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Potential effects of climate change on corn production in Zimbabwe

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ABSTRACT: This study uses Global Circulation Models (GCMs) and the dynamic crop growth model CERES-Maize to assess the potential effects of climate change on corn (*Zea mays* L.) in Zimbabwe. Corn is the most widely grown crop in Zimbabwe and is often under environmental stress due to high ambient temperature and low rainfall conditions. Global climate change scenarios suggest corn productivity in Zimbabwe will decrease dramatically under non-irrigated or irrigated conditions in some regions of agricultural production. The reductions in corn yields are primarily attributed to ambient temperature increases which shorten the crop growth period, particularly the grain-filling period. If climate effects occur farmers may find corn production an unacceptably risky activity. Adaptation options are available but financial costs may be prohibitive to communal area farmers.

KEY WORDS: Simulated model · *Zea mays* L. · Zimbabwe

INTRODUCTION

The impacts of global climate change on agricultural crop production may be significant (Rosenzweig & Parry 1994). Despite technological advances in plant breeding, fertilizers and irrigation systems, climate is a key factor in agricultural production. In the 1980s, continuing deterioration of food production in Africa was caused in part by extended drought and soil degradation. Assessments of climate change impacts on crop production in developed countries have been completed (e.g. Smith & Tirpak 1989), but less is known regarding impacts in developing countries.

Corn (*Zea mays* L.) is the primary staple food crop and occupies about half of the agricultural land in Zimbabwe (Chasi & Shamudzarira 1992). Ambient temperature, precipitation and soil moisture, as well as frequency of heat waves and droughts, are significant factors influencing corn production in southern Africa. Corn yields vary significantly among regions in Zimbabwe. Yields ranging from 3.2 to 1.1 Mg ha^{-1} have been observed in the commercial and communal sectors of Zimbabwe over the past 23 yr (Rukuni 1992, Ministry of Lands, Agriculture and Water Development 1994). The major objective of this study is to assess, using the crop simulation model CERES-Maize, the effect of climate change on corn production in Zimbabwe.

MATERIALS AND METHODS

Daily observed climate data (precipitation, solar radiation, maximum and minimum air temperature) from 4 stations in Zimbabwe were collated from the Department of Meteorology covering a period from 1951 to 1991. The stations were Beit Bridge, Masvingo, Gweru and Karoi. Using 2 GCMs, the observed climate data were modified to create climate change scenarios for each station. The GCMs used were developed by the Geophysical Fluid Dynamics Laboratory (GFDL) (Manabe & Wetherald 1987) and the Canadian Climate Centre Model (CCCM) (Boer et al. 1992). In his study, Unganai (1996) has used the 2 GCMs to estimate how climate will change as a result of doubling CO$_2$ levels. Southern Africa is likely to experience a temperature rise ranging from 2 to 4°C, while precipitation is anticipated to increase by 10 to 15%.

The CERES-Maize simulation model (Jones & Kiniry 1986) was used in the analysis. The model simulates crop responses to changes in climate, management variables, soils, and different levels of CO_2 in the atmosphere. Potential changes in corn yield responses were estimated using the CERES-Maize model under different climate scenarios. The model simulates crop yield responses (water balance, phenology and growth throughout the season) on a daily basis to the major factors of climate (daily solar radiation, maximum and minimum temperature and precipitation), soils and management (cultivar, planting date, plant population, row spacing and sowing depth).

Some assumptions were made in applying the CERES-Maize model and it tends to overestimate the simulated yields (Jones & Kiniry 1986). These assumptions are as follows: pests are controlled; there are no problem soil conditions such as salinity; there are no catastrophic weather events such as hailstorm; and technology and climate tolerance of cultivar do not change under conditions of climate change. The short season (120 days) corn variety R201, commonly grown under non-irrigated conditions, was selected for the analysis. Variety R201 would perform in both high and low rainfall areas. The 'genetic coefficients' of R201 were obtained from the Agricultural Research Trust in Harare. The soil characteristics for each of the study sites are given in Table 1.

Corn production in this analysis was simulated under non-irrigated and irrigated conditions to provide a range of possible scenarios and analyze the production changes. Since it was not possible to determine the irrigation water amounts for each region, irrigation was simulated with a hypothetical non-limiting situation (Inman-Bamber 1991). This approach allows comparison between relative changes in each site. If arbitrary irrigation amounts were applied, the uncertainty of the results would be larger and there would be errors when comparing results from different sites. For the irrigation simulation, the water demand was calculated as follows: 100% efficiency of irrigation system, 30 cm irrigation depth, irrigation when the available soil moisture is 50% or less of field capacity, soil moisture for each layer is re-initialized to 100% field capacity at the start of each growing season, and the plant population was kept the same in both non-irrigated and irrigated conditions at 4.4 plants m^{-2}.

The CERES-Maize model was validated using local data from 2 stations (sites) in Zimbabwe. The experimental data included aspects such as cultivar, planting date, growth analysis, fertilizer application, harvesting date, and final yield components (Jones & Kiniry 1986). Experimental crop data and climate were used for the 1988-89 season at Harare and for the 1986-87 season at Gweru, Zimbabwe (Table 2). At Harare, the observed yield was 9.5% lower than the simulated yield, and the observed season length was 2.3% shorter than the simulated season length. In Gweru, the mean observed yield was 3% lower than the simulated yield and the observed season length was 1.6% longer than the simulated season length (Table 2). These results are similar to those obtained by Muchena (1991).

The capability of the model to adequately simulate crop response to elevated CO_2 is questionable (Acock & Allen 1985). There are 2 primary interacting physiological responses to CO_2: increase in photosynthesis and water use efficiency. Crop response to elevated CO_2 levels is significant in species with a C_4 photorespiration process. The CERES crop models were not originally developed with the elevated CO_2 physiological response function (Jones & Kiniry 1986).

The baseline corn production scenarios include the following assumptions: (1) a short season variety, R201, that is commonly grown in the communal areas of Zimbabwe; (2) 5 different planting dates covering the

Table 1. Soil characteristics for 4 corn production sites in Zimbabwe

Station	Soil class	Soil description	Soil depth (cm)	Bulk density (g cm^{-3})	Clay content (<0.002 mm) (%)	Silt content (0.05 to 0.002 mm) (%)	Coarse fraction (>2 mm) (%)
Beit Bridge	4P.2	Fine clayey	110	1.80	42.0	16.1	41.9
Masvingo	5G/2	Coarse loam	200	1.59	41.8	13.7	44.5
Gweru	4E/2	Clayey, mixed	110	1.80	32.9	37.6	29.5
Karoi	5P	Fine to medium loam	200	1.59	41.8	23.7	34.5

Table 2. Simulation of maize growing seasonal yield using CERES-Maize simulation of corn production at 2 sites in Zimbabwe

Site	Year	Maize variety	Actual yield (kg ha^{-1})	Actual growing season length (d)	Simulated yield (kg ha^{-1})	Simulated growing season length (d)
Gweru	1986-87	R201	4986	120	5140	118
Harare	1988-89	R201	3897	124	4306	127

period from mid-October to mid-December (15 Oct, 1 Nov, 15 Nov, 1 Dec and 15 Dec) were used in the simulation exercise. The simulation had to include different planting dates because date of sowing is a factor that affects yields significantly under rain-fed conditions in Zimbabwe (Commercial Grain Producers Association 1983); (3) simulations for 40 seasons on each of the 4 sites representing the 4 agro-ecological zones in which corn is commonly grown; and (4) existing climate and the 2 GCM (CCCM and GFDL) scenarios. In each climate change scenario non-irrigated and irrigated conditions were simulated.

RESULTS

Simulated mean corn yields are presented in Table 3 for 5 planting dates, 4 stations and 3 climate scenarios. The effect of climate change on corn yield differed between sites. At Beit Bridge under existing climate, corn yields ranged from about 500 to 1200 kg ha^{-1}. Yield was generally enhanced if corn was planted after 15 November. Under the climate change scenarios, the GFDL scenario resulted in a higher yield in all planting dates relative to the CCCM model. At Masvingo, the existing climate scenario gives more consistently greater yields than either GCM scenario. Early planted corn under all climate scenarios gives the highest yields at Gweru. Corn yields are consistently higher (above 3000 kg ha^{-1}) under normal climate conditions for all planting dates at Karoi. Yields range from 40 to 4600 kg ha^{-1} under GCM scenarios at Karoi. Under existing climate, yields for late planted corn compare quite well with the early planted crops.

The simulated effect of climate change on corn production at 4 irrigated sites in Zimbabwe is presented in Table 4. The analysis reveals that in all scenarios irrigation raises the production of corn. However, even though irrigation improves the growing conditions of corn, the yields are lower under climate change conditions than under normal climate. The yield reduction under irrigated conditions due to climate change ranges from 11 to 17%. Corn yield is higher in all cases under the CCCM climate scenario than under the GFDL climate scenario. It is not known if irrigation water will be available under climate change conditions in quantities adequate to meet the irrigation requirements of Zimbabwe.

Table 3. Simulated mean corn yield (kg ha^{-1}) over 40 years at 4 sites without irrigation in Zimbabwe

Climate scenario	Planting date				
	15 Oct	1 Nov	15 Nov	1 Dec	15 Dec
Beit Bridge					
Normal climate dryland	737.6	1136.4	514.4	1203.4	1213.1
CCCM × 2 CO_2 dryland	514.3	837.6	1091.5	1304.3	713.2
GFDL × 2 CO_2 dryland	1639.9	1739.8	1421.7	1453.3	724.9
Masvingo					
Normal climate dryland	3006.1	2778.9	2591.9	2416.7	2339.0
CCCM × 2 CO_2 dryland	3493.1	2724.8	57.6	47.4	42.8
GFDL × 2 CO_2 dryland	3097.0	2402.3	47.4	44.6	40.1
Gweru					
Normal climate dryland	3006.4	2566.9	2507.0	2046.7	1121.3
CCCM × 2 CO_2 dryland	5011.2	4260.2	3443.5	3063.0	769.7
GFDL × 2 CO_2 dryland	5446.2	3697.0	2815.1	2640.3	734.9
Karoi					
Normal climate dryland	3726.5	3653.6	3530.5	3224.8	3142.9
CCCM × 2 CO_2 dryland	2633.6	4640.8	3512.3	2955.7	41.2
GFDL × 2 CO_2 dryland	2939.8	4629.6	3507.3	2939.5	40.9

Table 4. Simulated effect of climate change on irrigated corn yield at 4 stations in Zimbabwe. Data are average yield (kg ha^{-1}) and percent decrease in yield

Climate scenario	Beit Bridge		Masvingo		Gweru		Karoi	
	Yield	% decrease	Yield	% decrease	Yield	% decrease	Yield	% decrease
Normal climate	8731	–	11017	–	11862	–	11536	–
CCCM × 2 CO_2	7684	12	9144	17	9845	17	9920	14
GFDL × 2 CO_2	7771	11	9475	14	10201	14	10152	12

Analysis of season length per given climate scenario (e.g. CCCM or GFDL) revealed that growing seasons under existing climate are longer for all sites regardless of planting date. These results reveal a prevailing reduction of season length in all sites under all planting dates. This reduction is greater under the CCCM model than the GFDL model. Under the CCCM model season length reduction is greatest at Masvingo (17% on average) and lowest at Beit Bridge (7% on average). This implies that the decrease in season length might have an effect by way of reducing the potential yield of long season corn varieties. The difference in season lengths between short and long is at least 25 d.

Available precipitation simulated by the CCCM scenario is reduced at all sites regardless of the planting date. The mean decrease is 25% at Beit Bridge, Masvingo, Gweru, and Karoi, respectively. Under the GFDL scenario the effect of climate change increases precipitation by 8% at Beit Bridge for all planting dates. The increase in precipitation at Beit Bridge did increase corn yield because precipitation events occur outside the growing season. At all sites precipitation reduction is greatest for corn planted early (11–15 November) and becomes progressively less towards late planting dates (12–15 December).

DISCUSSION

The CERES-Maize simulation model results suggest global climate change may significantly influence future corn yields in Zimbabwe. Corn production at all stations is more stable under existing climate relative to future climate change conditions. Both climate change scenarios give rise to fluctuating corn yields thus making corn production a more risky agricultural activity for farmers. At Masvingo, there is a strong likelihood that climate change will make the region a non-corn-producing area. Similar agronomic crop responses to climate change have been reported previously (Rosenzweig & Parry 1994).

Late-planted crops at all sites will not produce yields that make agronomy a viable activity under climate change conditions. Climate change will result in significant yield increases in some regions of Zimbabwe and this will depend on proper timing of planting dates to achieve the maximum production (Bole et al. 1994). Even though irrigation will boost corn production in all areas, the yields will be lower under climate change conditions than under existing climate (Smith & Tirpak 1989). Crop growing season length may be shortened under climate change conditions and this may limit corn production to short season varieties.

Precipitation available each season will be reduced by more than 20% under the CCCM model at all sites. The greatest reduction is encountered when corn is planted early rather than late. The reduction in mean seasonal precipitation under climate change conditions implies that the water available for irrigation purposes might be affected accordingly. This will reduce the effectiveness of irrigation as a strategy to adapt to the effects of climate change (Qureshi & Iglesias 1992).

The overwhelming impact of increase in temperature, especially when coupled with decreases in precipitation, would be on crop grain filling (Rosenzweig & Parry 1994). If climate change results in a warmer and drier environment, additional problems may arise regarding water supplies for irrigation in Zimbabwe (Downing 1991). Because of hydrological uncertainties in the GCMs, future water supply for irrigation remains unknown. Future competition for agricultural water supplies from industrial and residential users has not been fully investigated in Zimbabwe.

Of Zimbabwe's 32 million ha of agricultural land, 16.4 million ha are in communal areas. Farmers in communal areas are small-holders living in rural areas whose livelihood is dependent upon tilling the land under rain-fed conditions. Socio-economic groups in this area, already vulnerable in terms of food self-sufficiency and food security, would be further marginalized (Downing 1992). Possible adaptation strategies include changes in the management practices of the corn cultivars (planting date and irrigation); and shifting to cultivars that might withstand the effects of climate change. Any increases in ambient temperature would contribute to a loss of soil moisture that is critical to the agronomic crops, especially under current management practice of non-irrigated farming (Nyamapfene 1991).

A likely response of farmers to warmer ambient temperatures would be to time the corn sowing date such that the high temperatures during the grain filling period are avoided (Smith & Lenhart 1996). Other strategies that could be employed: switch to millet and sunflower (although corn currently has the comparative economic advantage); grow shorter-season corn varieties; change plant population by altering plant spacing; apply appropriate fertilizers and insecticides as needed; rotate cereal crops with legumes. While farmers are aware of the benefits of these strategies, they have cited cash, risk, labor, land and input supplies as major constraints to their adoption (Downing 1992).

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