

**PERFORMANCE EVALUATION OF STICS CROP MODEL TO  
SIMULATE CORN GROWTH ATTRIBUTES IN RESPONSE TO N RATE  
AND CLIMATE VARIATIONS**

**J. Sansoulet, E. Pattey and B.L. Ma**

Agriculture and Agri-Food Canada  
960 Carling Avenue  
Ottawa, ON, Canada K1A 0C6

**G. Jégo**

Agriculture and Agri-Food Canada  
2560 Hochelaga bd.  
Québec, QC, Canada G1V 2J3

**N. Tremblay**

Agriculture and Agri-Food Canada  
430 Gouin Bd.  
Saint-Jean-sur-Richelieu, QC, Canada J3B 3E6

**C. Drury**

Agriculture and Agri-Food Canada  
2585 County Rd 20  
Harrow, Ontario, Canada N0R 1G0

**N. Beaudoin**

Institut National de la Recherche Agronomique  
Unité Agro-impact - Site de Laon - Pôle du Griffon  
02000 Barenton Bugny, France

## ABSTRACT

Improving nitrogen use efficiency in crop plants contributes to increase the sustainability of agriculture. Crop models could be used as a tool to test the impact of climatic conditions on crop growth under several N management practices and to refine N application recommendation and strategy. STICS, a crop growth simulator developed by INRA (France), has the capability to assimilate leaf area index (LAI) from remote sensing to re-initialize input parameters, such as seeding date and seeding density. The coupling with remote sensing derived LAI was successfully tested on corn (*Zea mays* L.) over small regions for predicting biomass and yield. In this study, we tested the model performance for various nitrogen rate applications. Predictions of corn biomass and N plant uptake were tested against a 16-year experimental database of the Mixedwood Plains ecozone of Eastern Canada (extending from southern Ontario to western Quebec) for N ranging from 0 to 250 kg N ha<sup>-1</sup>. Data were collected during several growing seasons in the period 1993-2010. Model predictions for LAI, biomass, N in plants were in good agreement with measurements. STICS predicted N in plants with mean errors and root mean square errors below 20% when rainfall was close to the normal and for N application rates close to the recommendations. Results complied with the expected trend that under wet conditions or dry conditions (and low temperatures), yields remained steady whatever the N rate application, especially for higher N rate applications. Under non limited water conditions, increasing N application rates generate a non-linear increase of yield and grain N concentrations until a certain level (140-180N). Scenarios results showed that rainfall has a stronger effect on yield and biomass whereas nitrogen application impacted more the plant N, denitrification and potential N leaching. Between one half and 76% of the inter-annual variance of these variables can be explained by a multiple regression analysis according to climate and N rate applications. The remaining unexplained part of the variance could be explained by interactions occurring between these driving factors.

**Keywords:** soil crop model, corn, biomass, nitrogen, rainfall, CHU, performance

## INTRODUCTION

Grain corn (*Zea mays* L.) is the main field crop grown in Ontario (Canada) with a production of 7.24 Mt in 2011. Dry yield currently exceeds 5-6 t ha<sup>-1</sup>, which is representative of rainfed agriculture (Wani et al., 2009). In the last two decades, yield increased with the release of new area cultivars (Ciampitti et al., 2012). The increasing N fertilizer price and potential environmental impacts should encourage growers to critically evaluate their N fertility program in corn, especially the Agronomic Optimum N Rate (AONR) defined as the N rate that produces maximum grain yield (Camberato et al., 2012). Corn production experiences substantial interannual variations of yield in response to climatic

variations (Cabas et al. 2010; Drury and Tan 1995; Tan and Reynolds, 2003). Effects of weather and field management can interact on long-term corn yield and soil-plant N dynamics; so, their interaction needs to be studied in order to develop effective beneficial management practices that are regionally adapted.

Water is often the most limiting factor in rainfed crop production. Adjusting Nitrogen (N) application rates for optimal economical yield under this variable constraint is challenging (Montemurro et al., 2006). Under optimal climatic conditions, increasing N rates results in higher grain yield with more protein. In various corn experiments, increasing N application rates generate a non-linear increase of grain N concentrations (Belanger et al., 2011; Berenguer et al., 2008; Plénet & Lemaire, 2000; Ziadi et al., 2008) until a certain level at which the additional application of N does not significantly increase biomass and yield. Corn biomass and yield do not respond to recommended N fertilization when water stress occurs during the reproductive stages (Pattey et al., 2001). The greater climatic variability expected to take place in relation to climate change should curb crop yield in mid-latitude regions, where water availability could decrease, in the coming decades (Adams et al., 1995; Bryant et al., 2000).

A few process-based models were used to study corn nutrient management in Eastern Canada. Long-term management effects on corn production, tile drainage and water quality was evaluated using the integrated Root Zone Water Quality Model (RZWQM) (Ma et al., 2007). Year-to-year variations in tile N loading flow were correctly simulated, while simulations of annual crop yield and plant N variations were not as good ( $r^2 = 0.52$ ). The Environmental Policy Integrated Climate (EPIC) model (Izaurralde et al. 2006) was used to estimate soil erosion, nutrient loss by runoff and leaching. The model accounted well for 69% of the year-to-year variability in grain yield. The STICS model performed well for predicting the interannual variations of LAI, biomass and yield for N recommended rates in the Mixedwood Plains ecozone of Eastern Canada (Jégo et al., 2011). STICS model has the capability to assimilate measured data of the Leaf Area Index (LAI) for re-initializing unknown initial conditions such as seeding date and density when used at regional scale. Coupling crop modelling and remote sensing is a relevant way to get accurate predictions of crop yield either at heterogeneous field scale (Varella et al., 2010) or regional scale (Jégo et al., 2011), which can be useful in Canada.

Our objective is to evaluate the performance of STICS to predict N fate, corn biomass and yield as a function of N application rates and climate variations in Eastern Canada. This preliminary study focuses on the response of the plant biomass and N uptake to N fertilization rates over several growing seasons and locations to capture the influence of climate variations. Our hypotheses are as follows: (i) climatic variations, which translate into variations in rainfall distribution and amount during the growing seasons, has a stronger impact in the combined influence of rainfall and N application rates on grain yield, plant N and biomass of corn (ii) STICS model is able to predict well year-to-year variations in biomass and crop N requirements in response to the interaction of climate and N management.

## **MATERIALS AND METHODS**

A large dataset of 16 experiments collected from two sites over 17 years (1993 to 2010) in Quebec and Ontario was used to calibrate and evaluate the performance of the model to predict, plant N, and shoot biomass of corn. The model was first calibrated as described with more details in (Jégo et al., 2011) to define two cultivars. Its performance to predict LAI, biomass and yield was evaluated for corn in which recommended rate of N was applied (Jégo et al., 2011). Two cultivars were calibrated and validated: CanMaïsNE, in the range of 2,500–2,900 CHU and CanMaïsSE, defined for the higher CHU range (2,900–3,300 CHU).

### **Study sites and experimentations**

The first experimental site was located near Saint-Jean-sur-Richelieu (St-Jean, 45°19'N, 73°21'W). Average available CHU was about 2950 °C d at this site. The second site, located at the Canadian Food Inspection Agency (CFIA) and Greenbelt Experimental Farms (45°18'N, 75°45'W, Ottawa, ON), had an average CHU of 2890 °C d. Conventional agricultural practices, representative of recommended corn field cultivation in Eastern Canada, were followed for seeding, fertilization, and chemical weed control (OMAFRA, 2002).

At Saint-Jean-sur-Richelieu (St-Jean), the dominant soil texture is a loam. Corn was planted between 3 and 12 May at a density of 7.9 seeds m<sup>-2</sup> in 2004 and 2005, 7.4 seeds m<sup>-2</sup> in 2006, and 7.0 seeds m<sup>-2</sup> in 2007. The experiments consisted in testing different N rates (0N to 250N), split between seeding and side-dressing (6-leaf stage). Shoot biomass was measured in these fields between emergence and maximum LAI. Final biomass (manual harvest) and grain yield (harvested with a combine) were also quantified. Climate data were obtained from an automatic weather station at the experimental farm of Agriculture and Agri-Food Canada of L'Acadie (near St-Jean).

At CFIA and the adjacent Greenbelt experimental farms, which include 16 km<sup>2</sup> of agricultural land, the dominant soil texture ranged from loam to clay loam. The same range of soil textures is found at the Central experimental farm. Key field management practices are indicated in Table 1. Corn was usually planted the third week of May. Seeding density ranged between 6.5 and 8.0 plants m<sup>-2</sup>. The N fertilization rate varied between 0N and 200N (the N rate recommendations in Ontario was 140 kg N ha<sup>-1</sup> for an expected grain yield of 8 t ha<sup>-1</sup>; OMAFRA 2002). Shoot biomass was measured 5-11 times during the growing season. Final shoot biomass (manual harvest) and yield (using a combine) were also measured. The weather stations were located either in or near the studied fields.

### **Main features of the STICS crop model**

The soil crop model STICS is a dynamic model that simulates C, N and water cycles. It is a one-dimensional model requiring daily climatic data, which takes into account soil properties and management practices (Brisson et al., 2003). The crop phenology is a function of growing degree-days, using 8°C as base temperature for corn. The potential accumulation of crop biomass is a linear relationship of the intercepted photosynthetically active solar radiation. The actual

crop growth rate takes into account the atmosphere CO<sub>2</sub> concentration, water and N stresses. The water stress integrates water requirements of the soil-leaf system and the simulated soil water content available for the crop root system. The N stress integrates the N nutrition requirements and the simulated soil mineral N content available for the root system. The critical N concentration curve within aerial biomass is used to indicate the minimum N content required to achieve the maximum growth rate. The critical N curve of corn was determined in France by Plenet and Lemaire, (2000) and confirmed for Canada by Ziadi et al., (2008)

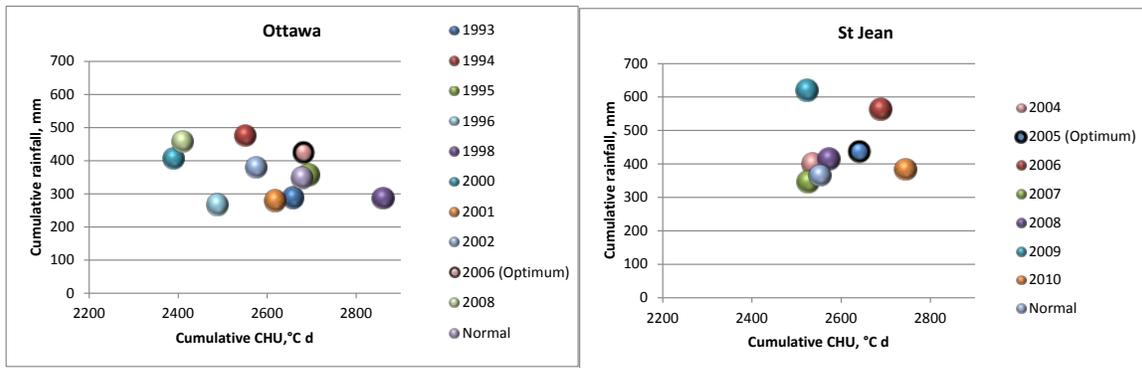
The input soil property data required to run the model are the organic N, clay, and carbonate content in the ploughed layer. Field capacity, wilting point and bulk density are required for all simulated soil layers. The following climatic data are also required: daily minimum and maximum temperature, solar radiation, rainfall, wind speed and relative humidity. The model inputs for crop management are the seeding date, depth and density, the rate and date of mineral and organic fertilization, the amount and date of irrigation, and the date and depth of soil tillage, including the description of crop residues and organic products returned to the soil.

### **Implementation, verification and simulation of scenarios using STICS**

The following functions and parameters were different from the ones used in Jégo et al., (2011): nitrification and denitrification were activated, mineralization was adjusted using clay content, soil evaporation was adjusted to a measured evaporation, macroporosity was activated to take into account a more optimal denitrification. Once these ameliorations were verified, the model performance was assessed according to the following statistical criteria: the Root Mean Square Error (RMSE), and the Mean Error (ME). The RMSE indicates the error of prediction of the model by giving more weight to high errors. A low value of RMSE, expressed in % of the measurements average, means a good prediction ability of the model. The ME gives an estimation of the bias of the model, expressed in % of the measurements average. The simulation is supposed to be excellent when  $RMSE \leq 10\%$ , good if the RMSE is between 10% to 20%, fair if the RMSE is between 20% and 30%, and poor if  $RMSE > 30\%$  (Jamieson et al. 1991).

Scenario simulations were carried out to evaluate the prediction reliability of crop biomass and N balance in response to either management or climate inputs. These scenarios consisted in using 5 N rates (0, 50, 100, 150, 200 and 250 N) applied in Ottawa site on 28 years (1981-2009) using actual climatic data. Different growth stages were analyzed: top dressing, end of vegetative phase and maturity. Analysis of multiple regressions were implemented with the Statistica software (Hill and Lewicki, 2007) to evaluate the influence of climate variations on corn grain yield, plant N, biomass, denitrification and N storage at harvest representing the potential N leaching during the following fall in response to increasing N application rates.

## **RESULTS AND DISCUSSION**



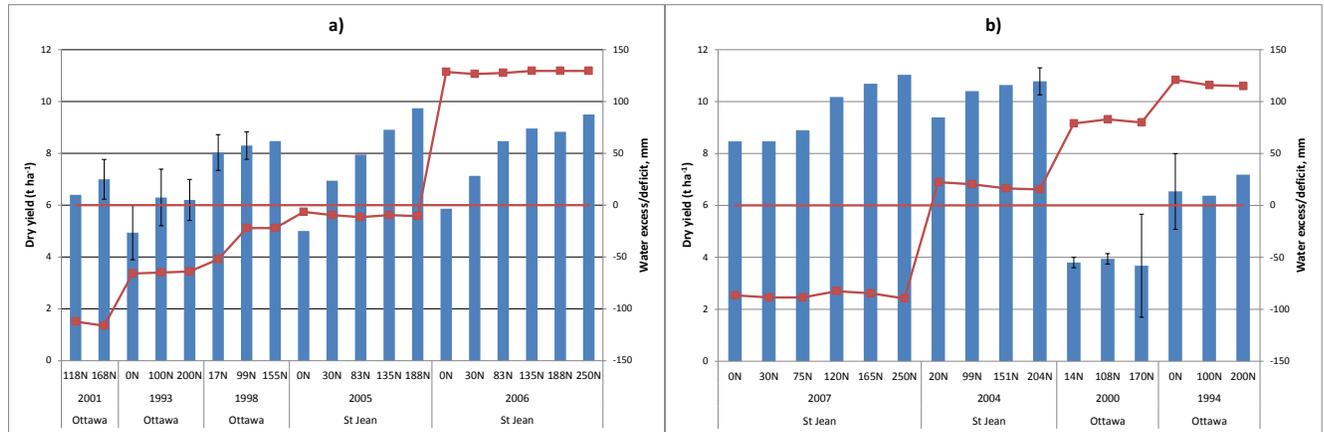
**Fig. 1: Cumulative rainfall (mm) as a function of CHU during the corn growing season of each experiment compared to the normal**

The cumulative rainfall over the growing season as a function of cumulative CHU is presented in Fig. 1 for each year at Ottawa and St Jean. The cumulative precipitation From April to August, ranged from 268 to 477 mm in Ottawa and from 347 to 621 mm in St Jean. Results showed that most of the rainfall data were close or above the normal during the growing season. The first month, drier rainfall conditions than the normal years were observed in 1996, 1998 and 2008 in Ottawa and in 2004, 2005, 2007 and 2010 in St Jean (data not shown).

For high N application rates, measured and predicted biomass at the end of the vegetative stage were up to  $10 \text{ t ha}^{-1}$  while N in plant was  $>130 \text{ kg N ha}^{-1}$  (average of  $6 \text{ t ha}^{-1}$  and  $95 \text{ kg N ha}^{-1}$ ; data not shown). At St Jean, biomass was higher when the rainfall was close to the normal early in season. At the end of the vegetative stage, increasing N application rates generated a non-linear increase of grain N concentration until a certain level at which the application of more N did not increase biomass nor yield. Plant N results had the same trend.

For season having  $\text{CHU} < 2600 \text{ }^{\circ}\text{C}$  and water in excess, observed yield increased with N rates up to the recommended rate and then plateaued. For season showing no deficit and no excess of water, the increase in N application rates had a strong effect. Finally for season having water deficit, increasing N rates led to a constant yield (Fig. 2). For season having  $\text{CHU} > 2600 \text{ }^{\circ}\text{C}$ , yields remained steady in response to N rates under very wet conditions, while it slightly increased with higher N rates under non-limited water and dry conditions.

Belanger et al. (2011) showed that grain yield, grain protein concentration and straw N content of plant increased significantly with N application rates in St Jean area. Ziadi et al. (2008) showed that N nutrition index (NNI) and leaf N concentrations increased with increasing N rates in St Jean area, Cabas et al. (2010) estimated that climate variability has a major impact on average yield in eastern Canada. Pattey et al. (2001) showed that biomass and yield were similar in two fields receiving recommended (155N) and suboptimal (99N) N rates when water deficit occurred. The experimental results showed that the interaction of both early season rainfall and N application rates influenced grain yield (Fig. 2), plant N and biomass of corn (data not shown).



**Fig. 2: Yield (blue bars) sorted as a function of water deficit and excess (red curve) at St Jean and Ottawa sites for cumulative CHU a) <2600°C d and b) >2600°C d. The deficit/ excess of water is expressed as (Rainfall – ETR) over the growing season. Only experiments having several N application rates are illustrated.**

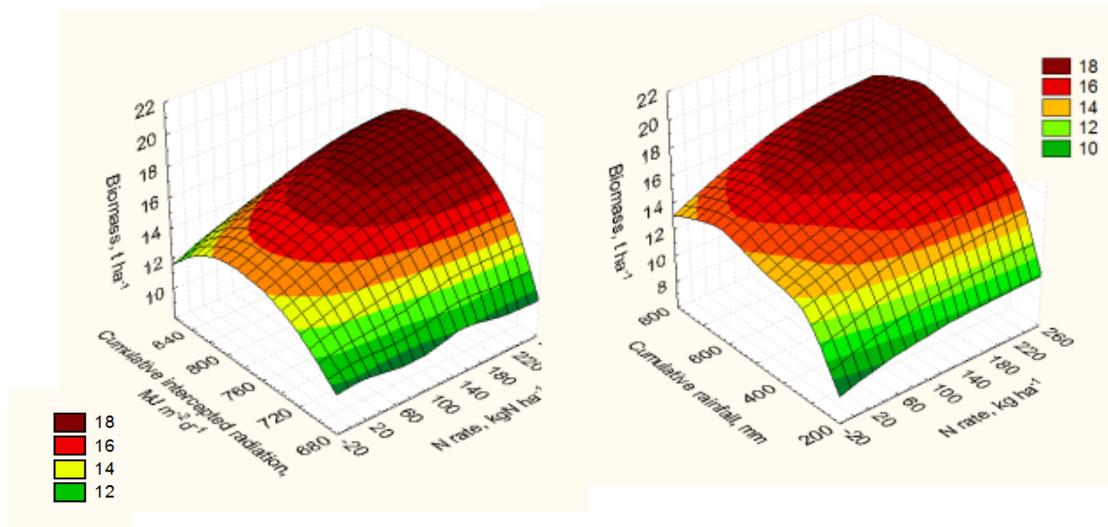
**Table 1: Performance of the model predictions of shoot biomass and nitrogen in plants at two different sites in Eastern Canada (Ottawa and St Jean sites) for entire growing seasons over the 1993-2010 period. Performance is evaluated by site and N rates. Results are sorted according rainfall amount early in season and N rate application.**

	ME		RMSE (%)	
	quantity	%	quantity	%
<b>By rainfall amount</b>				
<u>rainfall deficit</u>				
biomass	0.4	17.8	1.4	26.2
N in plants	-0.6	-26.4	1.0	44.9
<u>rainfall excess</u>				
biomass	0.9	25.6	1.6	43.6
N in plants	-0.3	-12.4	0.9	42.4
<u>close to normal</u>				
biomass	0.7	9.7	1.36	19.8
N in plants	0.0	0.6	0.3	23.0
<b>By N rate</b>				
biomass 0 -100N	0.7	17.8	1.6	41.9
biomass 100-140N	0.2	3.2	1.2	15.7
biomass 140-250N	0.5	11.0	1.3	28.9
N in plants 0 -100N	-0.3	-15.2	0.8	42.4
N in plants 100-140N	-0.6	-23.5	1.0	42.1
N in plants 140-250N	-0.5	-20.2	1.0	42.4

Shoot biomass and plant N predictions were good, especially when rainfall was close to the normal and when the N rate applied was close to the

recommendations ( $ARE < 10\%$ ,  $RMSE < 20\%$ ). When rain deficit or excess occurred, results showed that biomass tended to be overestimated while N in plant was underestimated (Table 1). The capacity of the STICS soil–crop model to simulate or predict grain yield and grain N concentration over a large range of growing conditions was fair. Simulations could be improved by activating the macroporosity in the model, which would permit soil moisture content to exceed field capacity. This would affect the amount of denitrified nitrogen, which has an impact on the estimation of plant N. Moreover, the root sensibility to anoxia and to soil drought could be tested in order to improve simulations in dry and wet conditions. Guillaume and al. (2012) conducted an agronomic analysis to evaluate the capacity of the STICS crop–soil model to simulate varying fertilization strategies and found RMSE values for grain yield of 14% for the optimized database and 20% for the evaluation database. These results are comparable to RMSE values reported by Brisson et al. (2003) for wheat and corn crops (15–20%).

Scenarios of simulations consisting in using 5 N rates (0, 50, 100, 150, 200 and 250 N) at Ottawa site during 28 climatic years (1981–2009) showed that biomass response to N rates was mainly a function of cumulative rainfall and intercepted photosynthetically active radiation (Fig. 3). The latter depends on climate and crop management, affecting canopy evolution. The multiple regression analyses were carried out only on the driving variables. Results showed that 53% of the yield was explained by the N application rates (22%), cumulative rainfall (25%) and global radiation (6%) whereas 76% of plant N variations was explained by the same variables in different proportions (N rates: 63%, cumulative rainfall: 11%, global radiation: 2%). On one hand, over the 28 year-period, even if the additive effect of N rate application and cumulative rainfall was obvious, there was no significant interaction between these two driving factors. On the other hand, in the explanation of yield, biomass and plant N variations, several growth periods needed to be considered: rainfall acted in a negative way before the stem elongation, which means that application of nitrogen should be more efficient when the rainfall positively influence yields, after stem elongation. In the same way, we could explain 76 % of the denitrification N and 55% of the soil mineral content, which represents the potential N leaching during the following fall, mainly affected by N rate application (respectively 67 and 33% of the variance).



**Fig. 3: Simulated biomass during 28 years at the Ottawa site as a function of cumulative rainfall and cumulative photosynthetically active intercepted radiation.**

## CONCLUSION

Under rainfall excess conditions, yield had very limited response to N rates, especially for high N rates. In absence of rainfall deficit or excess,, increasing N application rates generated a non-linear increase of yield and grain N concentrations up to 140-180N. Under rainfall deficit, when seasonal CHU was low, the yield remained constant while when seasonal CHU was high, yield tended to increase. Results showed the reliability of STICS predictions for crop biomass and N content. Shoot biomass predictions were better with rainfall close to the normal or when level of N rate was close to the recommended rate. Scenarios results seem to be consistent with our hypothesis in which we stated that both amount of N fertilizer applications and rainfall variation have an influence on potential biomass and N in plants: rainfall has a stronger effect on yield and biomass whereas nitrogen application impacted more the plant N. Between one half and 76% of the inter-annual variance of the crop yield, biomass and plant N can be explained by a simple multiple regression analysis according to the driving factors. The remaining unexplained part of the variance stems interactions occurring between these driving factors. These interactions cannot easily explicated by a statistical model while the mechanistic dynamic STICS model can mimic them and could be useful for implementing more precise crop management.

## ACKNOWLEDGMENTS

The authors would like to thank the research technicians and professionals (Ottawa: Doug Balchin, Vivianne Deslauriers, Dave Dow, Lynne Evenson,

Christophe Forget, and St Jean: Edith Fallon) and students that participated in the field experimentation and data processing. This work was funded by Agriculture and Agri-Food Canada A-base and SAGES initiative on “Understanding and predicting nitrogen dynamics in Canadian cropping systems to improve efficiency of nitrogen utilization and reduce environmental losses”. We also thank OECD co-operative research programme for funding the fellowship of Dr. Nicolas Beaudoin.

## REFERENCES

- Adams, R.M., R.A. Fleming, C.C. Chang, B.A. McCarl, and C. Rosenzweig. ...1995. A reassessment of the economic effects of global climate change on ...U.S. agriculture. *Climatic Change* 30:147-167.
- Berenguer, P., F. Santiveri, J. Boixadera, and J. Lloveras. 2008. Fertilisation of ...irrigated maize with pig slurry combined with mineral nitrogen. *European ...Journal of Agronomy* 28:635–645.
- Bélangier, G., A. Claessens, and N. Ziadi. 2011. Grain N and P relationships in ...maize. *Field Crops Research* 126(3):1-7.
- Brisson, N., C. Gary, E. Justes, R. Roche, B. Mary, D. Ripoche, D. Zimmer, J. ...Sierra, P. Bertuzzi, P. Burger, F. Bussiere, Y.M. Cabidoche, P. Cellier, P. ...Debaeke, J.P. Gaudillère, C. Hénault, F. Maraux, B. Seguin, and H. ...Sinoquet. 2003. An overview of the crop model STICS. *European Journal of Agronomy* 18:309-332.
- Bryant, C.R., B. Smit, M. Brklacich, T.R. Johnston, J. Smithers, Q. Chiotti, and B. ...Singh. 2000. Adaptation in Canadian agriculture to climatic variability and ...change. *Climatic Change* 45:181-201.
- Cabas, J, A. Weersink, E. Olale. 2010. Crop yield response to economic, site and ...climatic variables. *Climatic Change* 101:599–616.
- Ciampitti, I.A. and T.J. Vyn. 2012. Physiological perspectives of changes over ...time in maize yield dependency on nitrogen uptake and associated nitrogen ...efficiencies: A review. *Field Crops Research* 133:48–67.
- Camberato J., R.L. Nielsen , E. Miller and B. Joern. 2012. Nitrogen Management ...Guidelines for Indiana. Purdue University Department of Agronomy. ...<http://www.agry.purdue.edu/Ext/corn/news/timeless/nitrogenmgmt.pdf>. ...Applied Crop ResearchUpdate 8 p.
- Drury, C.F., and C.S. Ta. 1995. Long-term (35 years) effects of fertilization, ...rotation and weather on corn yields. *Canadian Journal of Plant Science* ...75:355–362.

- Guillaume, S., J.E. Bergez, D. Wallach, and E. Justes. 2011. Methodological ...comparison of calibration procedures for durum wheat parameters in the ...STICS model. *European Journal of Agronomy* 35(3):115- 126.
- Hill, T., and P. Lewicki. 2007. *STATISTICS Methods and Applications*. Tulsa, ...OK: StatSoft. WEB: <http://www.statsoft.com/textbook/>
- Izaurrealde, R.C., J.R. Williams, W.B. McGill, N.J. Rosenberg, and M.C. Jakas. ...2006. Simulating soil C dynamics with EPIC: model description and testing ...against long-term data. *Ecological Modelling* 192:362–384.
- Jamieson P.D., J.R. Porter, and D.R.Wilson. 1991. A test of the computer ...simulation model ARCWHEAT1 on wheat crops grown in New Zealand. ...*Field Crops Research* 27:337–350.
- Jégo, G., E. Pattey, G. Bourgeois, C.F. Drury, and N., Tremblay. 2011. Evaluation ...of the STICS crop growth model with maize cultivar parameters calibrated ...for Eastern Canada. *Agronomy for Sustainable Development* 31(3):557-570.
- Ma L, R.W. Malone, P. Heilman, D.L. Karlen, R.S. Kanwar, C.A. Cambardella, ...S.A. Saseendra, and L.R. Ahuja. 2007. RZWQM simulation of long-term ...crop production, water and nitrogen balances in Northeast Iowa. *Geoderma* ...140:247–259.
- Montemurro, F., M. Maiorana, D. Ferri, and G. Convertini. 2006. Nitrogen ...indicators, uptake and utilization efficiency in a maize and barley rotation ...cropped at different levels and sources of N fertilization. *Field Crops* ...*Research* 99:114-124.
- Ontario Ministry of Agriculture, Food and Rural Affairs, 2002. *Agronomy guide* ...for field crops, Publ. 811, OMAFRA, Ottawa, ON.
- Pattey, E., I.B. Strachan, J.B. Boisvert, R.L. Desjardins, and N.B. McLaughlin. ...2001. Detecting effects of nitrogen rate and weather on corn growth using ...micrometeorological and hyperspectral reflectance measurements. *Agricultural* ...and *Forest Meteorology* 108 (2):85-99.
- Plénet, D., and G. Lemaire. 2000. Relationships between dynamics of nitrogen ...uptake and dry matter accumulation in maize crops. Determination of critical ...N concentration. *Plant Soil* 216:65–82.
- Tan, C.S., and W.D. Reynolds. 2003. Impacts of recent climate trends on ...agriculture in southwestern Ontario. *Canadian Water Resources Journal* ...28:87–97.
- Varella H., M. Guerif, S. Buis, and N. Beaudoin. 2010. Soil properties estimation ...by inversion of a crop model and observations on crops improves the

...prediction of agro-environmental variables. *European Journal of Agronomy*  
...33(2):139-147.

Wani, S P, J. Rockstrom, and T. Oweis. 2009. Rainfed agriculture: unlocking the  
...potential. Wallingford, UK: CABI; Patancheru, Andhra Pradesh, India:  
...International Crops Research Institute for the Semi-Arid Tropics (ICRISAT);  
...Colombo, Sri Lanka: International Water Management Institute (IWMI) 310p.  
... (Comprehensive Assessment of Water Management in Agriculture Series 7).

Ziadi, N., M. Brassard, G. Bélanger, A.N. Cambouris, N. Tremblay, M.C. Nolin,  
...A. Claessens, and L.E. Parent. 2008. Critical nitrogen curve and nitrogen  
nutrition index ...for corn in eastern Canada. *Agronomy Journal* 100(2): 71-276.