Assessment of effective LAI & Water Use Efficiency in Maize & Alfalfa, using leaf- scale C3C4PM photosynthesis model & Eddy Covariance tower data

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I. Introduction

- Globally, about 11% (1.5 billion ha) of terrestrial land use is attributed to crop production.
- Corn (*Zea. mays)*, a C4-plant, and alfalfa (*Medicago sativa*), a C3-plant, are common crops globally. Predicting the response of their water use efficiency, WUE, to changing hydrologic and climatic conditions is vital.
- In C3-plants, the absorbed CO2 is photosynthesized in one chamber (Mesophyll) inside the leaf, whereas in C4-plants CO2 is photosynthesized in two connected chambers (Mesophyll and Bundle Sheath) inside the leaf.
- Many studies have quantified the photosynthesis process of both C3 and C4 crops at leaf- scale, but none have quantified the photosynthesis process at canopy scale and by considering the effective leaf area index and stomatal resistance.

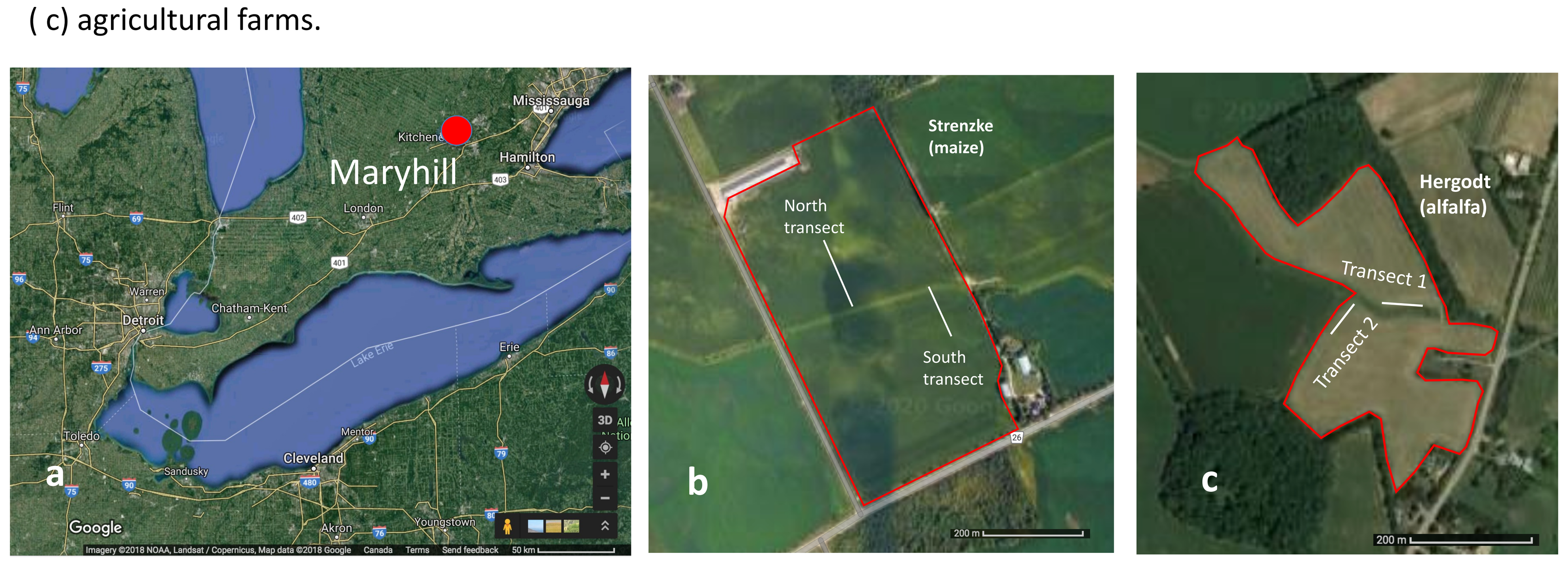
2. Objectives

In this study, we develop a theoretically-based photosynthesis C3-C4 model, (C3C4PM) with climate variables as input, and estimate effective leaf area index and stomatal conductance, as well as carbon assimilation and transpiration, at the canopy scale for corn and alfalfa.

3. Study Site & Methods

To develop the model we used 2018 observations from two farm fields located in Hopewell Creek Watershed near Maryhill, Ontario (Figure 1a), Canada. The maize (43.525° N, 80.425° W) and alfalfa (43.549° N, 80.381° W) agricultural fields were 4.4 km apart from each other and at an elevation of ~330m. The 30-year-mean (1981-2010) growing season (Jun to September) temperature for this area ranges from 13 to 20 °C. Both sites were partially or totally systematically drained by tile drain network. Maize was planted in rows with 80 cm spacing in early May. Alfalfa was seeded in 2016 and harvested four times during the 2018 growing season from June to September. Locations of the transects for stomatal conductance and LAI measurements are shown in Figures 1 b and c.

Figure 1: Study sites near Maryhill, Ontario (a); close –up view of the site boundaries of the maize (b) and alfalfa (c) agricultural farms.



4. The Model

C3-C4 photosynthesis model (C3C4PM) was able to simulate the photosynthesis in both C3 and C4 crops by considering the reaction and CO2 concentration in both Mesophyll and Bundle sheath.

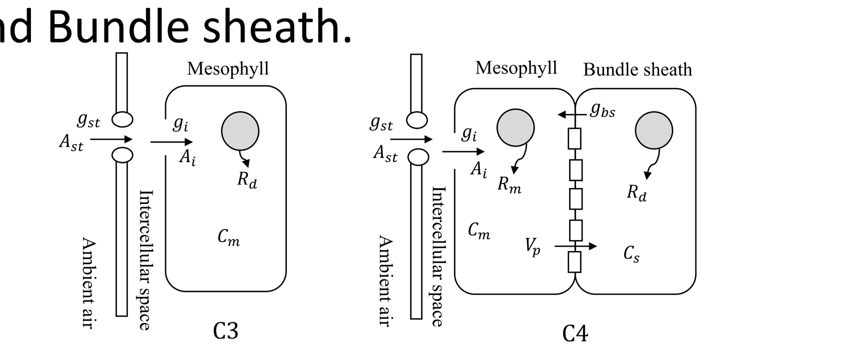


Figure 2: Schematic drawing of C3 and C4 leaf-scale photosynthesis with one and two chambers, respectively.

CO2 and H2O fluxes were determined based on the photosynthesis process and diffusion equation for the stomatal opening. By matching the photosynthesis curve (eLAI, Figure 3) and stomatal opening curve (ESCC, Figure 3), the equilibrium condition between the stomatal opening and photosynthesis rate was achieved.

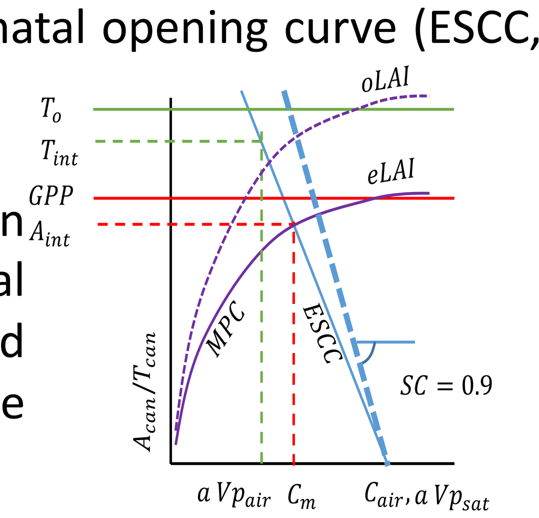


Figure 3: ESCC line relates transpirations (T , H_2o flux, y-axis) to air vapor pressure (aVpair, x-axis) and its slope controls by stomatal conductance. eLAI curve relates Assimilation rate (GPP, CO_2 flux, y-axis) to air and mesophyll CO_2 concentrations and shows the photosynthesis rate and its height controls by eLAI.

By changing iteratively the stomatal opening (T-loop, Figure 4) and canopy scale photosynthesis rate (eLAI –loop), the equilibrium point, where the observed and simulated fluxes are equal , was determined.

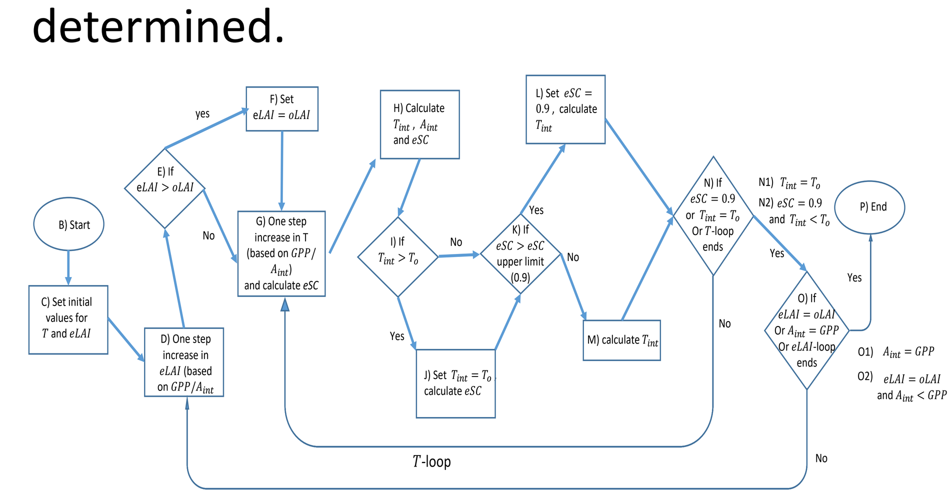


Figure 4: Flowchart of C3C4PM iteration steps. eLAI and stomatal opening (or transpiration rate , T) changes iteratively in eLAI-loop and T-loop to match the CO2 and H2O fluxes.

4. Results

Observed stomatal conductance was in good agreement with simulated stomatal conductance at leaf scale (Figure 5).

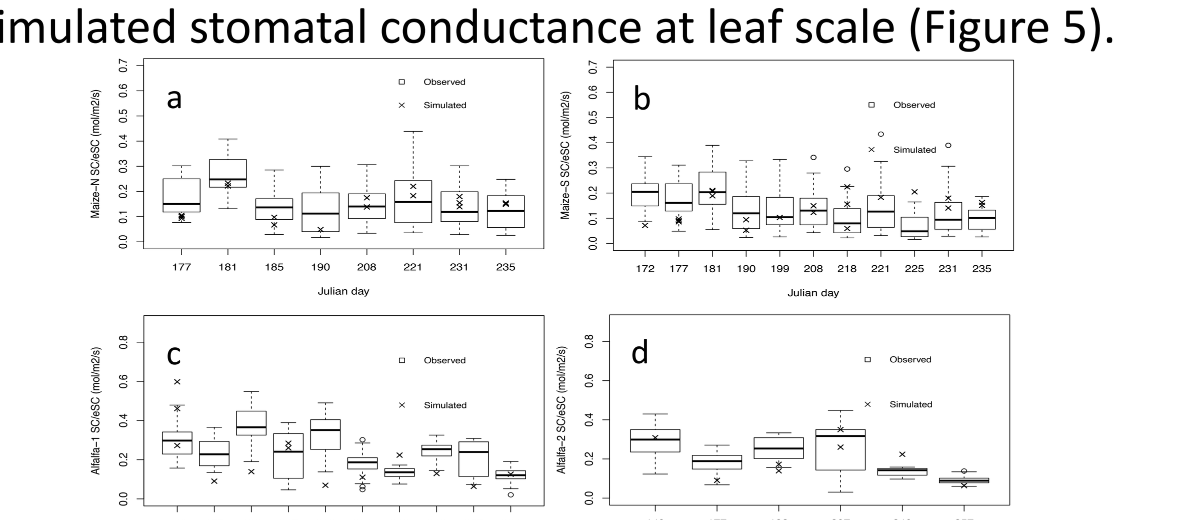


Figure 5: Simulated (boxplots) and observed (symbols) stomatal conductance in Maize's transects N (a) and S (b) and Alfalfa's transects 1 (c) and 2 (d).

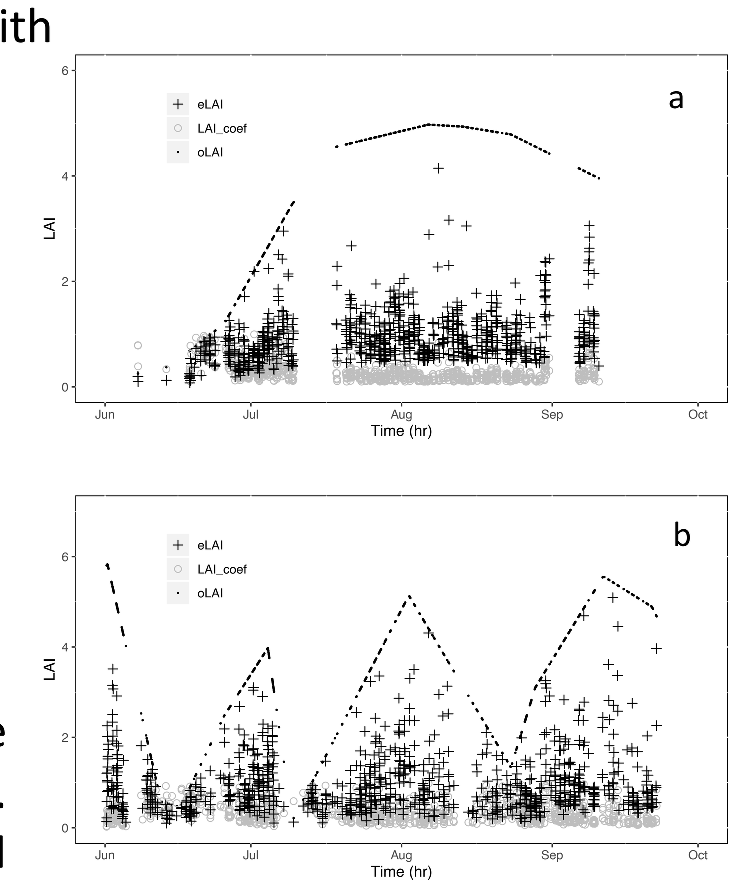


Figure 6: Time series of observed LAI (oLAI, interpolated in time), simulated effective LAI (eLAI) and the ratio between them, eLAI/oLAI (LAI_coef), for maize (a) and alfalfa (b).

Time series of observed LAI (oLAI) showed four separate peaks for Alfalfa because of three harvests (Figure 6). Effective LAI (eLAI) fluctuations followed those of oLAI (Figure 6). The ratio between eLAI /oLAI (LAI_coef) was around 25% and 32% for maize and alfalfa, respectively.

Temporal patterns of observed and simulated equivalent stomatal opening eSC (i.e. stomatal opening between the Mesophyll and ambient air, considering the intercellular space) were also in agreement (Figure 7). The simulated eSCs were based on the Eddy Covariance Tower measurements and represented those for the canopy, while the observed eSCs were based on observations from selected leaves within the canopy . Therefore, we did not expect an exact match between them.

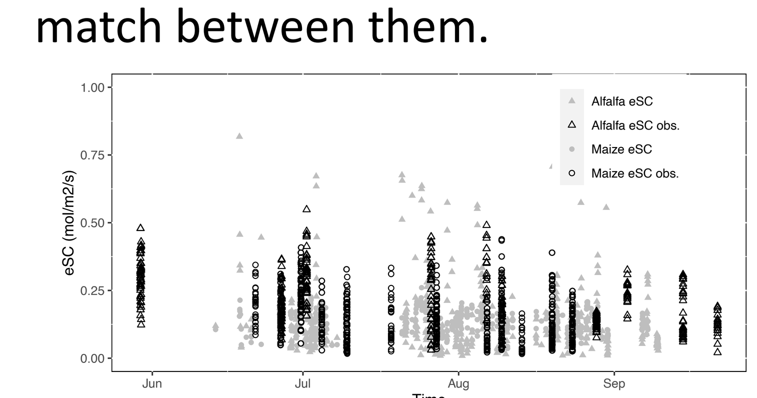


Figure 7: Time series of simulated equivalent stomatal conductance (*eSC*) and observed stomatal conductance.

As expected, there were diurnal variations in eLAI. Since the eLAI depends on how much solar radiation penetrates the crop's canopy, we expected maximum eLAI values around noon when the sun is almost vertically.

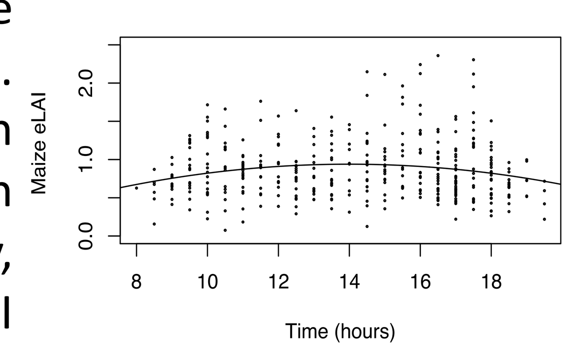


Figure 8: Daily variation of effective LAI (eLAI) for maize.

5. Discussion & Conclusions

~25 (maize) & 32% (alfalfa) of the observed crop LAI was involved in photosynthesis

- Extinction coefficient for beam radiation was 1.08 (maize) and 0.84 (alfalfa)
- Canopy stomatal conductance, CSC, was ~0.13 (maize) and ~0.15 (alfalfa)
- Effective LAI and canopy CSC can be evaluated by Eddy Covariance records

We found that WUEs were in the range of 8-9 mmol/mol. C3C4PM can be used in predictions of in these crops and other C3 and C4 crops under future climate scenarios and can assist land stewards in the management of these crops.

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