Mathematical Modeling to Increase the Crop per Drop for Dark Red Kidney Beans

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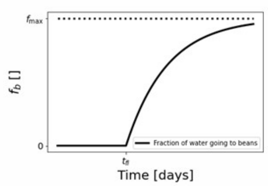
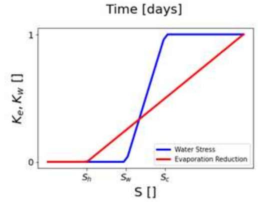
Abstract

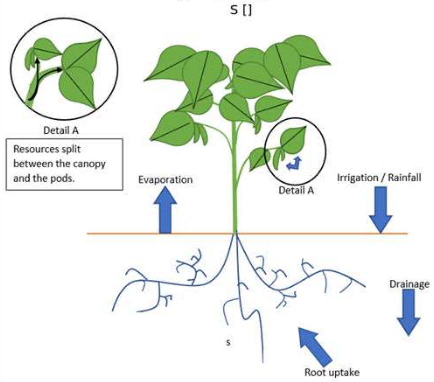
We developed a mathematical model consisting of three coupled differential equations tracking water in the soil, canopy, and total reproductive biomass throughout a kidney bean plant's life cycle. This model serves to predict the total yield of a plant given the irrigation levels as well as the characteristics of the plant and soil type. We then used numerical experiments to identify the irrigation levels that give the maximum kidney bean yield

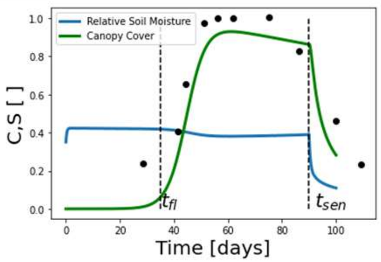
Introduction

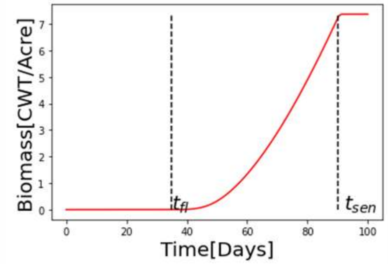
Current trends in farming are pressuring growers to generate higher crop yields with fewer resources. This pressure necessitates embracing precision agriculture, using data and science-based practices that are targeted at the micro-environments on the field level, to increase a grower's overall efficiency. Chippewa Valley Bean (CVB) is the world's largest processor of dark red kidney beans and works with growers all over Wisconsin and the Upper Midwest. Their agronomy team is looking to incorporate more precision agriculture to help their growers deliver higher yields of higher quality beans.











Relative Soil Moisture (S)

$$I = I_0 \cdot H(t - t_{sen}) \qquad E = (1 - C) \cdot K_{ev} \cdot ET_0 \cdot K_e(S, S_h)$$

$$T = C \cdot K_{cb} \cdot ET_0 \cdot K_w(S, S_w, S_c) \qquad D = K_{sat} \cdot S^d$$

$$\frac{dS}{dt} = \frac{I - E - T - D}{\phi \cdot Z}$$

Canopy Cover (C)

$$G = w \cdot (1 - K_f(f_b, f_\infty)) \cdot K_{cb} \cdot ET_0 \cdot K_w(S, S_w, S_c) \cdot C$$

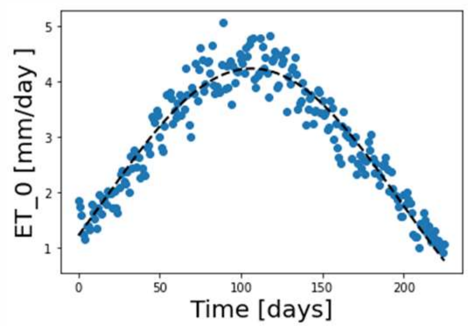
$$\frac{dC}{dt} = G - w \cdot K_{cb} \cdot ET_0 \cdot C^2 - \gamma \cdot C^2 \cdot (t - t_{sen}) \cdot H(t - t_{sen})$$

Biomass (B)

$$\frac{dB}{dt} = r_{bg} \cdot f_b \cdot C \cdot K_{cb} \cdot ET_0 \cdot K_w(S, S_w, S_c)$$

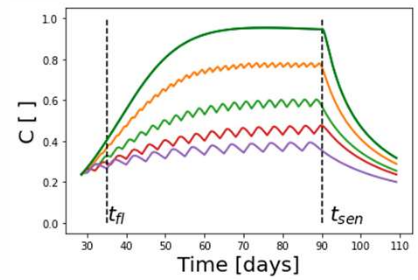
Evapotranspiration

Evapotranspiration (ET) is a process by which water is transferred from land to the atmosphere via evaporation from the soil and transpiration from the plants. Its rate depends on temperature. ET was set constant in previous iterations of the model but variability to this term was incorporated to simulate Wisconsin's temperature fluctuations during the growing season.

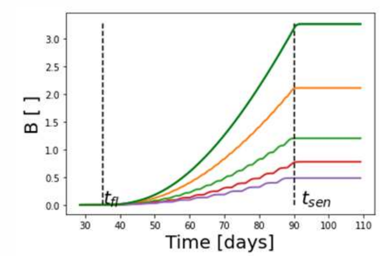


Results

The model serves many purposes. Two we focus on are: it is a predictive tool for helping growers use water more efficiently and it helps us learn how irrigation practices impact crop yield.



In this plot the percentage of canopy cover over a growing season is displayed for five separate kidney beans plants. Each plant received the same total amount of water over the same time period. The duration between watering periods was increased along with the amount dispersed during each watering. The results indicate irrigation timing has a significant impact on plant growth.



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Chippewa Valley Bean — since 1969 — A Taste of America's Heartland

Freshwater Collaborative of Wisconsin