

Research Application Summary

Sensitivity of Ceres-maize simulated yields to biogeochemical components

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Abstract

Change in environmental conditions including climate change is already occurring and is expected to affect crop production. This has led to a need to assess the impact of such changes to crop production so as to develop the adaptation strategies to assure sustainable production and food security. Crop simulation models are adopted for this kind of studies, however, the models' applicability varies with location, climatic conditions and purpose. For this study, CERES-Maize crop model sensitivity to climatic variables uncertainty and Nitrogen fertilizer was evaluated. Maize yields were simulated using a 31 years (1979-2009) climatic record for a range of important variables. The input ranges of variables were: Temperature (-2°C to +8°C), rainfall increment (25% to 200%), Carbon dioxide concentration (360 ppm to 720 ppm) and Nitrogen fertilizer (30 kg/ha to 180 kg/ha). The model was initially calibrated and evaluated for one and two years respectively. Sensitivity analysis was performed for one parameter level at a time while other parameters were fixed at their normal values. Sensitivity results showed high response to change in temperature (from 300 to 650) kg/ha, water (from 550 to 800) kg/ha, Nitrogen (500-1000) kg/ha and low sensitivity in Carbon dioxide concentration (550-600) kg/ha. It was concluded that CERES-Maize crop model is sensitive to Nitrogen fertilization as well as to all selected climatic variables. Thus, the CERES-Maize crop model can be used for crop simulation studies and climatic impact assessments.

Key words: Crop simulation models, climate change, maize

Résumé

Les changements dans les conditions environnementales, y compris les changements climatiques, se produisent déjà et devraient affecter la production végétale. Ceci a suscité le besoin d'évaluer l'impact de ces changements sur la production végétale afin d'élaborer des stratégies d'adaptation pour assurer la production durable et la sécurité alimentaire. Les modèles de simulation de production sont adoptés pour ces genres d'études, mais l'application des modèles varie en fonction de la localité, des conditions climatiques et de l'objectif. Pour cette étude, la sensibilité du modèle de production du Maïs-CERES à l'incertitude des variables climatiques et l'engrais azoté a été évaluée. Les rendements de maïs ont été simulés en utilisant des données climatiques sur 31 ans (1979-2009) pour une gamme de variables importantes. Les intervalles des variables considérées étaient: Température (2 ° C à + 8 ° C), augmentation des précipitations (25% à 200%), concentration

de dioxyde de carbone (360 ppm à 720 ppm) et engrais azoté (30 kg / ha à 180 kg /Ha). Le modèle a été initialement calibré et évalué respectivement pendant un et deux ans. L'analyse de sensibilité a été effectuée pour chaque paramètre en considérant les valeurs normales des autres paramètres comme fixes. Les résultats de sensibilité ont montré une réaction élevée aux variations de température (de 300 à 650) kg / ha, d'eau (de 550 à 800) kg / ha, et d'azote (500-1000) kg / ha et une faible sensibilité à la concentration de dioxyde de carbone (550-600) Kg / ha. A partir du modèle, Il a été conclu que le Maïs-CERES est sensible à la fertilisation en azote ainsi qu'à toutes les variables climatiques choisies. Ainsi, le modèle de simulation de production du Maïs-CERES peut être utilisé pour les études de simulation de production de cultures et les études d'impact climatique.

Mots clés: Modèles de simulation de culture, changement climatique, maïs

Background

Crop growth models have considerable potential in agricultural research, development of cropping technologies, and decisions making. The models have provided useful insights on the functioning of crops and agricultural systems, in particular, the interactions between crops and their environment (White *et al.*, 2011). The models are used worldwide for assessing crop growth conditions and yield potentials with respect to different environmental conditions. In addition, models are widely used in various studies to evaluate the impact of climate changes on maize production and provide critical information for identifying potential adaptation options (Wang, 2011).

Variables relevant to crop models have high spatial and temporal variability, which makes the precise estimation difficult (Tarantola *et al.*, 2002). Evaluation of the effectiveness of the simulation models to changes in the environmental factors to better explain how particular model input variables contribute to changes in output such as yields, biomass among others, becomes an imperative. This will provide guidance to improve the quality of assessment practices and decision support systems used in agricultural and environmental decision-making, ultimately improving models reliability, transparency and credibility. Therefore, the objectives of this study was to analyze CERES-Maize model sensitivity to biogeochemical components including; changes in temperature, water, atmospheric carbon dioxide concentration and nitrogen fertilization with respect to maize grain yield in Kongwa-Kiteto maize belt. It is hoped that this will increase the confidence on model reliability for evaluation of maize yield response to climate changes and adaptation options for sustainable maize production.

Literature summary

CERES (Crop-Environment-Resource-Synthesis) is a crop simulation model embedded in the Decision Support System for Agro technology Transfer (DSSAT). The model operates on a daily time step and takes into account the effect of weather, soil moisture, nutrients, cultivar and crop management (Hoogenboom *et al.*, 2004). This model has been validated on across different climate and soil conditions for different crop varieties and types

including rice, wheat, and barley (Rötter *et al.*, 2011). The model provides accurate simulation of actual maize yields across range of crop soil types and seasons (Jones *et al.*, 2003). It has also been widely used in various studies (Jin *et al.*, 2002; Lobell *et al.*, 2006; Wang, 2011) to assess the impact of climate change on maize production and to provide critical information for identifying potential adaptation options.

Study description

Daily weather data including maximum and minimum temperatures (°C), solar radiation (MJ m⁻² day⁻¹) and rainfall (mm/day) for current climate (1989-2010) were used to create the weather file. Soil profile information, details of the field characteristics and management practices were incorporated in the Zipped survey template file. Quad UI software tool was used to create model-ready input file for DSSAT model simulation. Sensitivity analysis of grain yields to Carbon, temperature, rainfall and Nitrogen fertilizer were analyzed using R-statistical Package.

Research application

Results based on the sensitivity analyses for maize yield with respect to CO₂ concentration (Figure 1) showed that there is a slight increase in grain yield with increase in CO₂ concentration (450ppm and 540ppm compared to baseline 360 ppm) but there is no change in grain yield with further increase in CO₂ concentration (540-720 ppm). Growth and performance of maize as in other many C4 plants may be simulated by an increase in CO₂ concentration. However, there is no further response with high elevated CO₂ concentration due to adaptive characteristics of maize to CO₂ accumulation.

An increase in grain yield with decrease in current climate temperature by 2°C and maize yield decrease with increase in current climate temperatures by +2, +4, +6, +8 was observed (Figure 2). Low temperatures often tend to extend the growing season, thereby maximizing light interception and enhancing crop yields. On the other hand warming accelerates crop growth and shortens the length of growth periods thereby reducing the time for plant and grain development. This limits the attainment of full yield potential.

With respect to current climate rainfall there is increase in grain yield with increase in percentage rainfall up to 75% (Figure 3). Overall yield reduction with further increment in rainfall (100% to 200%) was also observed. This is because rainfall provides water which is essential for plant growth and development. However further rainfall increment brings excess water which may cause soil waterlogged conditions that reduce water and nutrients transportation, and accelerate root senescence and finally resulting in reduction in grain yield.

There is a relative increase in grain yield with increase in N-fertilizer (from 0 to 60) and decrease with further N increase because N is an essential nutrient and a determining factor

in crop production but excess nitrogen application causes osmotic stress, leading to reduced growth and eventual yield of plants (Figure 4).

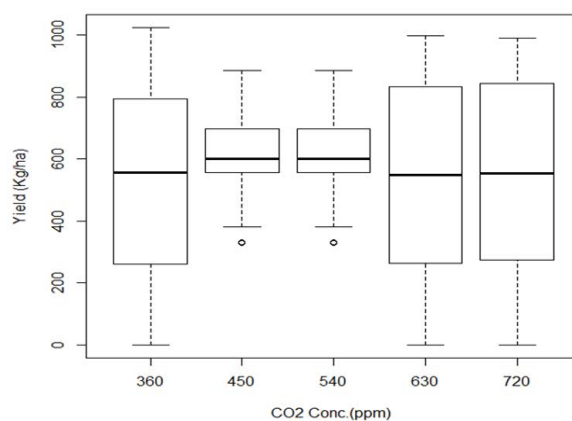


Figure 1. CERES model response to changes CO₂ concentration with respect to maize grain yield

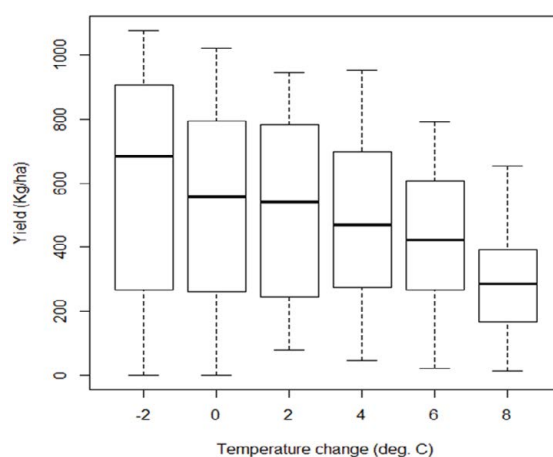


Figure 2. CERES model response to changes in temperature with respect to maize grain yield

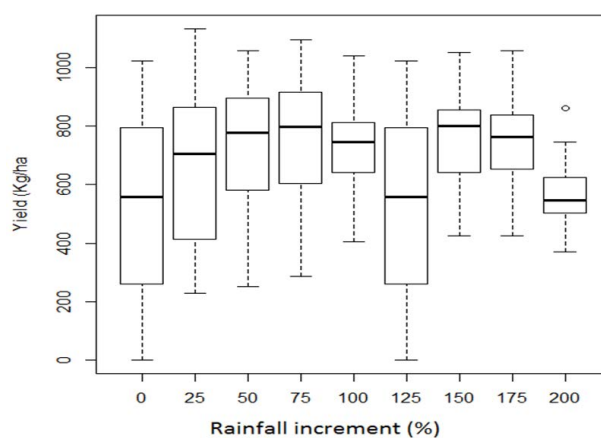


Figure 3. CERES model response to rainfall increment with respect to maize yield

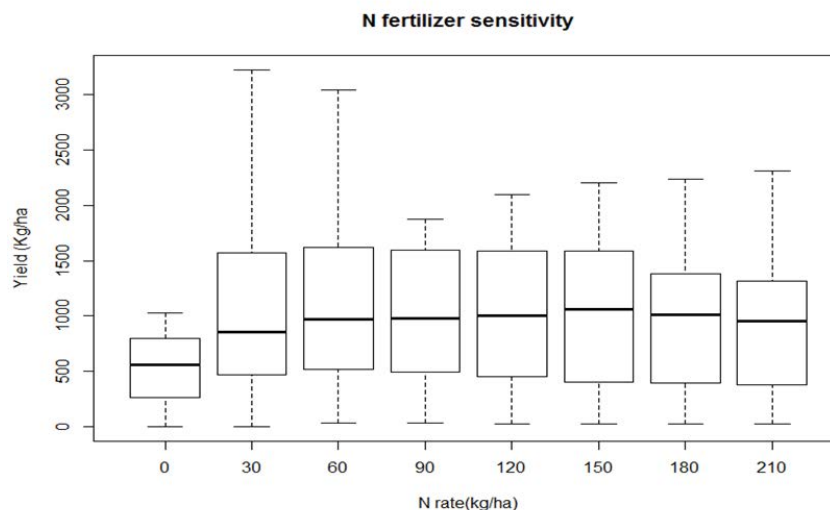


Figure 4. CERES model response to Nitrogen fertilizer rates with respect to maize grain yield

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References

- Hoogenboom, G., Jones, J.W., Wilkens, P.W., Porter, C.H., Boote, K.J. and Hunt, L.A. 2010. Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.5, Honolulu, University of Hawaii, CD ROM.
- Jin, Z.Q., Ge, D.K., Shi, C. and Gao, L. 2002. Several strategies of food crop production in the Northeast China Plain for adaptation to global climate change. *Acta Agronomica Sinica* 28 (1): 24–31.
- Jones, P. G. and Thornton, P. K. 2003. The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change* 13 (1): 51-59
- Lobell, D., Field, C., Cahill, K. and Bonfils, C. 2006. Impact of future climate change on California perennial crop yields: model projections with climate and crop uncertainties. *Agricultural and Forest Meteorology* 141 (2): 208-218.
- Wang, M ., Li,Y., Ye,W., Bornman, J.F. and Yan, X. 2011. Effects of climate change on maize production, and potential adaptation measures: a case study in Jilin Province, China. *Clim. Res.* 46 (3):223–242.
- White, J.W., Hoogenboom, G., Kimball, B.A. and Wall, G.W. 2011. Methodologies for simulating impact of climate change on crop production. *Field Crops Research* 124 (3): 357–368.

- Tarantola, S., Saisana, M., Saltelli, A., Schmiedel, F. and Leapman, N. 2002. Statistical techniques and participatory approaches for the composition of the European Internal Market Index 1992-2001. *Report EUR 20547 EN*. European Commission–Joint Research Centre, Ispra.