SHORT COMMUNICATION: Climate change and biofuel wheat: A case study of southern Saskatchewan

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Wang, H., He, Y., Qian, B., McConkey, B., Cutforth, H., McCaig, T., McLeod, G., Zentner, R., DePauw, R., Lemke, R., Brandt, K., Liu, T., Qin, X., White, J., Hunt, T. and Hoogenboom, G. 2012. **SHORT COMMUNICATION: Climate change and biofuel wheat: A case study of southern Saskatchewan**. Can. J. Plant Sci. **92**: 421–425. This study assessed potential impacts of climate change on wheat production as a biofuel crop in southern Saskatchewan, Canada. The Decision Support System for Agrotechnology Transfer-Cropping System Model (DSSAT-CSM) was used to simulate biomass and grain yield under three climate change scenarios (CGCM3 with the forcing scenarios of IPCC SRES A1B, A2 and B1) in the 2050s. Synthetic 300-yr weather data were generated by the AAFC stochastic weather generator for the baseline period (1961–1990) and each scenario. Compared with the baseline, precipitation is projected to increase in every month under all three scenarios except in July and August and in June for A2, when it is projected to decrease. Annual mean air temperature is projected to increase by 3.2, 3.6 and 2.7°C for A1B, A2 and B1, respectively. The model predicted increases in biomass by 28, 12 and 16% without the direct effect of CO_2 and 74, 55 and 41% with combined effects (climate and CO_2) for A1B, A2 and B1, respectively. Similar increases were found for grain yield. However, the occurrence of heat shock (>32°C) will increase during grain filling under the projected climate conditions and could cause severe yield reduction, which was not simulated by DSSAT-CSM. This implies that the future yield under climate scenarios might have been overestimated by DSSAT-CSM; therefore, model modification is required. Several measures, such as early seeding, must be taken to avoid heat damages and take the advantage of projected increases in temperature and precipitation in the early season.

Key words: Climate change, wheat, biofuel crop, heat shock, seeding date

Wang, H., He, Y., Qian, B., McConkey, B., Cutforth, H., McCaig, T., McLeod, G., Zentner, R., DePauw, R., Lemke, R., Brandt, K., Liu, T., Qin, X., White, J., Hunt, T. et Hoogenboom, G. 2012. **COMMUNICATION BRÈVE: Le changement climatique et la culture du blé comme biocarburant : le cas du sud de la Saskatchewan**. Can. J. Plant Sci. **92**: 421–425. Cette étude évalue l'incidence potentielle du changement climatique sur la culture du blé en tant que biocarburant dans le sud de la Saskatchewan, au Canada. Les auteurs ont recouru au modèle de système cultural du système de soutien à la prise de décisions en matière de transfert de technologie agricole (DSSAT-CSM) pour simuler le rendement de la biomasse et le rendement grainier selon trois scénarios climatiques (scénarios IPCC SRES A1B, A2 et B1 du CGCM3) dans les années 2050. Les données climatiques synthétiques de 300 ans ont été obtenues au moyen du générateur stochastique de relevés climatologiques d'AAC pour la période de référence (1961–1990) et pour chacun des trois scénarios. Comparativement à la période de référence, on prévoit une hausse mensuelle des précipitations sauf en juillet et en août, pour les trois scénarios, et en juin pour le scénario A2, mois durant lequel les précipitations pourraient diminuer. La température annuelle moyenne de l'air devrait respectivement augmenter de 3,2, 3,6 et 2,7 °C selon les scénarios A1B, A2 et B1. Le modèle prévoit une hausse de 28, 12 et 16 % de la biomasse, sans l'effet direct du CO_2, et une hausse de 74, 55 et 41 % quand on combine l'effet du climat à celui du CO_2, pour les scénarios A1B, A2 et B1, respectivement. Le rendement grainier connaîtrait une hausse similaire. Toutefois, le choc thermique (>32 °C) sera plus fréquent durant le remplissage du grain, dans les conditions climatiques envisagées, ce qui pourrait réduire considérablement le rendement, un aspect que ne simule pas le

DSSAT-CSM. Il s'ensuit que ce modèle pourrait surestimer le rendement futur selon le scénario climatique et qu'il est nécessaire de le modifier. Plusieurs mesures comme des semis hâtifs devront être prises si l'on veut éviter les dommages causés par la chaleur et profiter des avantages associés à l'élévation prévue de la température et des précipitations au début de la période végétative.

Mots clés: Changement climatique, blé, biocarburant, choc thermique, date des semis

Approximately 44% of Canada's agricultural land is located in the province of Saskatchewan and the major (close to 40%) crop is wheat (*Triticum aestivum* L.), which is a potential biofuel crop. This case study is to use the Decision Support System for Agrotechnology Transfer-Cropping System Model (DSSAT-CSM) to assess the impact of climate change on the production of wheat as a biofuel crop grown in southern Saskatchewan.

The site selected for this study was located on a gently sloping Swinton silt loam (Typic Haploboroll) at the Semiarid Prairie Agricultural Research Centre, Swift Current, in southern Saskatchewan. Soil property inputs (organic carbon, total nitrogen, clay and silt in percent, cation exchange capacity, pH, soil lower, drained upper and saturated points, saturated hydraulic conductivity, and bulk density) were observed on the site. The management used for simulation was a continuous wheat rotation under no-till with a seeding depth of 5 cm. Nitrogen fertilizer was assumed to be applied at a rate of 100 kg ha^{-1} at planting time. Seeding dates were predicted with the model described by McGinn et al. (1999).

DSSAT-CSM, a widely used process-based modeling package (Jones et al. 2003), was selected for simulating the wheat production system. This model simulated wheat yield and biomass generally well in western Canada (Wang et al. 2010a). The wheat module of DSSAT-CSM (v4.0) was modified to improve the prediction of seedling emergence rate (Wang et al. 2009a, b) and leaf appearance rate (Wang et al. 2010b). The spring wheat cultivar Biggar (Canada Prairie Spring Wheat class) was used for modeling because this wheat class has a higher starch content and lower protein concentration in comparison to bread wheat class and is recognized as a viable feedstock for ethanol. Genetic coefficients of the variety Biggar were calibrated with the data collected by Jame and Cutforth (2004) and tested using data from the New Rotation experiment at Swift Current (Zentner et al. 2003). The model was run with the Sequence Analysis option, which allows the user to carry out simulations of crop rotations or crop sequences order to predict the long-term yield and environmental impacts.

Weather data during the period of 1961–1990 were measured on the site and were treated as the baseline climate. Climate change scenarios in 2050s (2040–2069) were projected by the third generation global climate model developed at the Canadian Centre for Climate Modelling and Analysis (CGCM3) with the forcing of three greenhouse gas emission scenarios (i.e., IPCC SRES A1B, A2 and B1) (Nakicenovic et al. 2000). Synthetic 300-yr weather data were generated by the AAFC Stochastic Weather Generator (AAFC-WG) for the baseline period (Qian et al. 2004) and each scenario by perturbing weather generator parameters based on the climate change simulated by CGCM3 (Qian et al. 2010). These generated data were used to predict the climate effect on wheat production with the DSSAT model. Qian et al. (2011) found that simulations of crop models with 30-yr observed and the 300-yr synthetic weather data generated by AAFC-WG with parameters calibrated from the same 30-yr observed data, in general, do not show significant differences, with regard to timing of biomass accumulation, crop maturity date, as well as biomass and grain yield at maturity. The simulations were run with and without direct effects of increased atmospheric CO_2 levels. The CO_2 levels were 550 ppm for A1B and A2 and 450 ppm for B1. The hourly air temperature was calculated using the subroutine HTEMP of DSSAT-CSM. It is worthwhile to mention that uncertainties in climate projections are large in association with such as climate models, forcing scenarios and natural climate variability in the climate system. In this study, climate change simulations from one climate model (CGCM3) with three forcing scenarios were used to demonstrate the uncertainties related to GHG emission scenarios. Other aspects of the uncertainties in climate projections are beyond the scope of this study; however, plenty of information on the uncertainties in climate projections can be found in literature (e.g., Intergovernmental Panel on Climate Change 2007).

Statistical analyses were done using SAS software (SAS Institute, Inc.). Means, lower and upper limits of the 95% confidence interval and standard errors of the mean for synthetic air temperature and precipitation were calculated and compared among baseline and climate change scenarios by PROC MEANS. Predicted and calculated variables were compared between scenarios with PROC MIXED.

All the climate change scenarios projected increases in annual precipitation compared with the baseline period (331 mm, Fig. 1). The most significant increase is projected by Scenario A1B (55 mm), followed by A2 (39 mm) and B1 (37 mm). All three scenarios projected an increase of precipitation in every month except July and August, and June for A2, when less rains are projected. Scenario A2 was similar to A1B in terms of precipitation distribution except that it is projected to be less (10 mm) than A1B in June. Predicted precipitation

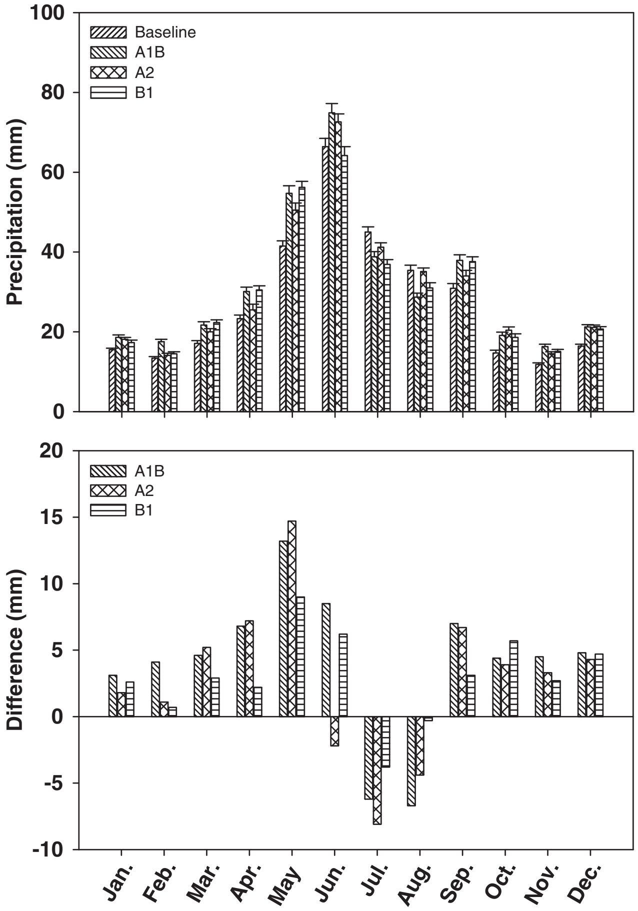

Fig. 1. Monthly precipitation under baseline and three scenarios and difference between baseline and scenarios. Vertical bars represent standard error of the mean.

by scenario B1 was slightly less than that of A1B in every month, except in July and August when B1 had more rain than A1B.

Air temperature in all climate scenarios was projected to increase compared with the baseline climate (Fig. 2). Scenarios A1B, A2 and B1 predicted 3.2, 3.6 and 2.7°C higher annual mean air temperatures than the baseline, respectively. The highest difference in temperature is projected to occur in winter, followed by summer, spring and fall. Scenario A2 generated the highest temperature in most of the days of the year. The projected change in pattern and difference between scenarios in daily maximum and minimum air temperatures were similar to that in daily mean temperature (data not shown).

The predicted seeding dates under all climate change scenarios are 6 d earlier than the prediction under the baseline climate (day 124) (Table 1). Because of the earlier seeding and higher temperatures, predicted dates of anthesis and maturity averaged nine and 13 d earlier than simulations based on the baseline climate, respectively. The predicted vegetative (from emergence to anthesis) and grain filling stages were shortened by 2–3 and 3–5 d, respectively. The total time to maturity was shortened by 6–9 d. Among the three climate scenarios, the scenario that reduced days to plant maturity the most was scenario A2, which is associated with its projected higher temperature.

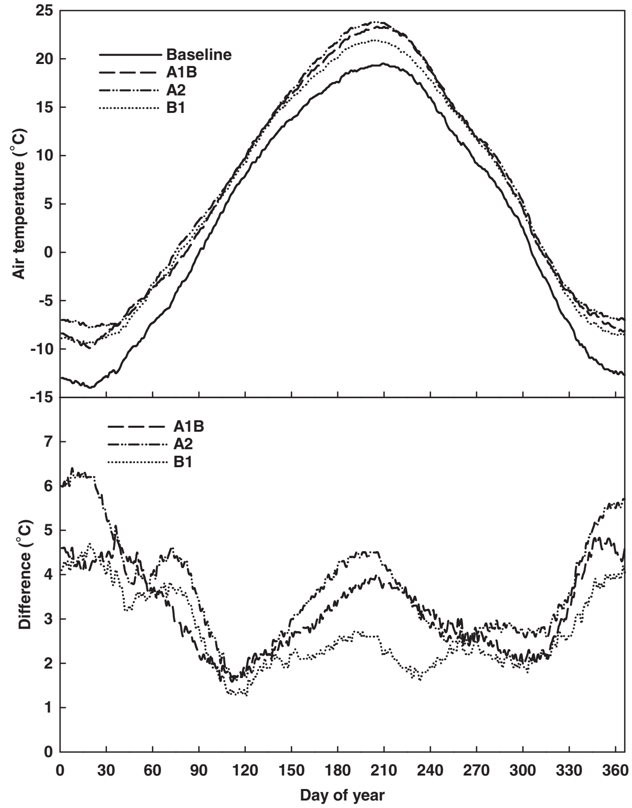

Fig. 2. Daily mean air temperature under baseline and three scenarios and difference between baseline and scenarios.

Without the direct effect of CO_2, the model predicted that all three climate change scenarios significantly increase biomass production compared with the baseline (Table 2), with A1B increasing the most (28%) followed by B1 (16%) and A2 (12%). The combined effects (climate and CO_2) increase biomass production much more, with A1B increasing the most (74%) and A2 (55%) and B1 (41%) being similar. The simulation shows that increases in CO_2 concentrations of 220 and 120 ppm result in increases of biomass production of 43–45% and 25%, respectively, compared with the baseline. The predicted effect of the climate change scenarios on grain yield shows the same trend as biomass (Table 2). The estimated increase in yield under climate change is consistent with the study by Arthur (1988), who predicted an increase in wheat yield under climate change in Saskatchewan. It seems that climate change may increase both grain ethanol and cellulosic ethanol productions. However, caution must be exercised when interpreting the model-simulated results, especially when interpreting the simulated increase in

Table 1. Effects of climate change on phasic development of wheat

	Day of year			Duration (d)			
Scenario	Seeding	Anthesis	Maturity	Seeding to emergence	Emergence to anthesis	Grain filling	Seeding to maturity
Baseline	123.5*a*	185.2*a*	218.4*a*	11.3*a*	50.4*a*	33.1*a*	94.8*a*
A1B	118.0*b*	176.7*bc*	205.5*c*	10.9*ab*	47.9*c*	28.7*c*	87.5*c*
A2	117.8*b*	175.7*c*	203.8*d*	10.7*b*	47.1*d*	28.1*d*	86.0*d*
B1	118.1*b*	177.5*b*	207.5*b*	10.9*ab*	48.6*b*	30.0*b*	89.4*b*

a–d Within columns, values followed by the same letter are not significantly different at the 0.05 level of probability.

Table 2. Effects of climate change on biomass and grain production of wheat

Scenario	CO_2 (ppm)	Biomass (kg ha^{-1})	Grain yield (kg ha^{-1})
Baseline	330	5039*f*	2467f
A1B	330	6463*d*	3167*d*
A1B	550	8753*a*	4349*a*
A2	330	5651e	2834*e*
A2	550	7813*b*	3978*b*
B1	330	5856*e*	2880*e*
B1	450	7104*c*	3520*c*

a–f Within columns, values followed by the same letter are not significantly different at the 0.05 level of probability.

Table 3. Effects of climate change on duration of air temperature surpassing 32°C during the first 20 d of grain filling

Scenario	Day	Hour
Baseline	5.0*d*	30.1*d*
A1B	9.3*b*	72.8*b*
A2	10.9*a*	87.3*a*
B1	7.6*c*	55.5*c*

a–d Within columns, values followed by the same letter are not significantly different at the 0.05 level of probability.

grain yield as the effect of heat stress is not well described by the model.

Heat stress occurs often in wheat on the Canadian prairies, especially during reproductive growth, which has markedly negative impacts on yield (McCaig 1997). At the grain growth stage (anthesis to maturity), heat stress is divided into two types: chronic stress (20–32°C) and heat shock (>32°C). Chronic stress involves a progressive decrease in kernel weight with increasing temperature because the increase of grain filling rate associated with the increase of temperature cannot compensate enough for the reduction of grain filling duration. In southern Saskatchewan, McCaig (1997) found that a cumulative maximum daily air temperature >20°C during and after anthesis was negatively correlated with the yield of wheat. Heat shock can inhibit pollen growth, cause sterility and abortive grain, trigger premature senescence, inhibit kernel development and cause significant reduction in grain yield (Wang et al. 2007).

The occurrences of chronic stress (data not shown) and heat shock (Table 3) are projected to increase by all climate change scenarios. Under the baseline climate, heat shock (>32°C) occurred for only 30 h during the first 20 d of grain filling. Heat shock could occur for 73, 87 and 56 h during this same period under climate change scenarios A1B, A2 and B1, respectively, which are 1.8–2.9 times of that under the baseline climate. Note that if daily temperature is used, increases of heat shock are significant, but not as tremendous as calculated by using hourly temperatures. This means that under climate change conditions heat shock could occur for a longer period in a day than under the baseline climate. Heat shock will damage kernel development and reduce grain yield if future cultivars do not have improved in heat shock resistance. Like many models, DSSAT-CSM does not simulate the yield loss caused by heat shock; therefore, grain yield and probably biomass, was likely overestimated.

Adaptation measures must be taken with regard to the projected high temperature under climate change. One possible strategy is early seeding. This would allow wheat to mature earlier, avoiding heat shock, which will mostly occur in July. The prediction of seeding dates in this paper (Table 1) was calculated by an empirical model (McGinn et al. 1999), which is based on observations from 1950s to 1980s. In recent years, the adoption of no-till and stubble mulch tillage systems allows seeding even earlier. Therefore, seeding dates could be much earlier than the predicted dates under the projected climate change scenarios. Early seeding of wheat on the Canadian prairies may have other advantages, such as reducing the application of herbicides for weed control, reducing the incidence of some insects and diseases, and improving the timeliness of planting operations in the spring, as well as reducing the effect of drought conditions on the plants during crucial periods such as flowering and seed set. Dormant-seeding in the fall or winter is another possible method, which is already practiced by some farmers.

Two other strategies to cope with the heat stress are breeding heat-resistant cultivars and adopting improved tillage methods. The surface residue and standing stubble in no-till and stubble mulch systems act as insulation and impede the exchange rate of thermal energy between the soil and atmosphere. The higher near-surface soil moisture under this system can also help buffer the extremes in daily soil temperatures and reduce root heat stress. Merrill et al. (1996) and Wang et al. (2007) observed that no-till could mitigate heat stress of wheat and improved biomass and yield.

In conclusion, DSSAT-CSM predicted increases in both biomass and grain yield of wheat under three climate change scenarios in Southern Saskatchewan. The positive effect of climate change on wheat growth, however, may be overestimated because the negative effect of heat stress, especially heat shock, on wheat production was not well described by the model. To improve the prediction of climate change impacts on biofuel wheat production, model modification is required. The estimation of optimum seeding dates under future climate should also be improved. To capitalize on the advantages and reduce risks arising from the climate change, adaptation measures, such as early seeding, no-till and breeding heat tolerant cultivars must be taken.

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