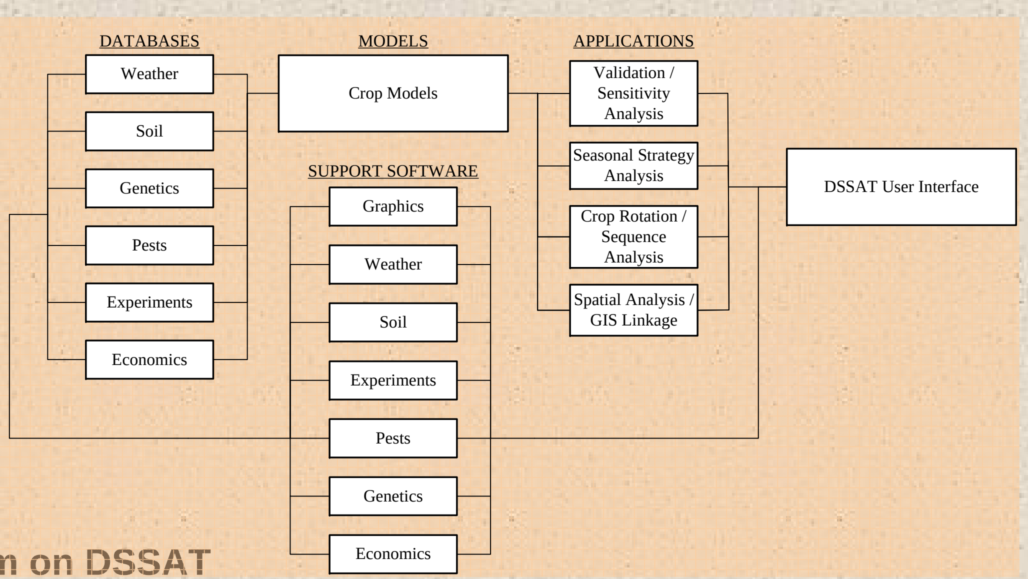
Introduction to Systems Approach

- Basic Concepts
- Simple Crop Growth Model
- Example Uses of Crop System Models



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Information Needs in a Systems Approach

- Agricultural Science is not a science unless it predicts and tests its predictions (P. G. Cox, 1996)

- Understanding → Prediction → Control, Manage (H. Nix, 1983)

- A wealth of research information exists concerning the possibilities for change, the options available and the likely effects of a range of land use practices. However, it is less clear how this information is of use to, or can be filtered into, decision making processes. (J. Park and R. A. F. Seaton, 1996)

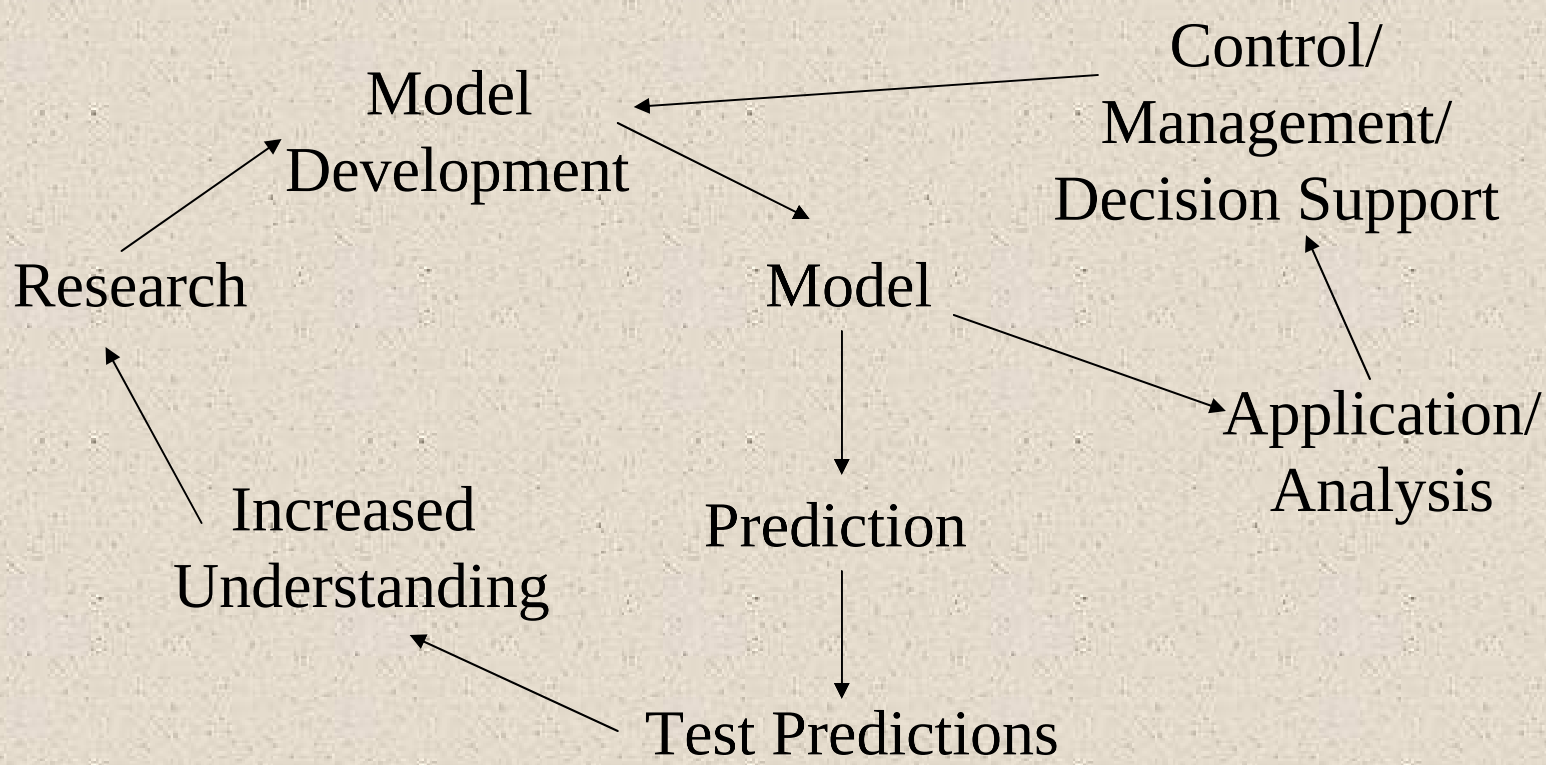
Terminology

- System – Collection of Components
- Boundary – Separates System Components from its Environment
- Model – Mathematical Representation of System (Components & their Interactions)
- State Variables – Measures of System that Change over Time
- Environmental Variables (inputs) – system dynamics do not affect them
- Simulation – Solving a Model, predicting system behavior over time

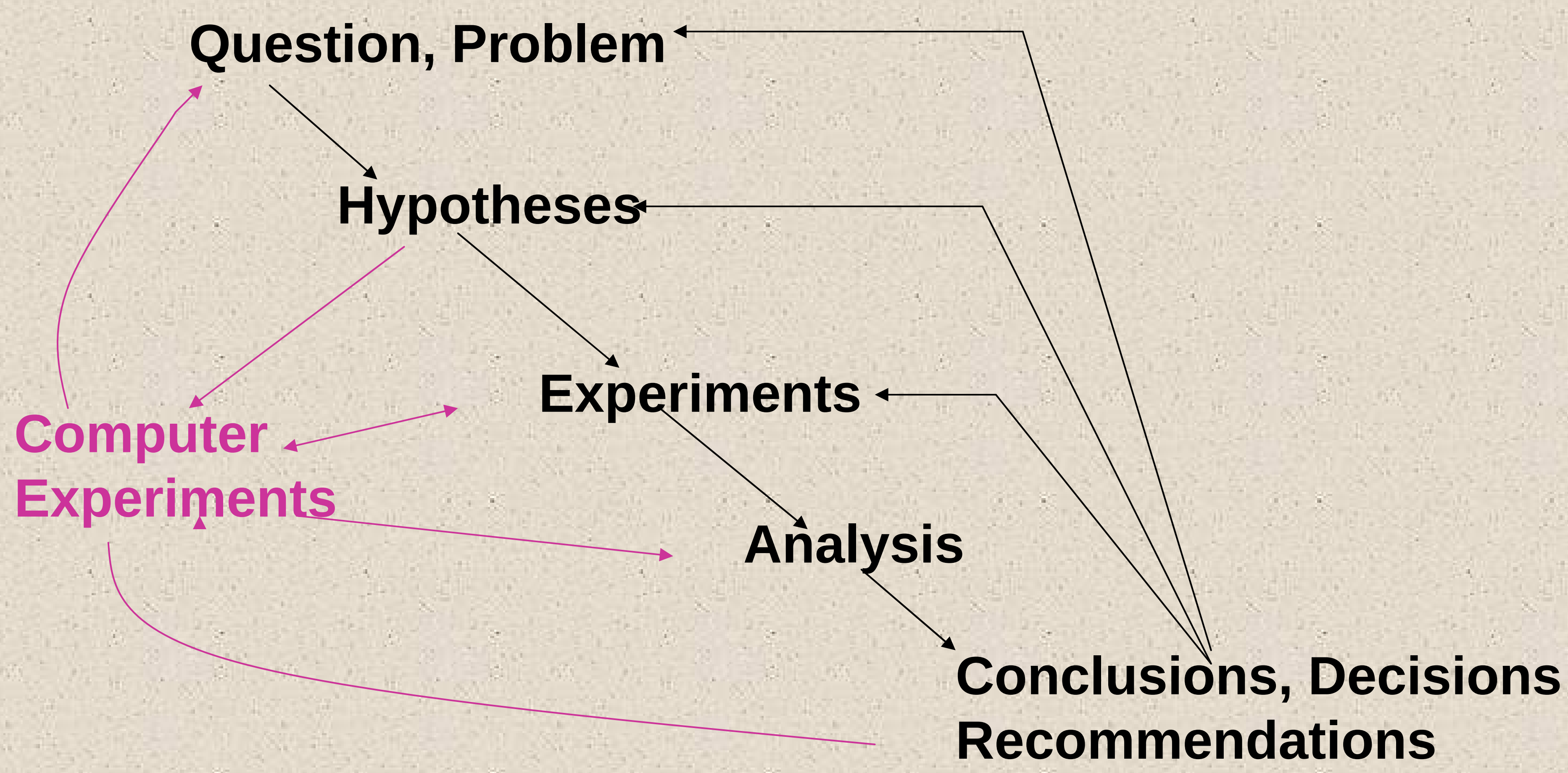
Systems Approach

Research for Understanding

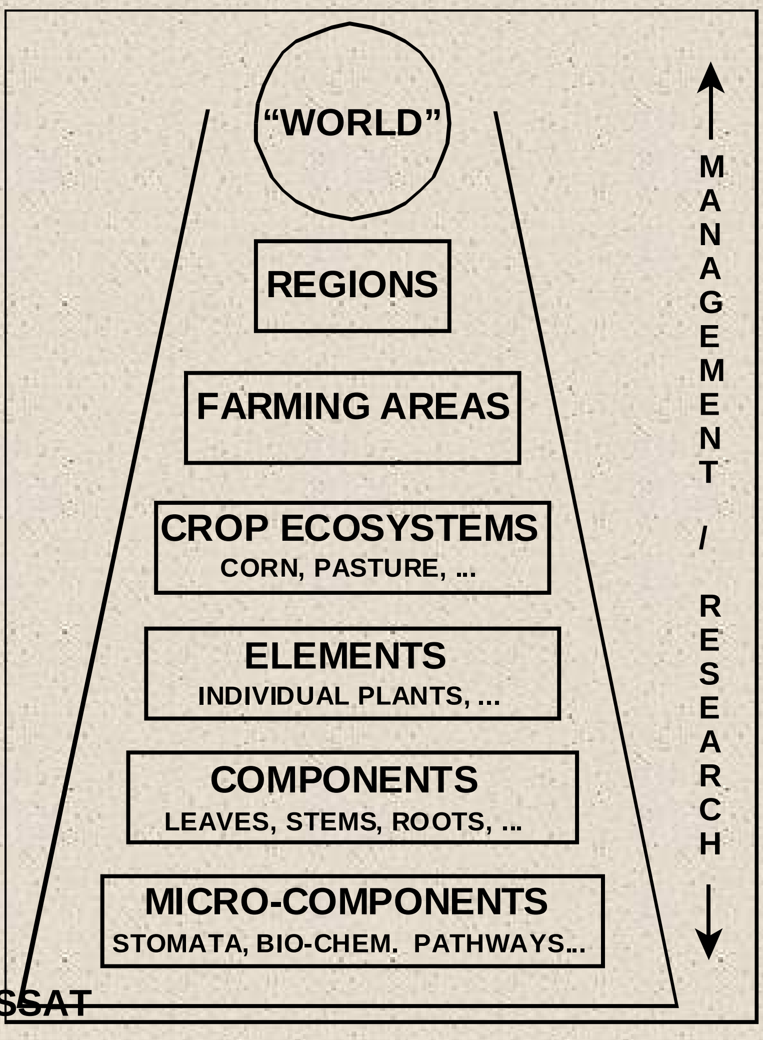
Problem Solving



Incorporating Crop Models into Traditional Agronomic Research



Hierarchy is Important in Biological/Ecological/Agricultural Systems



Models

Statistical Model Example

$$Y = a_0 + a_1 X_1 + a_2 X_2 + \varepsilon$$

Where

Y = dependent variable

X_i = independent variables, i = 1, 2 in this example

a_i = regression coefficients, and

ε = residual error

Dynamic Models

Biophysical Model Example

$$\overline{X}(t) = f\{\overline{X}, \overline{p}, \overline{u}(t), \overline{\varpi}(t), t\}$$

Where

$\overline{X}(t)$	=	vector of variables that describe state of system at time t
f	=	functional relationships among variables
$\overline{p}$	=	vector of parameters or coefficients associated with physiological, physical relationships of components in the model
$\overline{u}(t)$	=	vector of control or management variables, varying with time t
$\overline{\varpi}(t)$	=	vector of input variables, varying with time t

A Simple Dynamic Model

Rate of Change of N = k * N

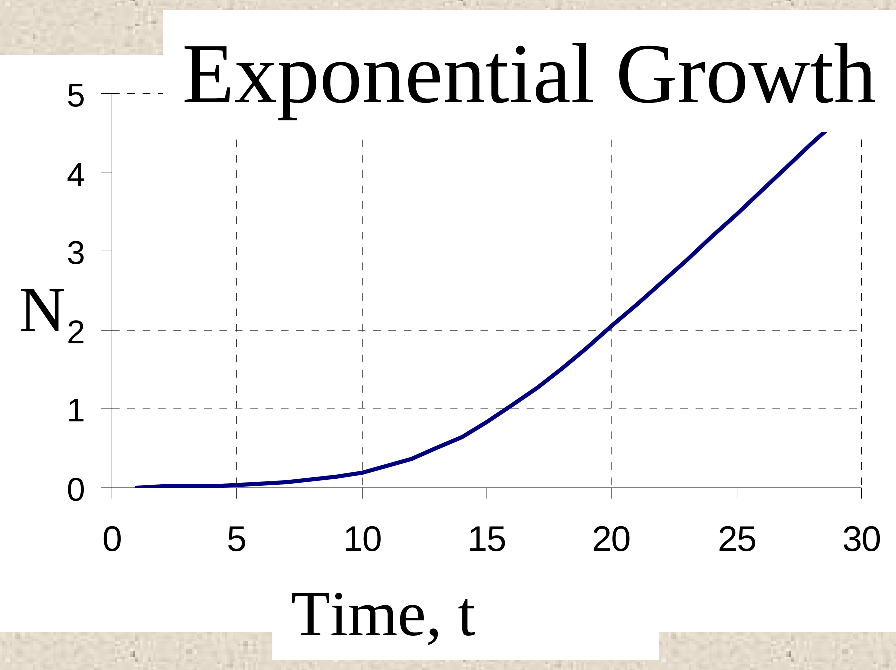
$dN_t/dt = k * N_t$

Which can be approximated by

$(N_{t+dt} – N_t)/dt = k * N_t$

Solving the model

$N_{t+1} = N_t + k * N_t * dt$



Modeling

- Development of equations that describe the relationships among state variables, parameters, control/management inputs, and environmental inputs. In other words, developing the *f* in the previous slide

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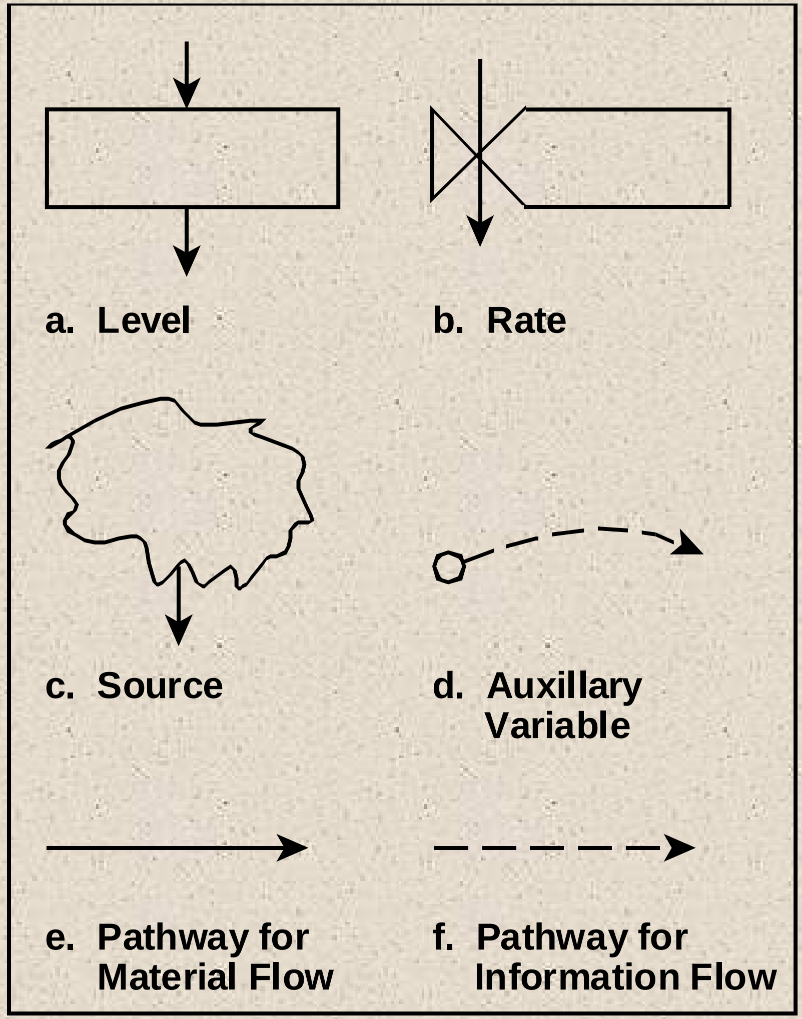
Forrestor Diagrams; Developing and Communicating Conceptual Model of System



<u>General Equations for ***Level i*** Dynamics:</u>

$$dx_i /dt = \Sigma_j I_{i,j} - \Sigma_k O_{i,k}$$

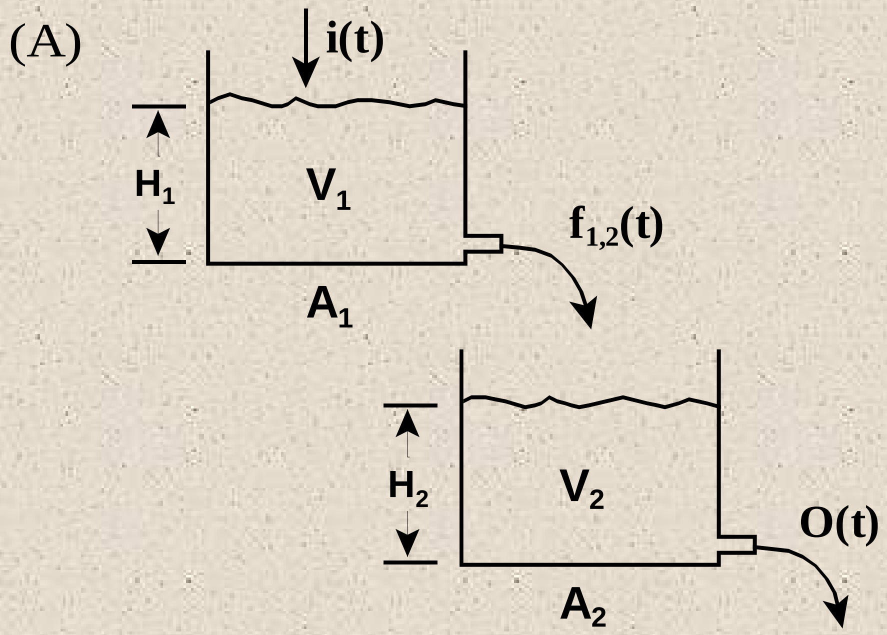
where x_i = level of i^{th} variable,

dx_i /dt = rate of change in the level of the i^{th} variable,

$I_{i,j}$ = rate of flow into level i, from source j,

$O_{i,k}$ = rate of flow out of level i, to source k.

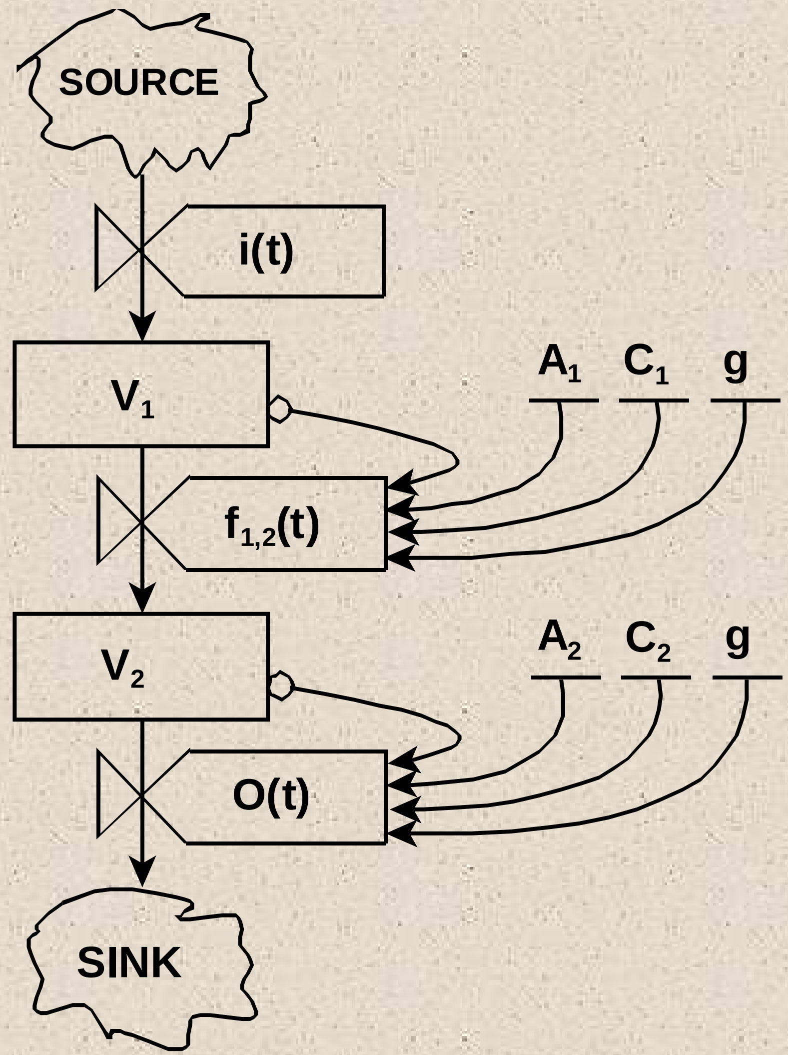
Simple 2- State Variable Example



Two tanks, water flow between them

Forrestor Diagram, Two-tank System

(B)



Equations of Conservation:

$dV_1/dt = i(t) - f_{1,2}(t)$

$dV_2/dt = f_{1,2}(t) - O(t)$

Final Equations:

$dV_1\ /dt= i(t) - C_1(2gV_1/A_1)^{½}$

$dV_2/dt = C_1(2gV_1/A_1)^{½} - C_2(2gV_2/A_2)^{½}$

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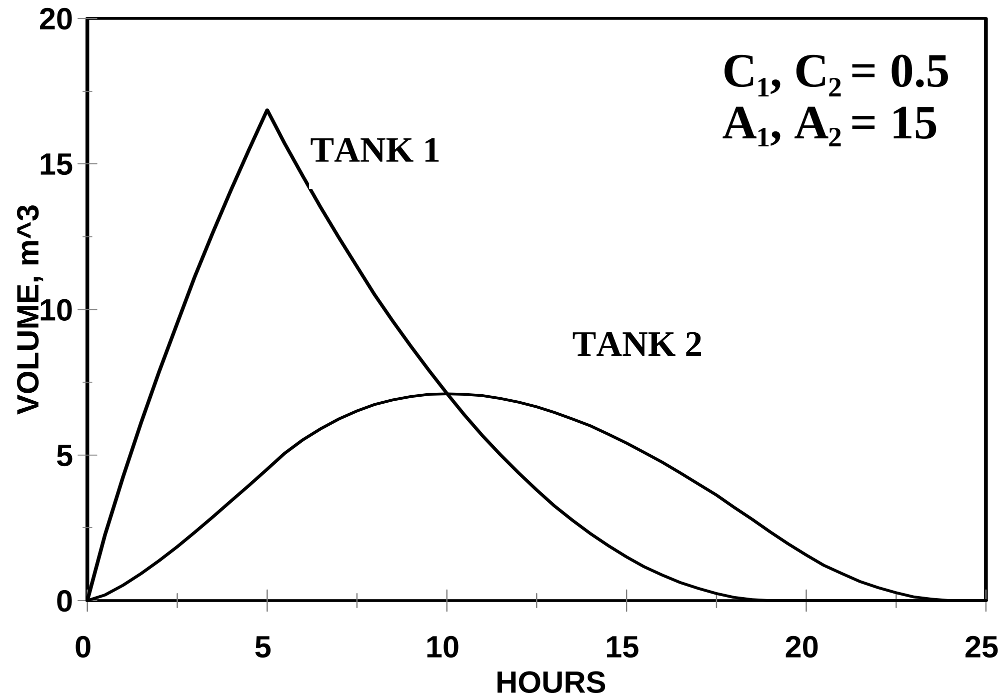
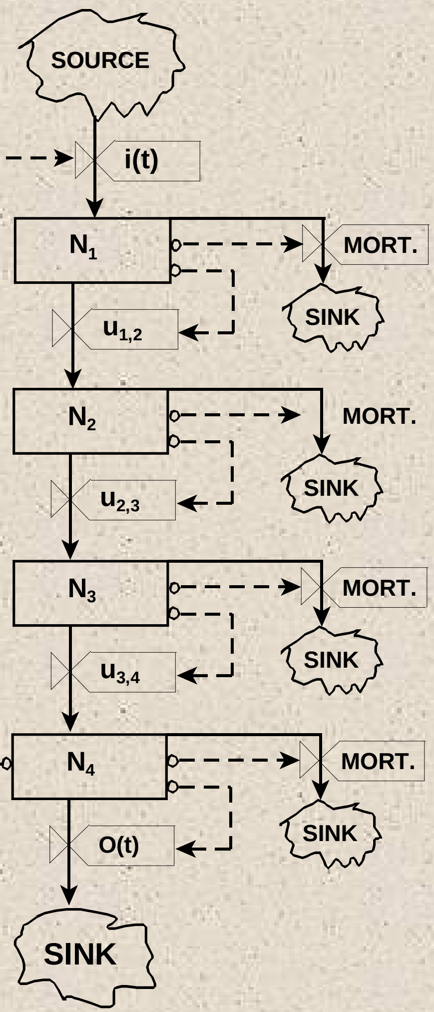
Simulation Results
Constant i(t) for 5 hours, specific values of coefficients



Forrestor Diagram for Insect Population Model



BIOLOGICAL MODEL EXAMPLES

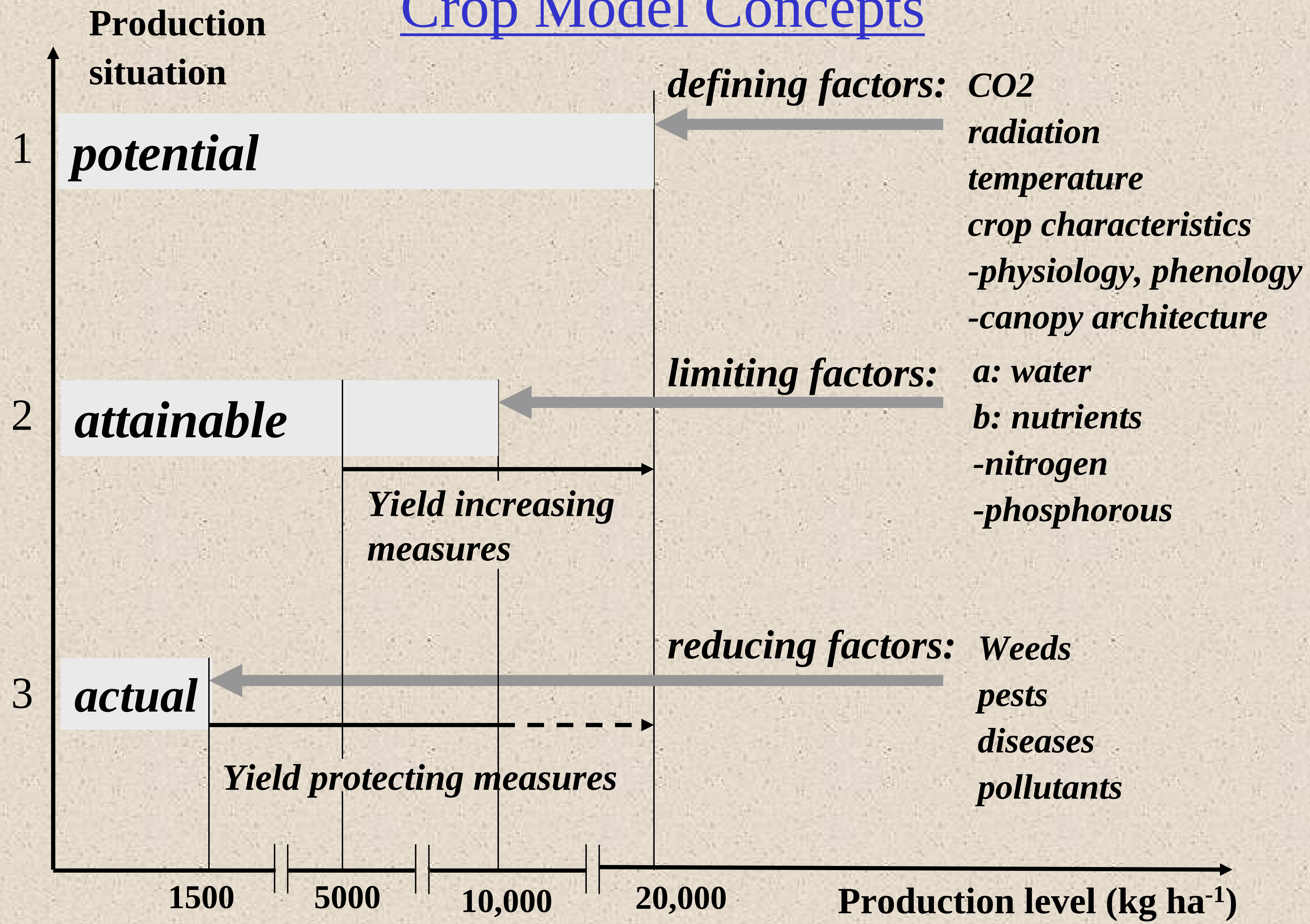
- Crop Growth
- Soil Organic Matter
- Microbial Growth
- Insect Populations
- Predator-Prey Populations
- Bio Reactors
- Fish Growth and Reproduction
- Heart Function
- Animal Temperature Regulation
- Eutrophication Processes
- Chemical Transport in Soil, Water
- Food Chain
- Livestock growth
- Plant and Animal Genetics

Crop System Models

- Crop growth and yield models have been developed for various purposes, among others:

  precision agriculture
  yield forecasting
  irrigation management
  crop sequencing
  nutrient management
  pest management
  land use planning
  climate change assessment
  economic risk

Crop Model Concepts



Source: World Food Production: Biophysical Factors of Agricultural Production, 1992.

Simple Crop Model

<u>Reference:</u>

J.W. Jones and J.C. Luyten, 1998. Simulation of biological processes. Pages 19-62 in: R.M. Peart and R.B. Curry (Eds) Agricultural Systems Modeling and Simulation.

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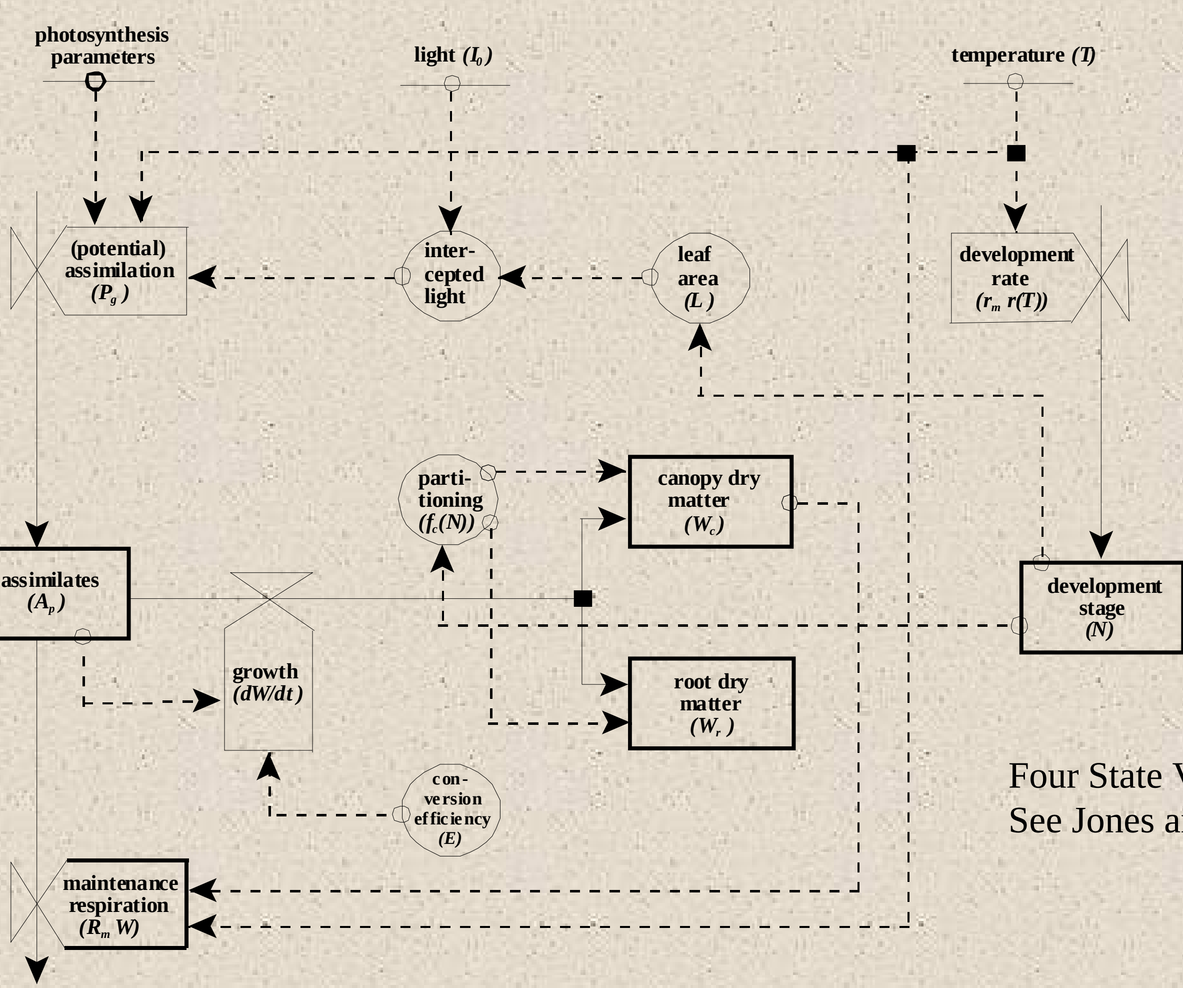
Simple Crop Model



Four State Variables.
See Jones and Luyten, 1998

Rate of Crop Dry Weight Growth

- Photosynthesis minus maintenance respiration

$$dW/dt = E\,(P_g - R_m W)$$

where

dW/dt = rate of dry weight growth of the crop, g [tissue] m^{-2} h^{-1},
W = total plant dry weight, g m^{-2},
R_m = maintenance respiration rate, g [CH_2O] g^{-1} [tissue] h^{-1},
E = conversion efficiency of CH_2O to plant tissue, g [tissue] g^{-1} [CH_2]),
P_g = canopy gross photosynthesis rate, g [CH_20] m^{-2} [ground] h^{-1}.

Canopy Photosynthesis (1)

- Many different models. We used the Acock et al. (1978) model.
- *Pg* is a function of light, CO_2, temperature and plant size.

$$Pg = D \frac{\tau\, C\, p(T)}{K} \, \mathrm{Ln}\left[\frac{\alpha\, K\, I_o + (1 - m)\, \tau\, C}{\alpha\, K\, I_o \exp(-KL) + (1 - m)\, \tau\, C} \right]$$

where

D = coefficient to convert photosynthesis calculations from μmol [CO_2] $m^{-2}s^{-1}$ to g [CH_20] $m^{-2}h^{-1}$,

τ = leaf conductance to CO_2, μmol [CO2] m^{-2}[leaf] s^{-1}

C = CO_2 concentration of the air, μmol [CO_2] mol^{-1} [air],

p(T) = dimensionless function of temperature,

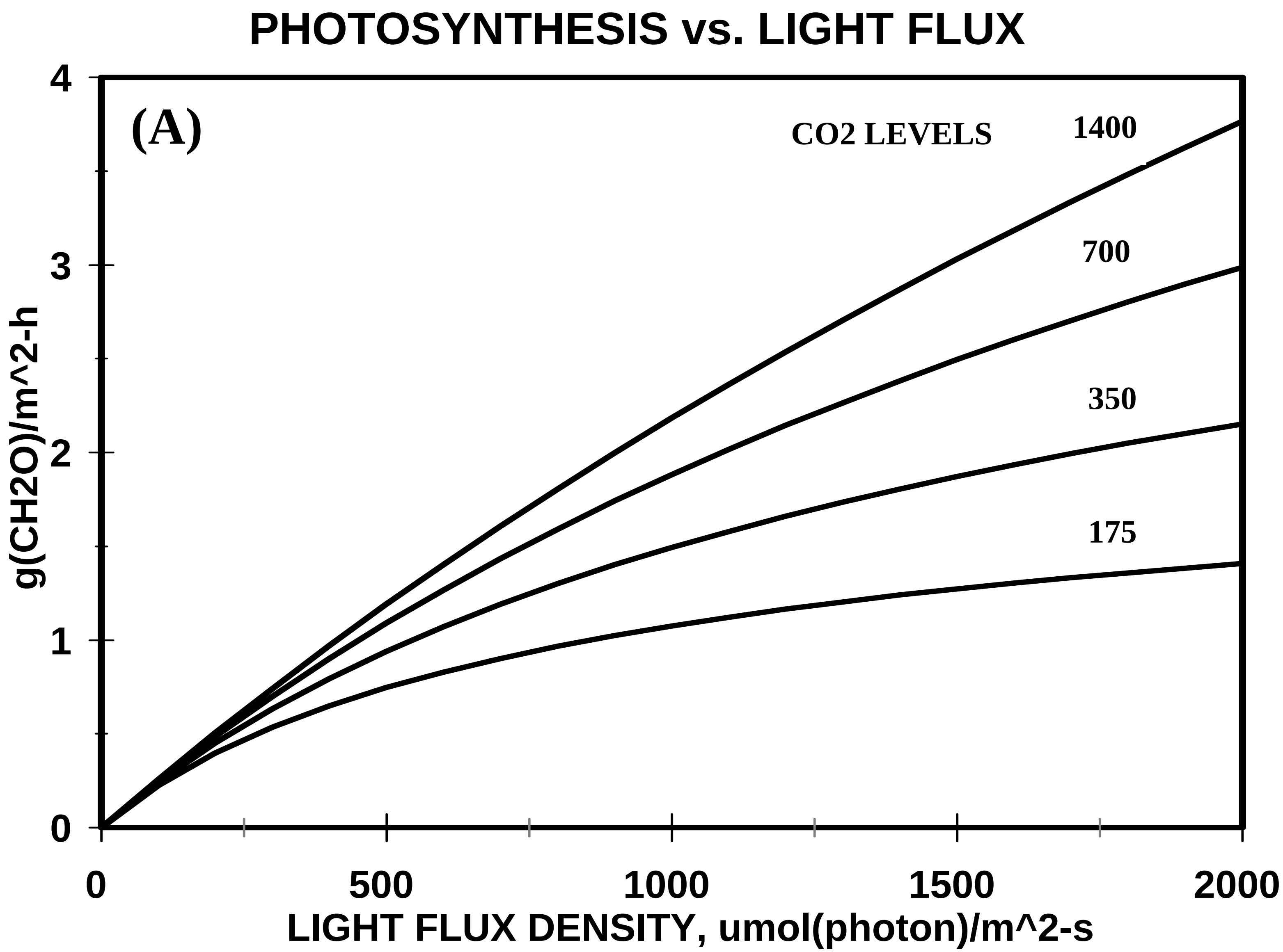
α = leaf light utilization efficiency, μmol [CO_2] μmol^{-1} [photon],

K = canopy light extinction coefficient,

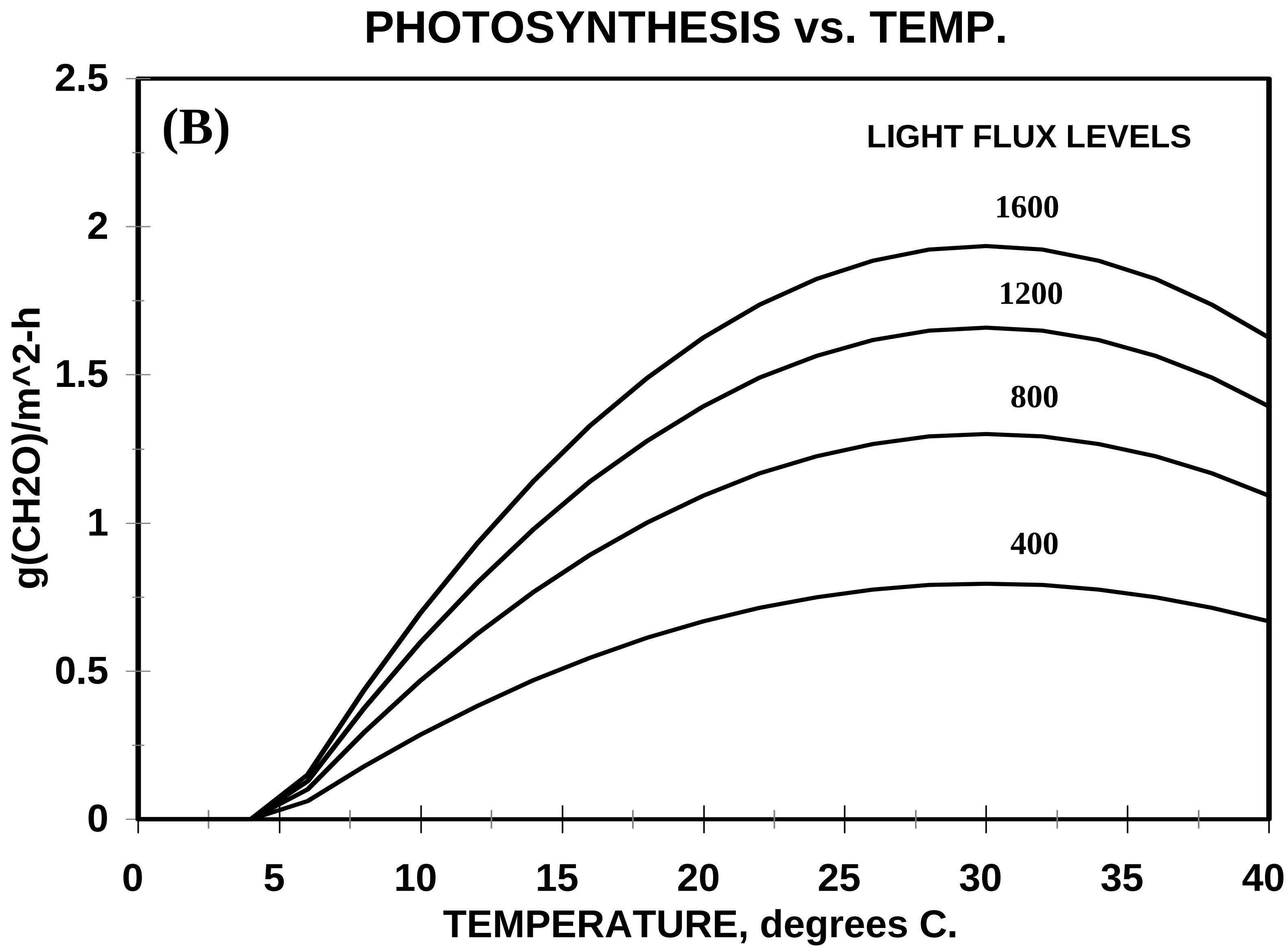
I_o = light flux density at the top of the canopy, μmol [photon] m^{-2} [ground] s^{-1},

m = light transmission coefficient of leaves,

L = canopy leaf area index, m^2 [leaf] m^{-2} [ground].



Constant: LAI=4; T=30 ºC



Constant: LAI=4; CO_2 = 350

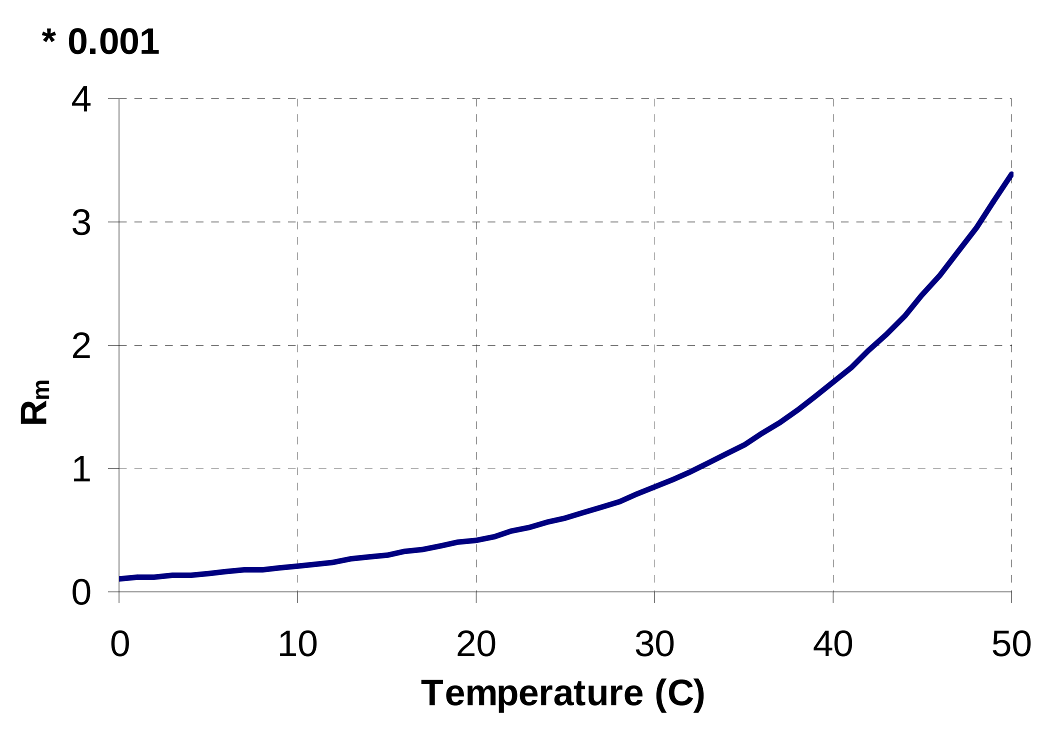
Respiration (maintenance)

- Loss of CO_2 from plants due to breakdown and resynthesis of existing tissue

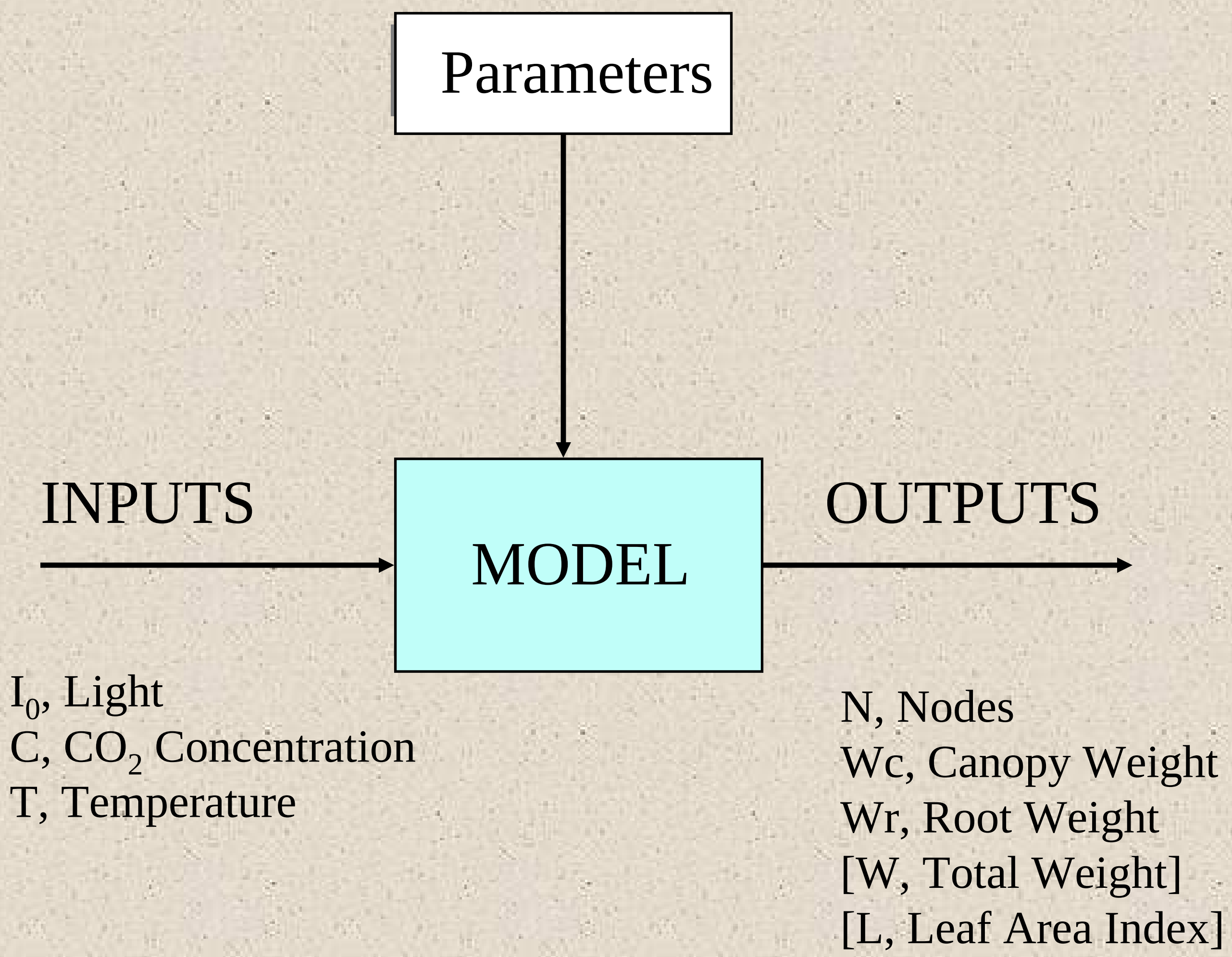
$$R_m = k_m \exp(0.0693[T-25])$$

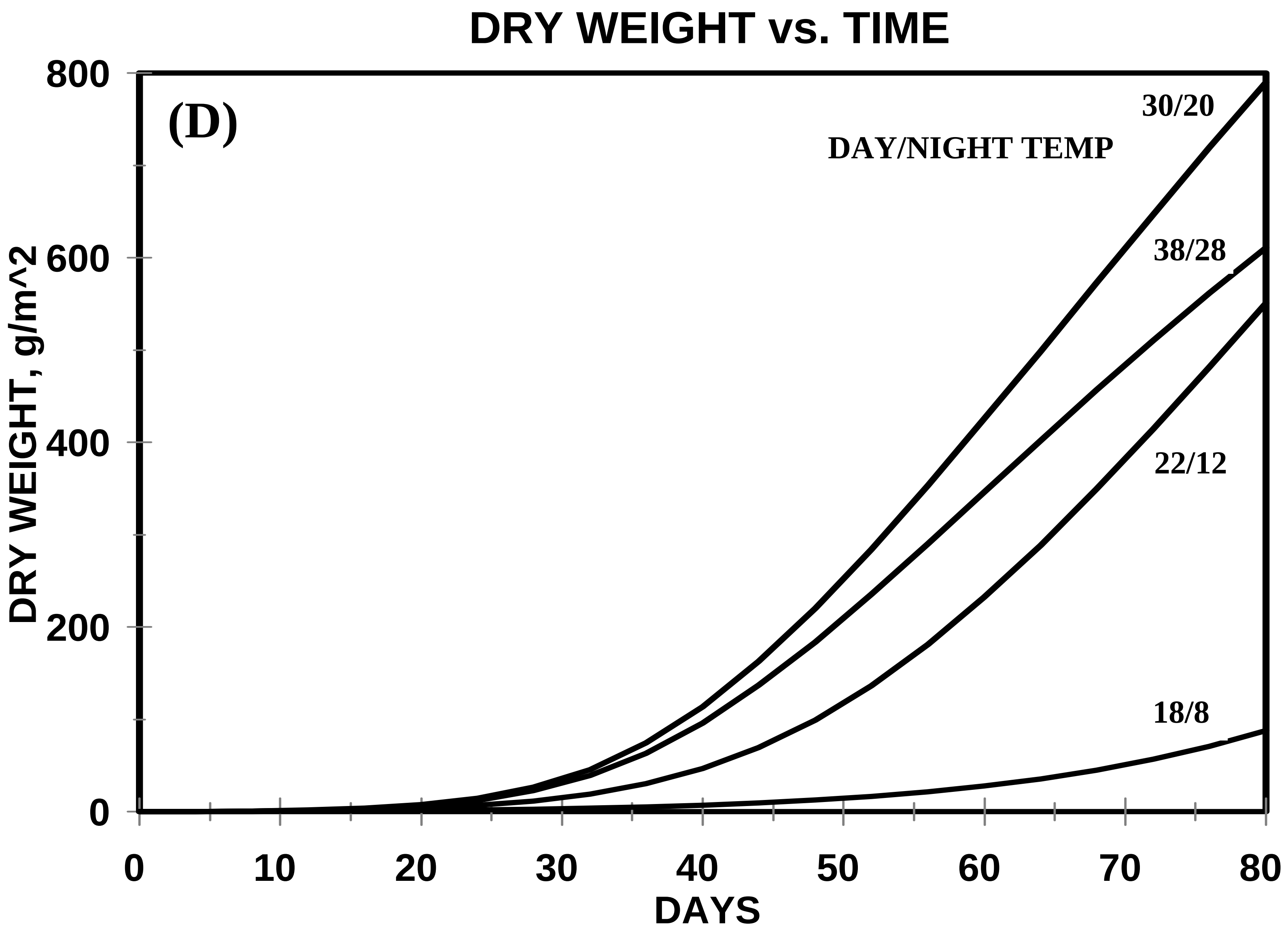
where

R_m = maintenance respiration rate, g $[CH_20]$ g^{-1} [tissue] h^{-1},
T = temperature,
k_m = respiration rate at 25°C, g $[CH_2O]$ g^{-1} [tissue] h^{-1},

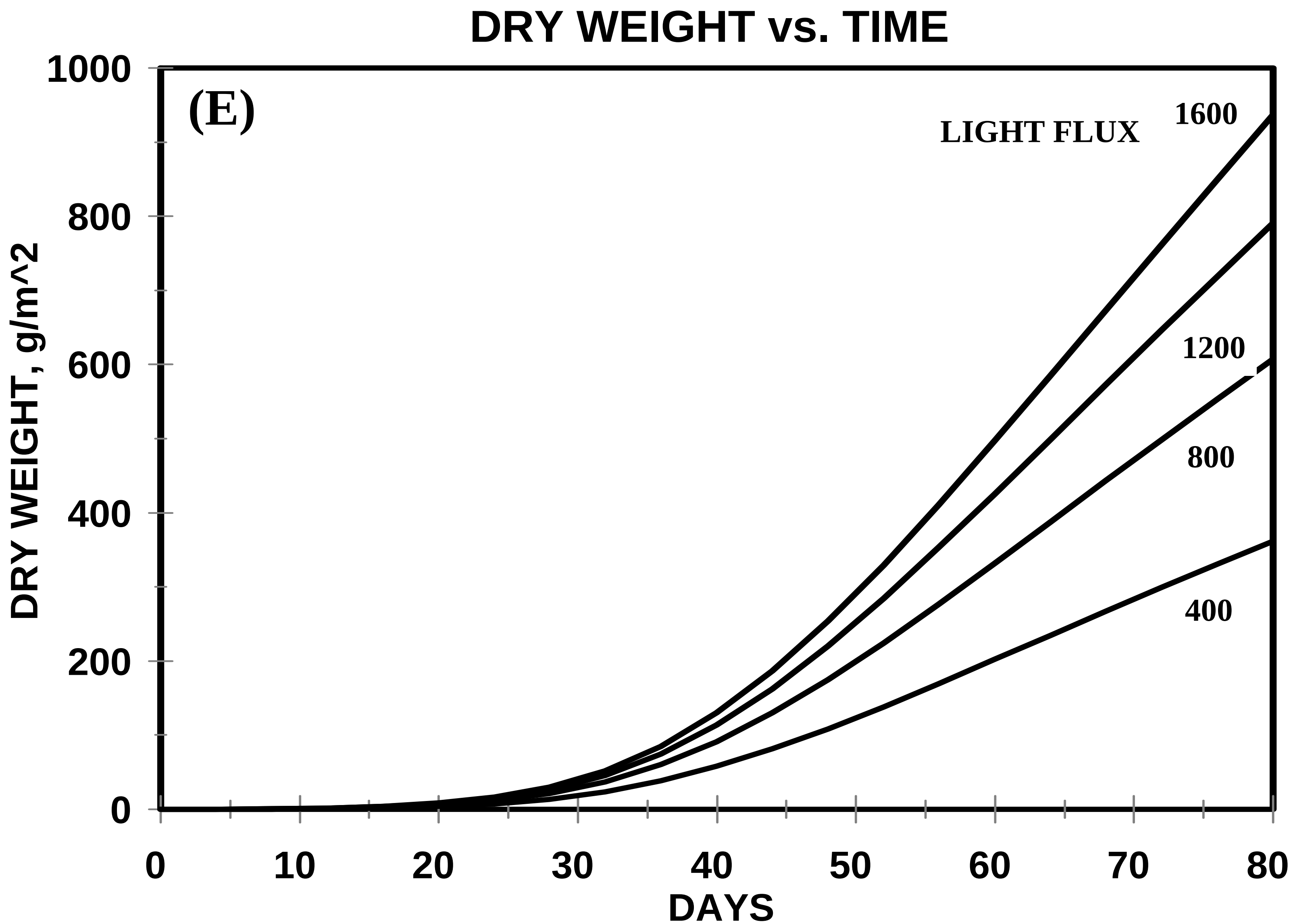


SIMPLE CROP GROWTH MODEL EXAMPLE





Constant: CO_2 = 350, Light flux = 1200; 12 hr days



Constant: CO_2 = 350, 12 hr days; day/night temp = 30/20 ºC

Evaluation of Crop Models for Intended Applications is Critically Important

- Conduct sensitivity analysis of model, critically evaluate results based on existing knowledge, trends
- Demonstrate ability to re-create results from existing and/or new experiments
- Do conclusions from model agree with conclusions from experiments?
- Evaluate using independent data
- Be careful and ensure that inputs are accurate
- Be critical; characterize limitations

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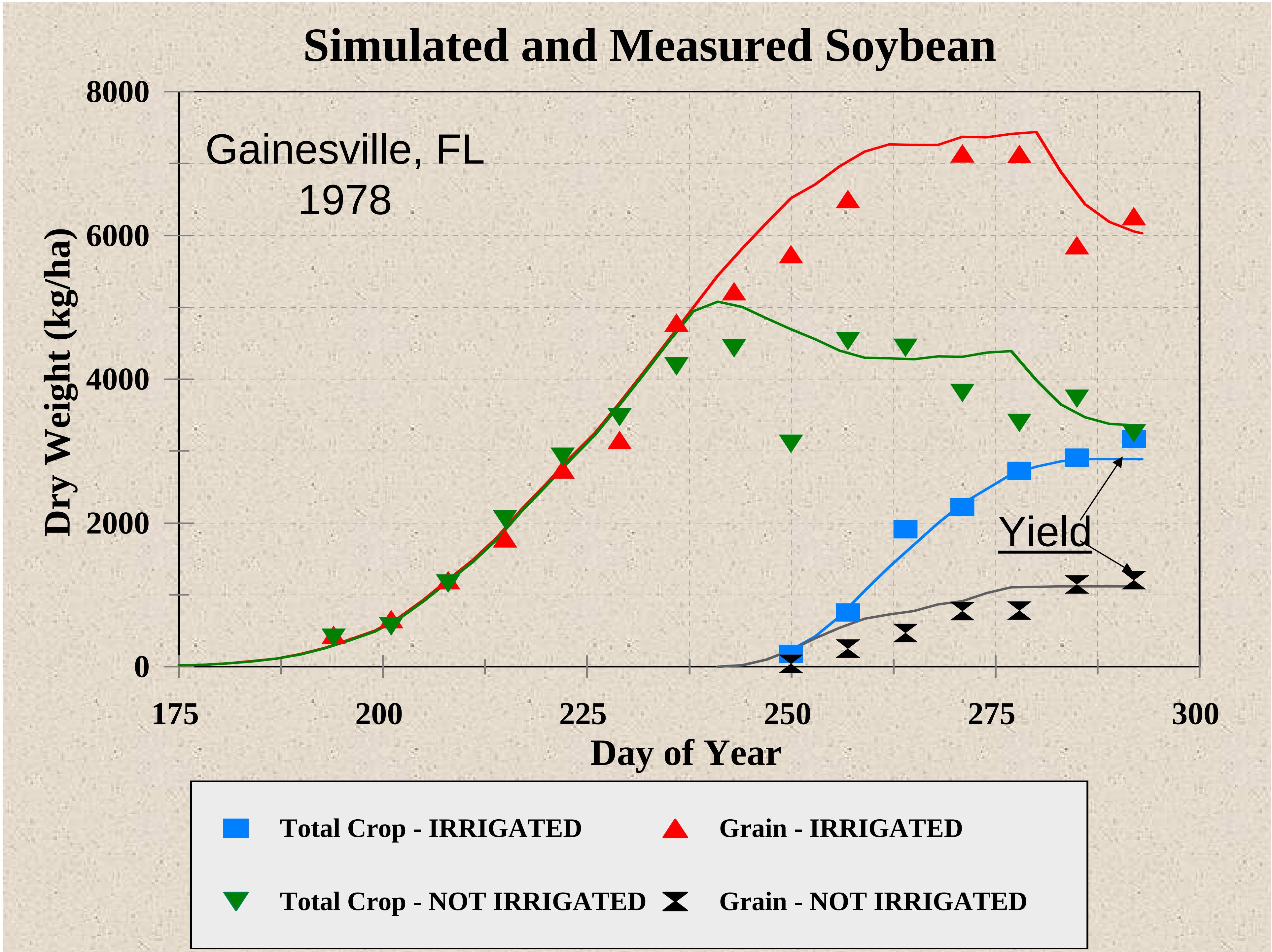
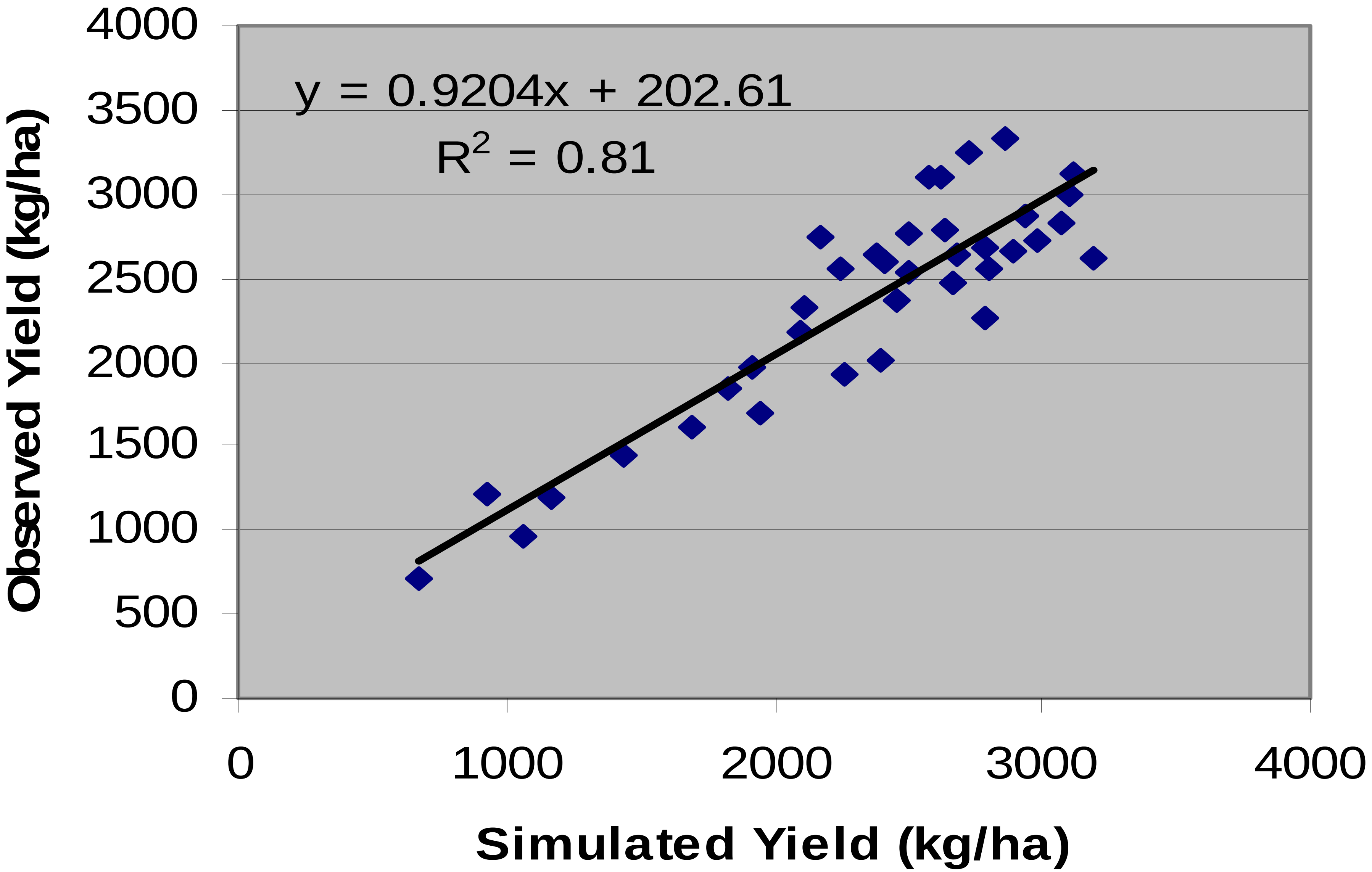
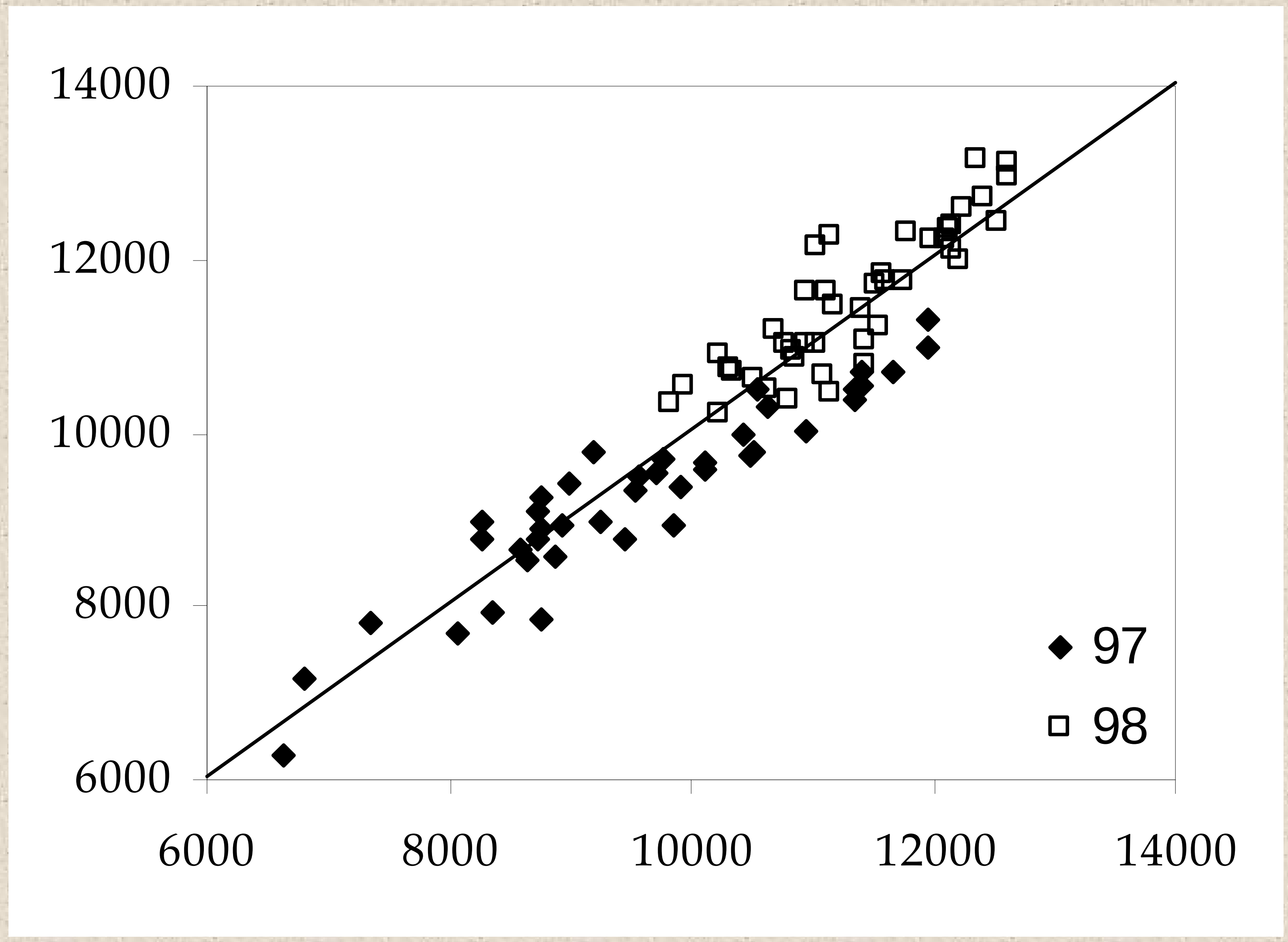

Simulated and Measured Soybean
Gainesville, FL
1978
Dry Weight (kg/ha)
8000
6000
4000
2000
0
175
200
225
250
275
300
Day of Year
Yield
Total Crop - IRRIGATED
Grain - IRRIGATED
Total Crop - NOT IRRIGATED
Grain - NOT IRRIGATED

Testing model predictions, Soybean in Georgia (1987-1996)

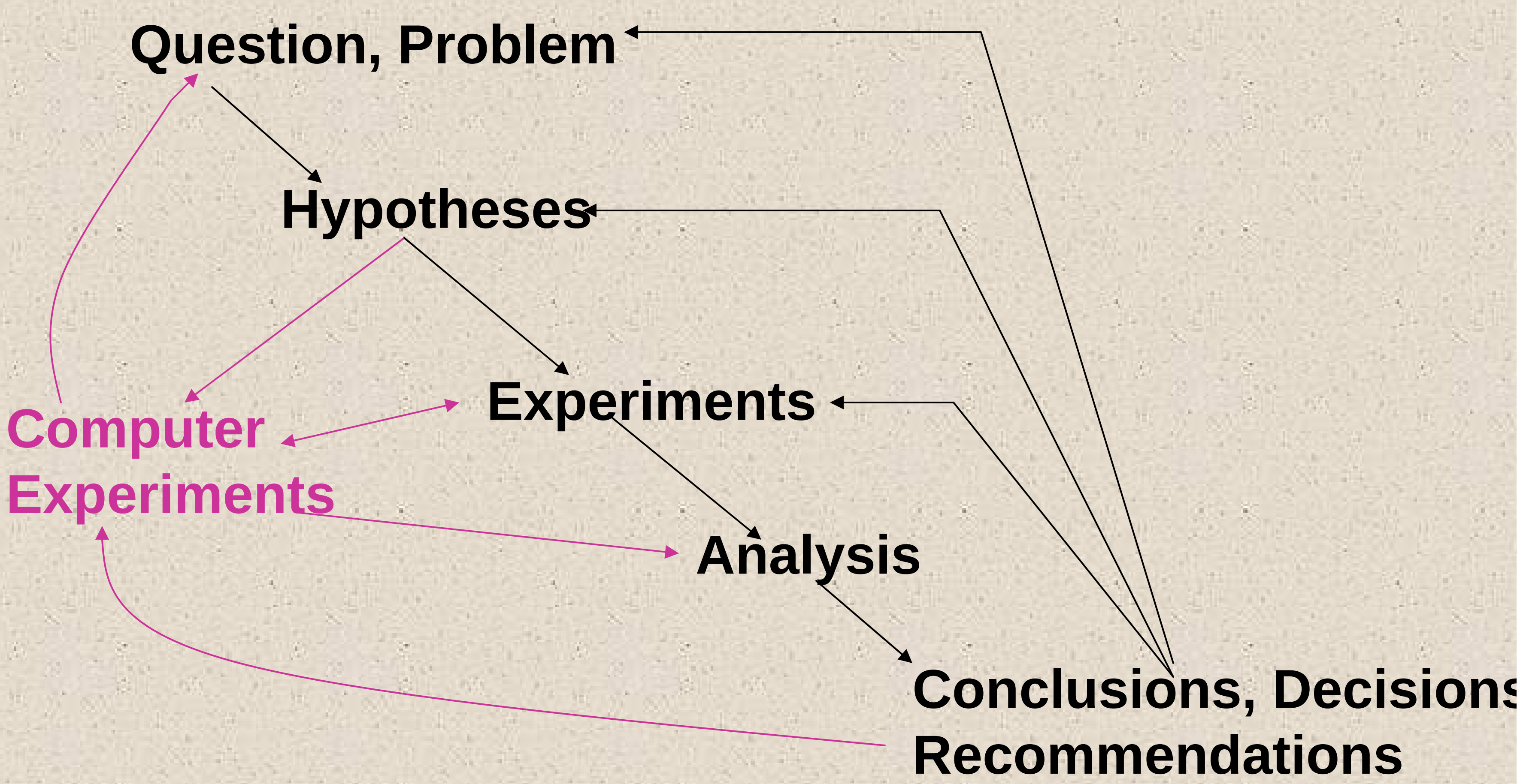


With accurate inputs, crop models can accurately predict yield



Simulated versus observed maize grain yield, two years, using field-measured spatially varying soil parameters in Michigan. R. Braga (2000).

Incorporating Crop Models into Traditional Agronomic Research



Need for Modeling, Systems Approach

- Complex problems, Interdisciplinary Research Needed
- Increased demands for agricultural products
- Increased pressures on natural resources
- Rapid changes in technology, ...
- Globalization of trade, economies
- Information needed for decision making
- Gap between information needed and that created by disciplinary research
- Trial & Error approach to agricultural research is inadequate
- Integration of knowledge is essential