Introduction to Crop Modeling

Connecting Crop Modeling with Breeding

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Outline

Education and Research

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- B.S. Agronomy (University of Buenos Aires, 2001)
- M.S. and PhD in Crop Sciences (University of Illinois, 2004, 2007)
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- Post-Doc at the Energy Sciences Institute (University of Illinois, 2008 – 2009)

Research

- Maize physiology
- Cover crops on Maize yield
- Miscanthus Production and Modeling
- Model Development for Biomass Crops

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Why model?

- Science is concerned with prediction.
- Conceptual model are hypotheses
- Models are logically and quantitatively constructed series of beliefs about how a system works

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Why model?

Why model?

- research knowledge synthesis
- crop system decision management
- policy analysis

Potential Uses and Limitations of Crop Models. Boote et al (1996). AJ.

Outline

Simple Crop Models

$$W = \int_{Tt=e}^{Tt=pm} R \cdot dt$$

where

$$\frac{dW}{dt}$$

= rate (R) of change of dry weight $(g\ m^{-2} d^{-1})$ Typical value might be around 20 $g\ m^{-2} d^{-1}$ (10-30)

Let us try this for corn

$$W = \int_{e}^{pm} R \cdot dt$$

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$$W = R \cdot \int_{e}^{pm} dt$$

Let us try this for corn

$$W = \int_{e}^{pm} R \cdot dt$$

$$W = R \cdot \int_{e}^{pm} dt$$

$$W = R \cdot [pm - e]$$

Let us assume emergence day of the year is 127 and physiological maturity 252

Let us try this for corn

$$W = \int_{s}^{pm} R \cdot dt$$

$$W = R \cdot \int_{e}^{pm} dt$$

$$W = R \cdot [pm - e]$$

$$W = 20 \cdot [252 - 125]$$

$$W = 2500$$

Let us try this for corn

$$W = \int_{e}^{pm} R \cdot dt$$

$$W = R \cdot \int_{e}^{pm} dt$$

$$W = R \cdot [pm - e]$$

$$W = 20 \cdot [252 - 125]$$

$$W = 2500$$

What does 2500 mean?

Let us try this for corn

$$W = \int_{e}^{pm} R \cdot dt$$

$$W = R \cdot \int_{e}^{pm} dt$$

$$W = R \cdot [pm - e]$$

$$W = 20 \cdot [252 - 125]$$

$$W = 2500$$

2500 $g\ m^{-2} d^{-1}$ or 25 $Mg\ ha^{-1}$ total biomass of corn 12.5 $Mg\ ha^{-1}$ grain (199 bushels ac^{-1})

Limitations of the previous approach?

Limitations of the previous approach?

- Not limited by radiation, water or nutrients
- growth rate is constant (linear)
- Does not take into account genetics
- Does not take into account management, pest or weeds

How can we improve the model?

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$$W = \int_{e}^{pm} Q \cdot RUE \cdot dt$$

where
Q = Quantum flux
RUE = Radiation Use Efficiency

How can we improve the model?

$$W = \int_{e}^{pm} Q \cdot f(LAI) \cdot RUE \cdot dt$$

where
Q = Quantum flux
RUE = Radiation Use Efficiency
f(LAI) = efficiency of interception which depends on LAI (Leaf Area Index)

How can we improve the model?

$$Y = \int_{e}^{pm} Q \cdot f(LAI) \cdot RUE \cdot g(W) \cdot dt$$

where
Q = Quantum flux
RUE = Radiation Use Efficiency
f(LAI) = efficiency of interception which depends on LAI (Leaf Area Index)
g(W) = fraction of total biomass harvested (harvest index)

"Models should be made simple, but not simpler"

"A crucial notion in choosing either to use or develop a model is balance. Balance means that the model should be sufficiently but not overly detailed for the question that is to be addressed."

Outline

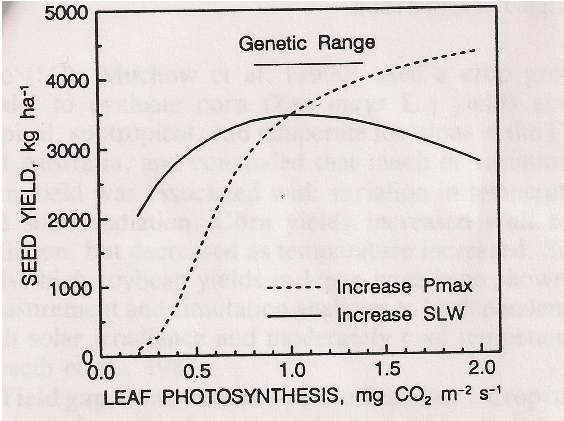
Genetic Improvement

View from Crop Modeling

- Crop ideotype
- Tradeoff between competing purposes

Potential Uses and Limitations of Crop Models. Boote et al (1996). AJ.

Soybean leaf photosynthesis



Advancing Breeding and Biological Complexity

- Plant breeding is not advancing crops as fast as it has in the past
- cost-per-unit yield gain has risen substantially
- Prediction of phenotype based on genotype is crucial for advancing breeding
- Gene-by-gene engineering is one approach for improvement
- However, little of this promise has been realized for key complex traits

Flowering in Biomass Crops
A trait to modify?

Flowering in Biomass Crops

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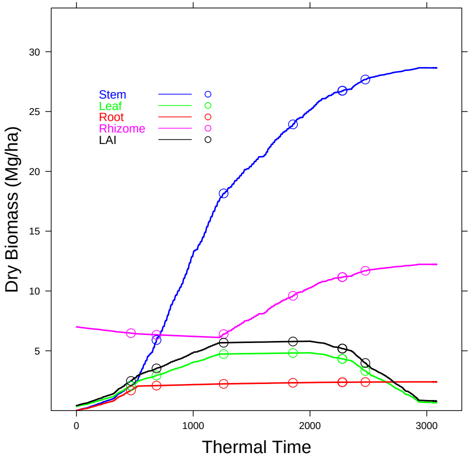
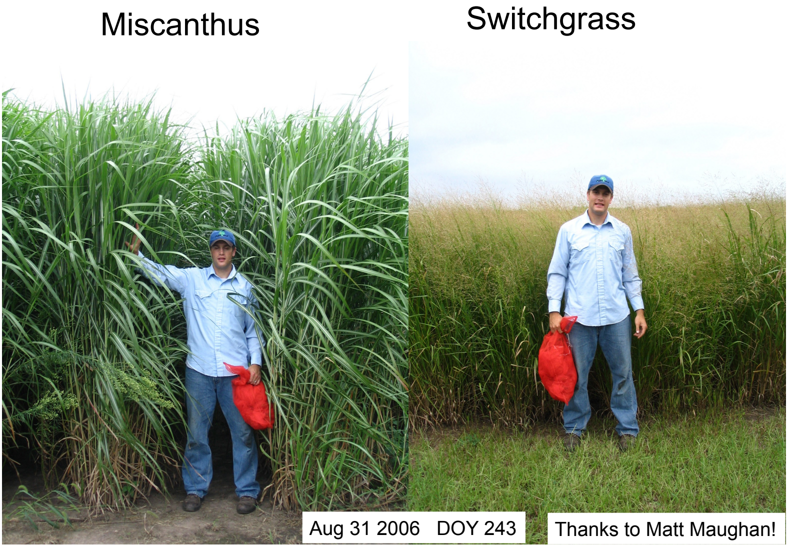


Produced with BioCro

- biomass is partitioned into plant components
- delaying flowering favors vegetative growth
- flowering also triggers remobilization of nutrients to rhizome

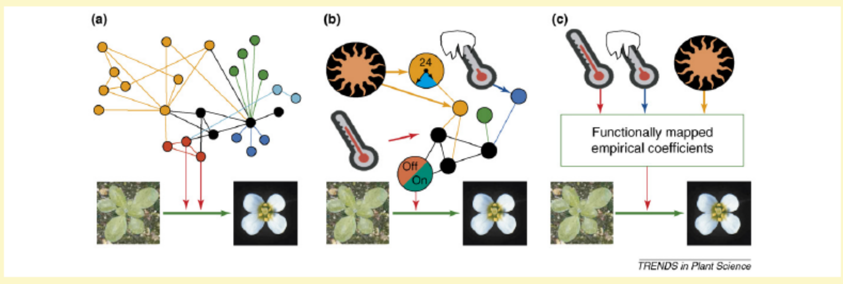
Flowering in Biomass Crops

A trait to modify?



Flowering in Arabidopsis

Combining mathematical models and gene networks



Leaf Elongation in Maize

Greatly affected by water stress

- Water stress is poorly described in most crop models
- It affects CO_2 uptake and productivity
- Can not model N stress independently from water stress

What do we know about water stress?

process or parameter affected	sensitivity to stress: very sensitive → intensitive; reduction in tissue ψ required to affect the process: 0 — 1 — 2MPa	selected references
cell growth (−)		Acevedo *et al.* 1971; Boyer 1968
wall synthesis† (−)		Cleland 1967
protein synthesis† (−)		Hsiao 1970
protochlorophyll formation‡ (−)		Virgin 1965
nitrate reductase level (−)		Huffaker *et. al.* 1970
ABA synthesis (+)		Zabadal 1974; Beardsell & Cohen 1974
stomatal opening (−):		
(*a*) mesophytes		reviewed by Hsiao 1973
(*b*) some xerophytes		Van den Driesche *et al.* 1971
CO_2 assimilation (−):		
(*a*) mesophytes		reviewed by Hsiao 1973
(*b*) some xerophytes		Van den Driesche *et al.* 1971
respiration (−)		
xylem conductance§ (−)		Boyer 1971; Milburn 1966
proline accumulation (+)		
sugar level (+)		

Hsiao et al. 1976

Leaf Growth in Maize

$$\frac{dL}{dt} = (T - T_0) \cdot (a + b \cdot VPD + c \cdot \Psi)$$

where

$\frac{dL}{dt}$ = Leaf expansion rate (LER)

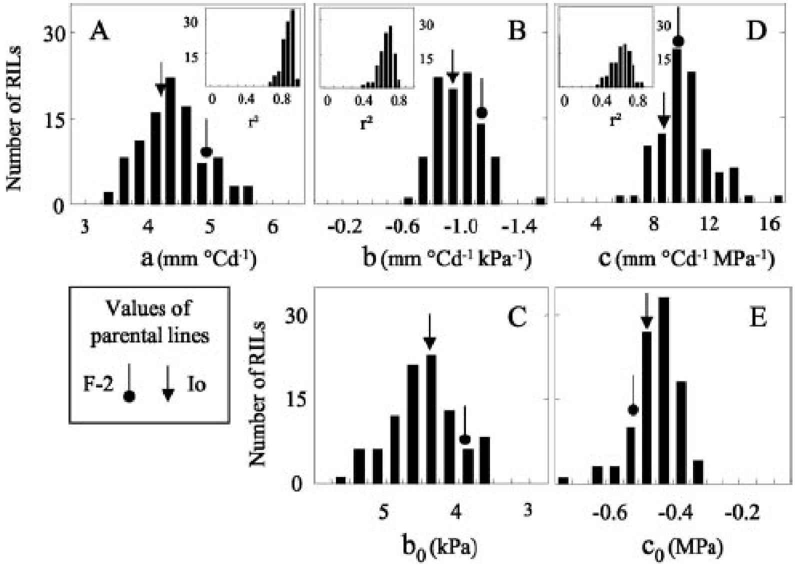
$T - T_0$ = Temprature at the meristem minus base temperature

a = slope of LER to Temp

b = slope of LER to VPD

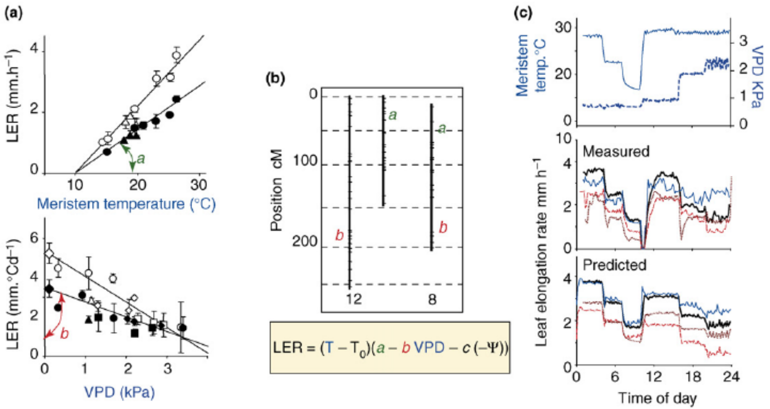
c = slope of LER to pre-dawn leaf water potential

Parameters in 100 RIL



Leaf growth in Maize

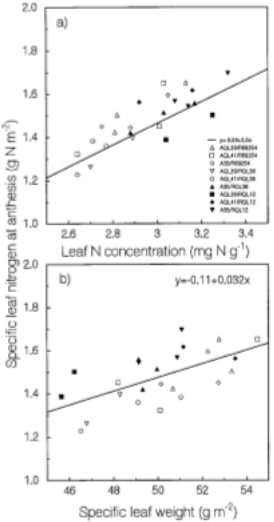
Combining mathematical models and QTL



Staygreen in Sorghum

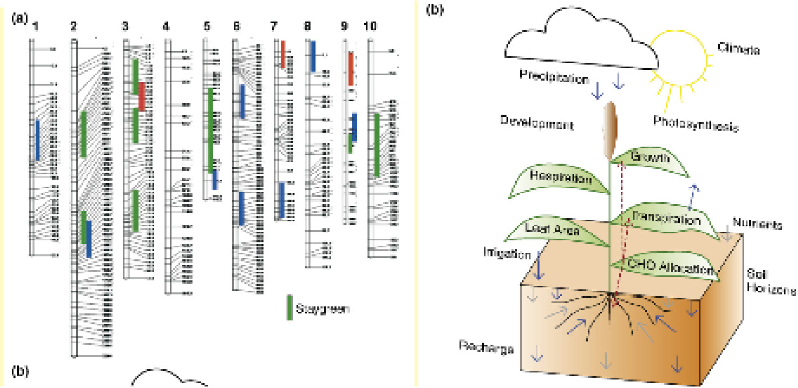
- Poor association between QTL and yield
- Effect of staygreen on yield is complex
- Crop models $\int f(G, E, M)dt$
- Phenotypic expression of stay-green is a result of leaf size, leaf N, dry matter partitioning and N uptake

Staygreen in Sorghum



- How does staygreen occur?
- Staygreen is complex
- Higher LAI, CO2 uptake, grain number

Staygreen in Sorghum



References

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Questions ?