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# The simulation of energy, water vapor and carbon dioxide fluxes over common crops by the Canadian Land Surface Scheme (CLASS)

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**Abstract**

The performance of the Canadian Land Surface Scheme (CLASS) was evaluated against observed eddy covariance flux data from four commonly cultivated crops growing in different climatic conditions. Of the four crops examined, wheat and soybean are $C_3$ plants, whereas maize and millet are $C_4$ plants. Physiological modules to simulate photosynthesis, respiration and growth for $C_4$ plants were added to CLASS. Apart from maximum photosynthesis capacity, and root and soil respiration rates at reference temperatures, most model parameters were kept constant for each crop. The diurnal and seasonal cycles of simulated energy, water vapor and carbon dioxide fluxes were similar to the measurements made during the growing seasons for each of the four crops. Simulated values of canopy conductance were in agreement with observations. The model was able to explain 84, 76, 84 and 58% of the variance in the half-hourly net ecosystem productivity values for the maize, soybean, wheat and millet crops, respectively. Similarly, 77, 76, 77 and 78% of the variance in observed half-hourly evaporative fluxes was accounted for by the model for the maize, soybean, wheat and millet crops, respectively. We conclude that despite the process-based physics of the model, it is still critical to correctly specify detailed model parameters such as maximum carboxylation rate $V_{\mathrm{cmax}}$, plant and soil carbon pools and temperature sensitivity coefficients to obtain close agreement between simulated and observed fluxes. Increasing the complexity of the model physics further necessitates the accurate specification of additional model parameters depending on the intended use of the model. The enhanced version of CLASS when coupled to Canadian global and regional climate models or when used as a stand-alone component can potentially be a valuable tool to evaluate the impact of climate change on the growth and health of terrestrial ecosystems.

*Keywords:* Crops; Photosynthesis; Net ecosystem productivity; Evapotranspiration; Canadian Land Surface Scheme; Eddy covariance fluxes

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## 1. Introduction

The global climate change debate has increased the focus on the role of the terrestrial land surface as a potential sink of atmospheric carbon dioxide ($CO_2$). General Circulation Models (GCMs) are used to enhance our understanding of the cycling of carbon through the biosphere and its effects on climate and vegetation. Most GCMs treat atmospheric $CO_2$ concentration as a prescribed variable, however newer versions such as those being examined in the Coupled Carbon Cycle Model Inter-Comparison Project (C4MIP) simulate atmospheric $CO_2$ concentration as

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a prognostic variable. The land surface scheme is the key component of GCMs (Pitman, 2003). It controls the exchange and storage of energy and moisture between the land surface and the atmosphere. The Canadian Land Surface Scheme (CLASS) (Verseghy, 2000) is one of several such schemes and is the operational soil-vegetation atmosphere-transfer (SVAT) package of the Canadian Global Climate Model (Flato et al., 2000).

As has been the case with all SVAT models, CLASS was developed and tested as a stand-alone model, prior to its coupling to a climate model. To date, CLASS has been successfully tested for forests (Arain et al., 2002; Bartlett et al., 2000; Wu et al., 2000; Wang et al., 2001), Northern high-latitude vegetation (Lafleur et al., 2000; Bellisario et al., 2000) and wetlands (Comer et al., 2000; Munro et al., 2000). CLASS has also been rigorously evaluated and compared to other land surface schemes under various phases of the Project for the Inter-comparison of Land surface Parameterization Schemes (PILPS) (Henderson-Sellers et al., 1995) and the Fluxnet-Canada Research Network model inter-comparison study (Grant et al., in press-a,b). Most of the biomes for which CLASS has been tested occur naturally and occupy large areas of the Earth's surface such as forests, grasslands and wetlands. However, as the resolution of climate models increase, it will be necessary to represent those biomes that are managed and exist at finer spatial scales, such as croplands. In the near future, land-use changes will play a significant role in atmospheric $CO_2$ exchanges (Houghton et al., 1999). Agricultural crops are a recognized sink for $CO_2$ in the 20th century because they are capable of storing carbon in the soil through improved management practices (Caspersen et al., 2000; Cox et al., 2000). Recent studies, such as the Inter-governmental Panel on Climate Change (IPCC) report, suggest that with an increasing human population a larger area of the land surface will be placed under agriculture.

In general, there has been limited testing of land surface schemes for crops. To our knowledge, the only application of CLASS to crops was conducted by Bailey et al. (2000) and Arora (2003). The duration of the Bailey et al. (2000) study was restricted to 10 days of soybean data and did not include an analysis of net ecosystem productivity (NEP). The focus of the Arora (2003) study was to determine the effectiveness of the single-leaf or two-leaf parameterization over wheat. Furthermore, both these crops utilize the $C_3$ photosynthesis pathway (phosphoglyceric acid having three carbon atoms), and crops with $C_4$ pathways (oxaloacetic acid having four carbon atoms, e.g. maize and millet) were not tested. $C_4$ species may have high $CO_2$ fixation rates under high light, warm temperature and low nutrient environments.

Arain et al. (2002) initially incorporated photosynthesis and respiration algorithms for $C_3$ plants in CLASS. This version of the model is hereafter referred to as C-CLASS. The objectives of this study are: (i) to incorporate algorithms for $C_4$ photosynthesis in C-CLASS; (ii) to validate mechanistic photosynthesis and autotrophic and heterotrophic respiration algorithms of C-CLASS using observed eddy covariance flux data for both $C_3$ and $C_4$ crops growing in different environments; (iii) to determine the range of sensitivity of ecophysiological parameters used to simulate energy, water vapor and $CO_2$ fluxes for common crops.

## 2. Methods

### 2.1. Model description

C-CLASS is a physically based land surface model that simulates energy, water and carbon fluxes from a canopy (Arain et al., 2002; Verseghy, 1991; Verseghy et al., 1993). The model treats the land surface as a composite of four primary features: soil, snow, vegetation and snow covered soil or vegetation. Soil processes are modelled for three layers with a thickness of 0.10, 0.25 and 3.75 m, respectively. The layer temperatures and moisture contents are treated as prognostic variables. The vegetation properties are determined as a composite of four vegetation types: coniferous trees, deciduous trees, grass and crops. If more than one vegetation cover is present, the canopy is treated as composite canopy using weighted averages of surface parameters. While this method is optimal for most off-line simulations, Best et al. (2004) have shown that weighting fluxes is a better method than combining parameters. Roughness length, rooting depth, leaf area index (LAI) and other structural properties of the four vegetation types that vary over seasonal time scales are constrained by a specified range in the model.

In C-CLASS, the single "big-leaf" of the original CLASS is replaced by the "two-leaf" (sunlit and shaded) model of Wang and Leuning (1998), which is based on the multi-layer photosynthesis model of Leuning et al. (1995) that evolved from Farquhar et al. (1980). Fractions of sunlit and shaded leaves are calculated using an extinction coefficient for solar radiation penetrating the canopy. Arora (2003) compared the "single-leaf" versus "two-leaf" formulations of canopy conductance and found the energy fluxes simulated by the latter agreed more closely with observations from a wheat crop. The maximum