Caroline Schulte
Professor Waller
BE 523
February 28, 2020

# Project Report 1

**Problem Description**

For this project, my group and I are focusing on creating organic photovoltaic greenhouse solar models as well as biological models of tomato and lettuce crop growth. Ideally, the information derived from the OPV models - solar model and shading model - will be used in the crop growth models to predict cultivation outputs for tomato and lettuce crops. For my specific section, I will be modeling tomato growth. The tomatoes being used are Rebelski - a variety of beef tomato. The two most important factors we are considering with regards to plant growth are temperature and light inputs. Both factors influence photosynthesis, which in turn affects plant yields.

The general equation for photosynthesis is $6H_2O + light + 6CO_2 -> C_6H_{12}O_2 + 6O_2$. Essentially, carbon dioxide and water in the presence of light is absorbed by plants to produce glucose and oxygen. Oxygen is created as a bi-product, but glucose is used by plants for growth and fruit bearing. Light received by plants is generally given in daily light integral (DLI). DLI is the total amount of photosynthetically active radiation (400-700nm) received per square meter per day. This range of light is important because it is the only light energy that plants respond to. For example, blue light (400-500nm) affects leaf growth, red light (600-700nm) affects flowering, far-red light (700-700nm) speeds up conversion of a red and far-red light photoreceptor allowing the plants to produce greater yields. Additionally, the chlorophyll within the plants can absorb PAR energy in order to create food. In general, plant growth rate per day is approximately linear to the DLI meaning plant growth increases with increasing average DLI received by plants. Therefore, knowing the DLI plants are receiving can be extremely helpful in predicting plant growth. Similarly, photosynthetic photon flux density (PPFD) is also helpful for predicting plant growth as it is a measure of the amount of photons falling on a particular surface each second. Ideally, tomatoes will receive a PPFD of 185 µmol/s*m$^2$.

With temperature, as it increases, photosynthesis, transpiration, and respiration rates increase. Consequently, growth rate tends to increase with a rise in temperature and decrease with a drop in temperature. However, once the temperature exceeds around 30 $^0$C, the rate of photosynthesis slows down because the enzymes involved in the chemical reactions are destroyed. Additionally, when temperatures are too high, the air is able to accommodate more water vapor. This leads to plants transpiring excessively, causing them to be stressed as they are unable to replace the amount of water lost. Tomatoes specifically thrive in temperatures of about 21$^0$C during the day and night temperatures between 60 and 64 $^0$C.

**Model Overview**

The model I will be making will be in Python; it will be derived from a simplified TOMGRO model as well as the original TOMGRO model. The TOMGRO model was made in 1991 as a means of modeling tomato growth and yield within a controlled environment. The inputs for the model were temperature, CO2, and photosynthetic photon flux (PPFD). The output of the model included 69 state variables (Jones, James...). On the contrary, the reduced TOMGRO model only has five variable outputs. My model will specifically focus on plant development through node number quantification and leaf area index (LAI) from the reduced model. I will also be modeling the number of fruits grown using the original model.

Node development rate is expressed using the equation $\frac{dN}{dt} = N_m * f_N(T)$ (see table one for definition of variables). This is given in number of nodes on the main stem developed per day. For $f_N(T)$, the equation assumes a single optimal temperature applying an increasing or decreasing factor (V0 = 0.25+0.25T and V1 = 2.5-0.05T) to simulate plant response to variations in air temperature (Bacci). In this equation, $N_m$ is estimated; for this project it is estimated to be 0.02083 nodes/day based on tomato phenology (Shamshiri, Redmond).

LAI is given as a function of time. The model equation is meant to express the leaf area developed ($m^2$[leaf]/$m^2$[ground]) per day. If LAI is less than or equal to LAI maximum, the model equation is $\frac{d(LAI)}{dt} = \rho * \delta * \lambda(T_d) * \frac{exp[\beta*(N-N_b)]}{1+exp[\beta*(N-N_b)]} * \frac{dN}{dt}$. Otherwise, $\frac{d(LAI)}{dt}$ = 0. In the LAI equation, $\beta$, $\delta$, and $N_b$ are all estimated values. Table two shows the possible range of values that these can be. For purposes of this model, $\lambda$ ($T_d$) is unnecessary because temperatures in the greenhouse will remain fairly constant meaning this will not have consequential effects on the leaf area expansion simulations (Shamshiri, Redmond).

To model number of fruit, the net rate of change of the number of fruit in a particular age class is given by the following equation $\frac{dN_F(i)}{dt} = r_F(T) * F(C) * n_F * N_F(i-1) - r_F(T) * F(C) * n_F * N_F(i) - P_F(i)$. This gives the number of fruit per meter squared per day. The variables can be found defined in table one below.

In order to create this model, I am breaking the process down into five parts. The first is establishing a model of the growth rate response to temperature using the node development rate equation. The equation assumes a maximum value of 30 $^0$C and zero values at -10 $^0$C and 50 $^0$C ; these values will be the graph's boundaries. Secondly, I will use this graph to create a user interface that allows a user to enter a temperature in order to receive an output of growth rate in terms of nodes/day. For LAI, using the temperature that was previously entered as well as the equation for LAI, a model of LAI as a function of days since transplanting will be shown. The user can then enter days since transplanting and receive output of an approximate LAI. The last part has to do with using the amount of fruit. The program will use the temperature value obtained and export a graph depicting the number of fruit as a function of time. Once again, a user can input the days since they planted crops in order to find out the average amount of fruit.

| Variable | Definition | Units |
|---|---|---|
| $\rho$ | Plant density | No. [plants] * $m^{-2}$[ground] |
| $\delta$ | Maximum leaf area expansion per node | $m^2$[leaf] * $node^{-1}$ |
| $\beta$ | $node^{-1}$ | Coefficient in expolinear equation (node) |
| $\lambda$ ($T_d$) | Temperature function to reduce rate of leaf area expansion | Unitless (0 to 1) |
| $f_N(T)$ | Function to modify node development rate as a function of hourly temperature<br><br>min(1,min(0.25+0.25T, 2.5-0.05T)) with T in degrees celsius | Unitless (0 to 1 function) |
| N | Number of nodes on mainstem | No. of nodes |
| $N_b$ | Coefficient in expolinear equation, projection of linear segment of LAI vs N to horizontal axis | node |
| $N_m$ | Maximum rate of node appearance (at optimal temp) | node * $d^{-1}$ |
| T | Hourly temperature | $^0$C |
| $r_F(T)$ | Rate of development of fruit at temperature T and 350 ppm CO2 concentration | 1/d |
| F(C) | Scaler function of CO2 concentration that modifies the rate of development for CO2 levels above or below 350 ppm | unitless |
| $n_F$ | Number of fruit age classes | No. fruit |

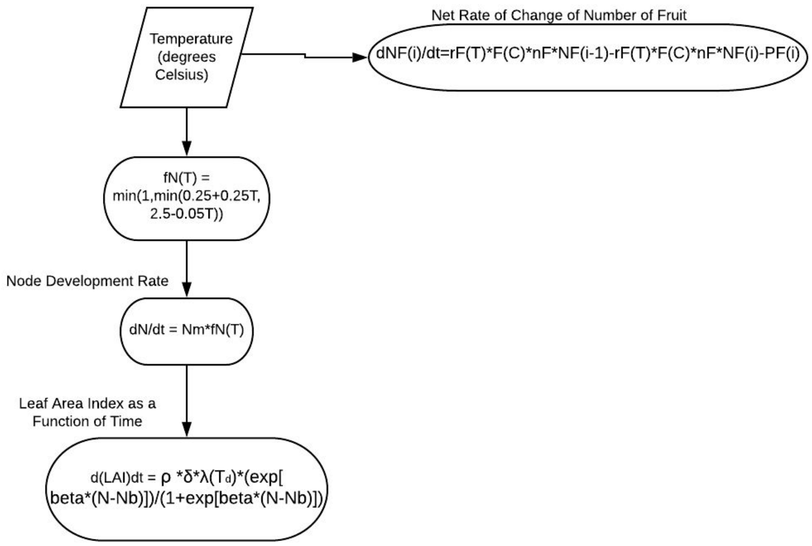
| | | |
|---|---|---|
| $N_F$ | Number of fruit/m^2 for age class i | fruit/$m^2$ |
| $P_F$ | Fruit loss caused by shading, insect damage, or diseases | No. fruit |

*Table 1: Defined variables used in model equations.*

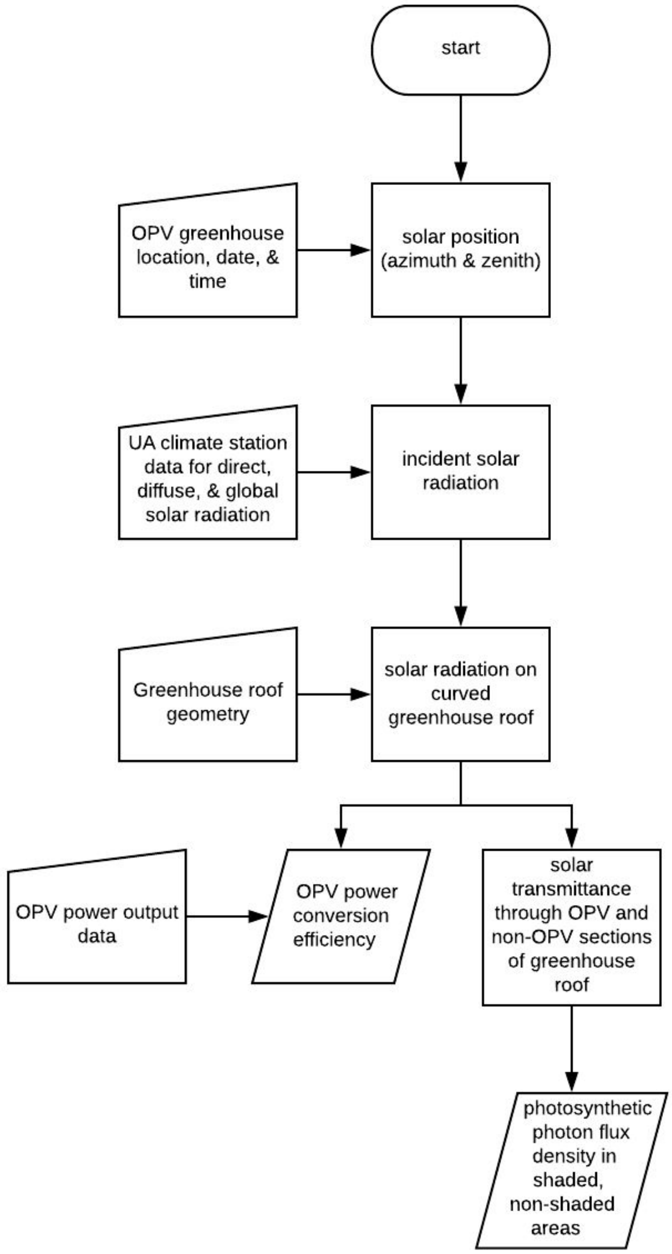
| Parameter | Description | Value | Range of Estimation | Values Reported by Other Authors |
|---|---|---|---|---|
| $N_b$ | Parameter in expolinear equation | 13* (16) | 8-25 | 16 |
| $\delta$ | Maximum leaf area expansion | 0.041* (0.038) | 0.01-0.1 | 0.030 |
| $\beta$ | Parameter in expolinear equation | 0.22* (0.169) | 0.06-0.5 | 0.169 |

*Table 2: Parameters estimated for reduced TOMGRO growth model (Ramirez*, Shamshiri, Redmond)*

**Model Flowchart**




## Group Flowchart




## References

Bacci L, Battista P, Rapi B. Evaluation and adaptation of TOMGRO model to italian tomato protected crops. *N Z J Crop Hortic Sci*. 2012;40(2):115-126. https://doi.org/10.1080/01140671.2011.623706. doi: 10.1080/01140671.2011.623706.

Jones, J. W., et al. “Reduced State-Variable Tomato Growth Model.” *Transactions of the ASAE*, vol. 42, no. 1, 1999, pp. 255–265., doi:10.13031/2013.13203.

Jones, James & Dayan, Engin & Allen, Leon & Keulen, & Challa, H.. (1991). A dynamic tomato growth and yield model (TOMGRO). Transaction ASAE 34 (1991) 2. - ISSN 0001-2351. 34. 10.13031/2013.31715.

Ramírez, A., et al. “Calibration And Validation Of Complex And Simplified Tomato Growth Models For Control Purposes In The Southeast Of Spain.” *Acta Horticulturae*, no. 654, 2004, pp. 147–154., doi:10.17660/actahortic.2004.654.15.

Shamshiri, Desa Ahmad, et al. “Evaluation of the Reduced State-Variable TOMGRO Model Using Boundary Data.” *2016 ASABE International Meeting*, 2016, doi:10.13031/aim.20162454205.

Shamshiri, Redmond R., et al. “Adaptive Management Framework for Evaluating and Adjusting Microclimate Parameters in Tropical Greenhouse Crop Production Systems.” *Plant Engineering*, 2017, doi:10.5772/intechopen.69972.