24.6	6.2	25	17.3	63.8	43.8	64.4	54.9
Tiko	2447	12.6	-0.6	12.5	3.5	49.8	34.5	50.7	40.1
Yaounde	2158	18.4	-2.7	20	7.8	55.9	31.7	57.8	44.3
Mean	1957	7.4	-14.6	8.2	-5.6	61	32.1	62.3	45
Sorghum									
Garoua	1311	-8.2	-35.7	-6.1	-28.5	67.4	17.2	70.1	28.8
Maroua	1484	3.2	-20.1	6.3	-14.2	38.3	5.7	42.8	14.9
Ngaoundere	1280	-16.6	-63.8	-12.3	-47.8	149	30	155.7	79.9
Mean	1358	-7.2	-39.9	-4	-30.2	84.9	17.6	89.5	41.2
Bambara									
Bamenda	1160	31.2	1.2	32.9	17.3	100.9	73.5	101.4	87.4
Garoua	1402	24.3	4.9	25.2	11.9	40.9	19.3	41.9	27.2
Maroua	1310	37.2	25.9	37.8	29.5	54.7	42.6	55.3	46.5
Ngaoundere	1571	52.5	46.8	53.4	49.1	65.2	58.7	66.1	60.9
Tiko	1184	9.3	-5.1	2	6.4	26.3	11.5	29.3	20.3
Yaounde	1193	21.5	3.9	24.6	12.8	35.7	17.2	38.7	27
Mean	1303	29.3	12.9	29.3	21.2	53.9	37.1	55.4	44.9

Table 4 CV of maize, sorghum and bambara groundnut yields without and with new cultivar (% change from base).

	GISS without adaptation				GISS with adaptation			
	A2 2020	**A2 2080**	**B2 2020**	**B2 2080**	**A2 2020**	**A2 2080**	**B2 2020**	**B2 2080**
Maize								
Bamenda	19.7	21.1	19.8	22.9	10.9	13.4	10.6	12.7
Batouri	10.4	18.8	16.8	12.3	16.8	15.5	17.5	14.2
Garoua	7.9	9.5	7.8	9.2	8.8	8.5	7.8	8.9
Kribi	7.9	8.6	8.2	7.5	6.8	7.5	6.8	6.6
Maroua	8.5	6.4	8.9	7.3	7.7	7.1	7.8	7.7
Ngaoundere	4.3	3.5	5.0	4.3	4.4	3.9	4.3	4.1
Tiko	5.2	5.6	4.9	5.1	5.1	5.0	4.9	4.5
Yaounde	6.2	7.0	6.2	7.5	5.9	6.7	6.1	7.0
Mean	8.8	10.1	9.7	9.5	8.3	8.4	8.2	8.2
Sorghum								
Garoua	16.4	12.7	16.9	13.9	14.3	12.2	14.3	13.2
Maroua	17.8	14.6	16.2	16.9	17.3	13.6	15.4	16.6
Ngaoundere	18.7	19.5	17.9	20.4	11.5	19.4	11.1	17.4
Mean	17.6	15.6	17.0	17.1	14.4	15.1	13.6	15.7
Bambara								
Bamenda	7.3	21.9	6.9	7.4	4.9	12.4	4.8	5.2
Garoua	4.3	4	4.3	4	3.8	3.9	3.8	3.7
Maroua	7.5	7.6	7.5	7.5	7.1	7.3	7.1	7.2
Ngaoundere	7	7.6	6.8	7.3	6.0	7.7	6.4	7.3
Tiko	29.1	26.5	39.8	25.3	30.5	26.5	30.7	26.4
Yaounde	8.3	8.5	8.2	8.5	7.8	8.3	8.6	8.3
Mean	10.6	12.7	12.3	10.0	10.0	11.0	10.2	9.7

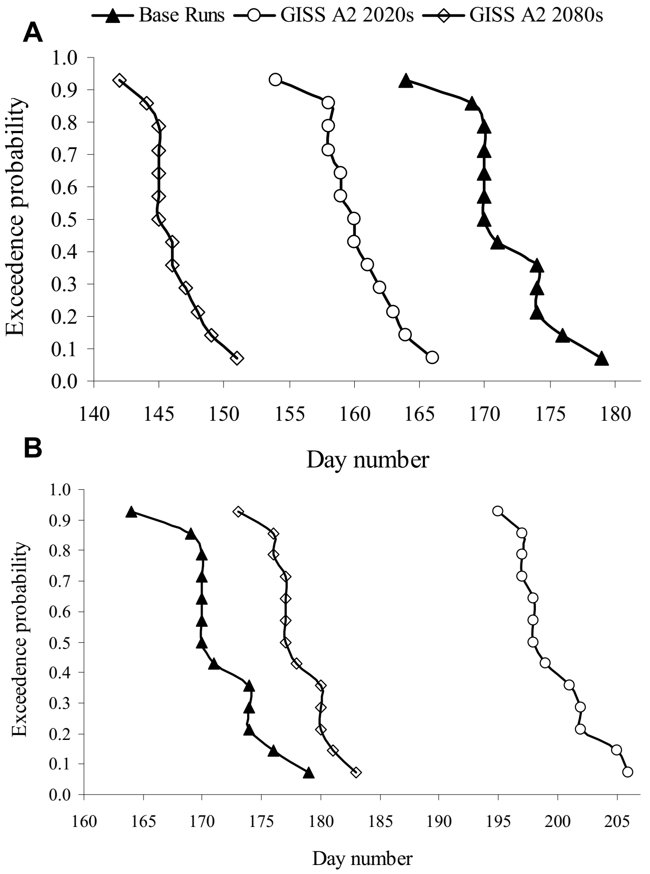

Fig. 1 Effects of adaptation (new cultivar) effects on number of days to maturity in maize at Bamenda. (**A**) base runs together with GISS A2 scenarios without adaptation (**B**) GISS A2 scenarios with adaptation.

increased by 22.3% to 95.9% in the early and latter part of the 21st century. Simulated duration for the crop growing cycle was between 5 and 29 days longer compared to the growing season under base conditions (e.g. **Figs. 1** and **2**).

Sorghum

In the 2020s, average yield increased with adaptation by 38.3% to 155.7% and by 5.7% to 79.9% in the 2080s under GISS projected climates (**Table 3**). Interannual variability in both time periods also presents a remarkable stability in yields dropping in the range 19.4 to 11.1% (**Table 4**). Ngaoundere registered highest gains across all scenarios, i.e., 30.0% to 155.7% higher than baseline yields. Average relative yield increases across locations range from 17.6 to 89.5%. With sorghum, the number of days from emergence to maturity increased across locations by 7 to 18 days.

Bambara groundnut

Substantial gains in yields were registered under this adaptation process. Increases in yield ranged from 11 to slightly more than 100 percent, and corresponding CVs dropped in the range 30.7 to 3.7% (**Tables 3, 4**). Bamenda registered the highest increase in yields (100.9%) under GISS A2 2020. Average yields in all growing sites increased by 37.1 to 55.4% while growing season increased by 5 to 13 days.

DISCUSSION AND POLICY IMPLICATIONS

Exploiting beneficial options to avoid or reduce negative effects of climate change is an imperative step in climate-sensitive activities. The simulations presented above indicate that adjustments in sowing dates and use of late-maturing cultivars could produce substantial gains in crop yield under future climate change in Cameroon.

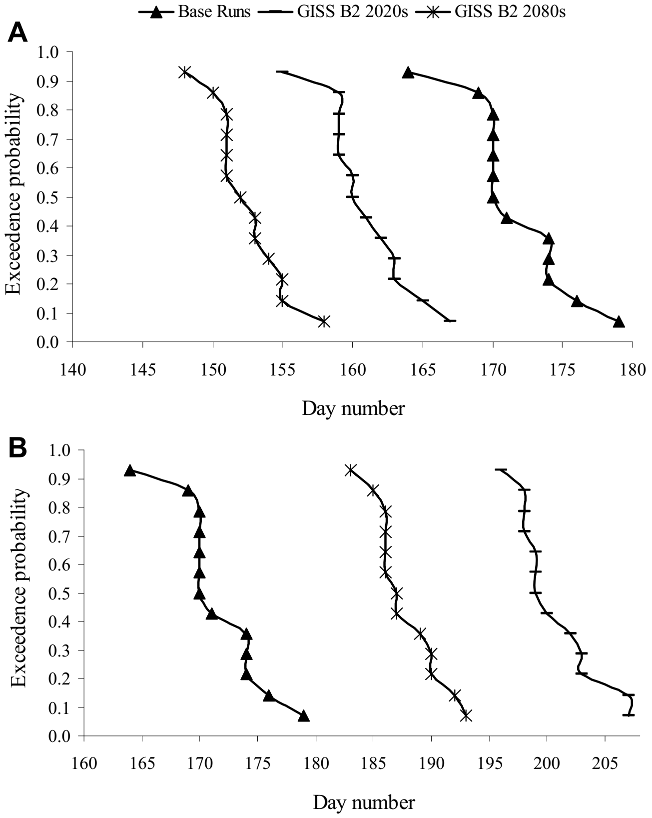

Fig. 2 Effects of adaptation (new cultivar) effects on number of days to maturity in maize at Bamenda. (**A**) base runs together with GISS B2 scenarios without adaptation (**B**) GISS B2 scenarios with adaptation.

Table 5 Length (days) of planting to flowering (P-F) and flowering to maturity (F-M) periods for maize at current planting date and 30 days earlier under SRES A2 scenario for year 2020 at Yaounde.

	Current		Thirty days before
	BASE	**GISS A2 2020**	**GISS A2 2020**
P-F	62	57	76
F-M	16	14	16

Advancing sowing dates by 30 days at Tiko and Yaounde, and delaying the same practice by 60 days at Garoua and Maroua for crops investigated would probably be the most appropriate response to offset the negative effects of a potential increase in temperature. Simply shifting sowing dates allows grown crops to develop under more favourable thermal conditions, increasing the duration of the vegetative phase, which in turn, would benefit the obtained grain number and hence the crop grain yield (**Table 5**). However, this adaptive strategy only works well at some of the locations. This is because at some locations under the climate change scenarios low rainfall coupled with increased temperature span across the whole year- thus no room for favourable growth with changed sowing dates. This is in line with Rosenzweig (1989) who found that altering sowing dates for dry land maize in the Southern plains of USA offset yield reduction caused by climate change at only one of the 12 locations while the other 11 locations continued to show yield reductions. Simulation results suggest that gains made from shifting sowing dates are irrelevant to offset negative changes when high temperatures affect early and later growth phases of the crops.

From simulation results, one of the most influential factors determining yield under the changed climatic conditions is an increase in temperature. High temperatures speed up phenological development of crops and leave less time for the grain/seed formation. The optimum adaptive response to increasing temperatures (i.e., global warming) in

Cameroon where adjusting planting dates does not shield crops from the effects of higher temperature, would be to develop and replace currently used cultivars with those with a higher thermal requirements for completion of phenological stages. Mimicking the outcome of selective breeding and genetic engineering programmes, we made changes in CropSyst genotypic parameters driving the phenological development of maize, sorghum and bambara groundnut. Simulations based on these changes led to significant increases in crop yields. This is in agreement with simulation results reported by Kaiser *et al.* (1993), Reilly and Schimmelpfenning (1999), and Butt *et al.* (2005).

Whereas simulation results for C3 crops showed substantial gains under climate change without any adaptation (2020s, 2080s), using a new cultivar, yields of bambara groundnut (an under-researched and under-utilised African legume) were almost trebled due to increased length of growing period and the positive effects of higher CO_2 concentrations. These results highlight the need to search for and promote new crop options as well as practices and methods that make maximum utilization of prevalent crop and climatic combinations.

Using this modelling framework, policy support for potential crop adaptation to climate change through breeding for late-maturing and more heat-tolerant cultivars can be explored and pursued in a rigorous manner. It is relatively simple to measure physiological parameters using modern apparatus and new analytical tools (Araus *et al.* 2002; FAO 2007). However, to develop a new crop variety takes up to a decade and might entail using a combination of new technologies such as genetic engineering and marker-assisted selection. Using the findings of this research, international donor agencies working in Cameroon and plant breeders could undoubtedly take up the challenge of developing late maturing, more productive cultivars that might better suit the climate change scenarios for Cameroon.

Important policy implications can be drawn from the analysis presented in this study. Intensification of effort in the development of new crop cultivars appears to be an important policy option to make agriculture in Cameroon more resilient to climate change. The past experience in developing countries suggests that a wider adoption of new genotypes may take more than a decade (Kurukulasuriya *et al.* 2006) and may also require effective promotional campaigns. An early start on the development and adoption of these genotypes is therefore imperative.

The costs of breeding new cultivars are uncertain but likely to be substantial and beyond the economic capacity of any single developing country such as Cameroon. Such strategies must be seen in the broader context of global environment governance under the UNFCCC and its Kyoto protocol. The results of this research may be used for countries like Cameroon to not only raise their voices for CO_2 abatement but also seek support from developed countries in the form of technology transfer, food aid, and flow of financial resources addressing Article 4.4 of UNFCCC which commits developed country parties to "assist developing country parties that are particularly vulnerable to the adverse effects of climate change...".

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