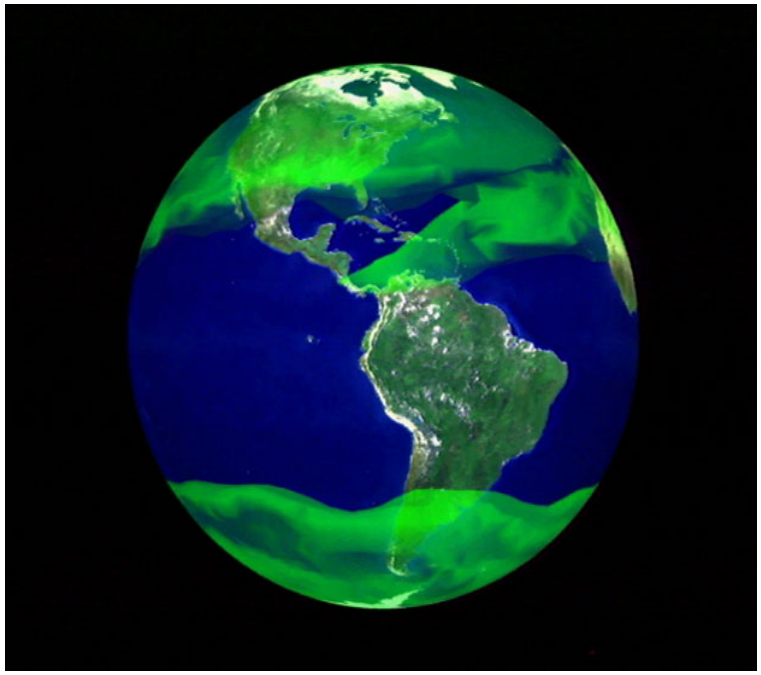
Overview of CropSyst

A cropping systems computer simulation model



Claudio O. Stöckle

Biological Systems Engineering,

Washington State University

USA

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DOWNLOAD CropSyst

Developed by:

Dr. Claudio O. Stöckle
Roger Nelson
Armen Kemanian

Contributors:

Marcello Donatelli
Luca Bechini
Francesc Ferrer
Frits Van Evert
Gaylon S. Campbell
Don McCool
Philippe Debaeke

Abstract

CropSyst is a is a user-friendly, conceptually simple but sound multi-year multi-crop daily time step simulation model. The model has been developed to serve as an analytic tool to study the effect of cropping systems management on productivity and the environment. The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion. Management options include: cultivar selection, crop rotation (including fallow years), irrigation, nitrogen fertilization, tillage operations (over 80 options), and residue management. The model is currently written in C++.

For more information about this model, comments or help in using the material presented here or the software package, contact Claudio O. Stöckle or Roger L. Nelson at the Biological Systems Engineering Dept., Washington State University, Pullman WA 99164-6120. Phone: (509) 335-1578 , FAX: (509)335-2722.

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About 1,970 results (0.05 sec)

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CropSyst, a cropping systems simulation model
CO Stöckle, M Donatelli, R Nelson - European Journal of Agronomy, 2003 - Elsevier
CropSyst is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils, and management on cropping systems productivity and the environment. **CropSyst** simulates the soil water ...
Cited by 507 Related articles All 7 versions Cite

CropSyst, a cropping systems simulation model: water/nitrogen budgets and crop yield
CO Stockle, SA Martin, GS Campbell - Agricultural Systems, 1994 - Elsevier
Abstract In agriculture, water and nitrogen are two critical resources for growing a crop. However, their management cannot be analyzed independently of weather, soil characteristics, field hydrology, crop characteristics, crop rotation, and management ...
Cited by 205 Related articles All 5 versions Cite More

Evaluation of **CropSyst** for cropping systems at two locations of northern and southern Italy
M Donatelli, C Stöckle, E Ceotto, M Rinaldi - European Journal of Agronomy, 1997 - Elsevier
We tested the capability of **CropSyst**, a cropping system simulation model, to simulate cropping systems at two locations (Modena and Foggia) representative of the largest plain areas of Italy. Experimental data collected from rotation experiments during the period ...
Cited by 74 Related articles All 3 versions Cite

Simulation of durum wheat (< i> Triticum turgidum</i> ssp. durum) growth under different water and nitrogen regimes in a mediterranean environment using **CropSyst**
M Pala, CO Stockle, HC Harris - Agricultural Systems, 1996 - Elsevier
CropSyst, a cropping system simulation model, was evaluated for its ability to simulate growth, yield, and water and nitrogen use of two wheat cultivars (Cham 1 and Hourani). These cultivars were grown under different water (rainfed, 60% and 100% of crop water ...
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WASH

Explorer(v4)

Look in: P:\AgMIP\Wheat Phase II\Low Information

- Low
- Low Informatior
  - Database
    - Crop
    - Format
    - Manager
    - Rotation
    - Soil
    - Weather
  - Scenarios
    - AgMIP W
    - AgMIP W
    - backup_t
    - CS01Higl
    - CS01low
    - CS02Higl

Name

- Database
- Scenarios
- .CS_project

P:\AgMIP\Wheat Phase II\Low Information\Scenarios\CS01low\.CropSyst_scenario

Description

Options | Weather | Soil | Crop & Management | Initialization | Recalibration | Reports

Cropping System | Fixed management schedule

No crop (fallow) | Single crop/season | Rotation | Established Orchard/Vineyard | <-- Select one of these options

Sowing date 2007/3/19

If you need to simulate multiple years and/or multiple crops, computed planting dates, or hydrothermal time emergence, use [Rotation] mode.

Database: Arbitrary / Master / Project / Scenario

Annual or perennial crop

P:\AgMIP\Wheat Phase II\Low Information\Database\Crop\Spring Wheat Yecora Rojo.crp

Select | Edit/Create

To select a file from another directory, press the [Select] button above.

Database: Arbitrary / Master / Project / Scenario

Management scheduled relative to crop sowing date or phenology

<Optional for single crop, orchard or vinard cropping system mode>.mgt

Select | Edit/Create

To select a file from another directory, press the [Select] button above.

Relocate parameter files | Parameter database editor | Run this scenario | View output

Parameters | Details | Notes | Help | Commands | Status | Explaination

Save/Close | Cancel | Explore

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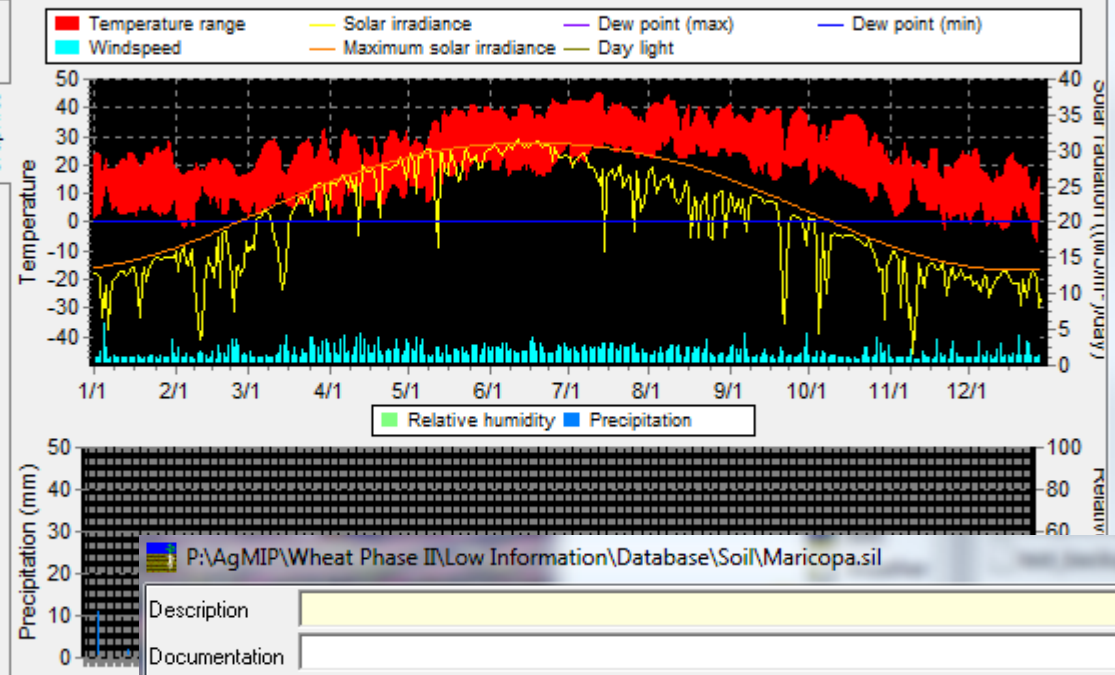
UED weather editor:P:\AgMIP\Wheat Phase II\Low Information\Database\Weather\AZ13030...

Geolocation | Daily weather

0 | Add year | 0 | 0 | [] | Delete elements years (range)

2003
2004
2005
2006
2007
2008
2009

Data | Graphics



OK | Ca

P:\AgMIP\Wheat Phase II\Low Information\Database\Soil\Maricopa.sil

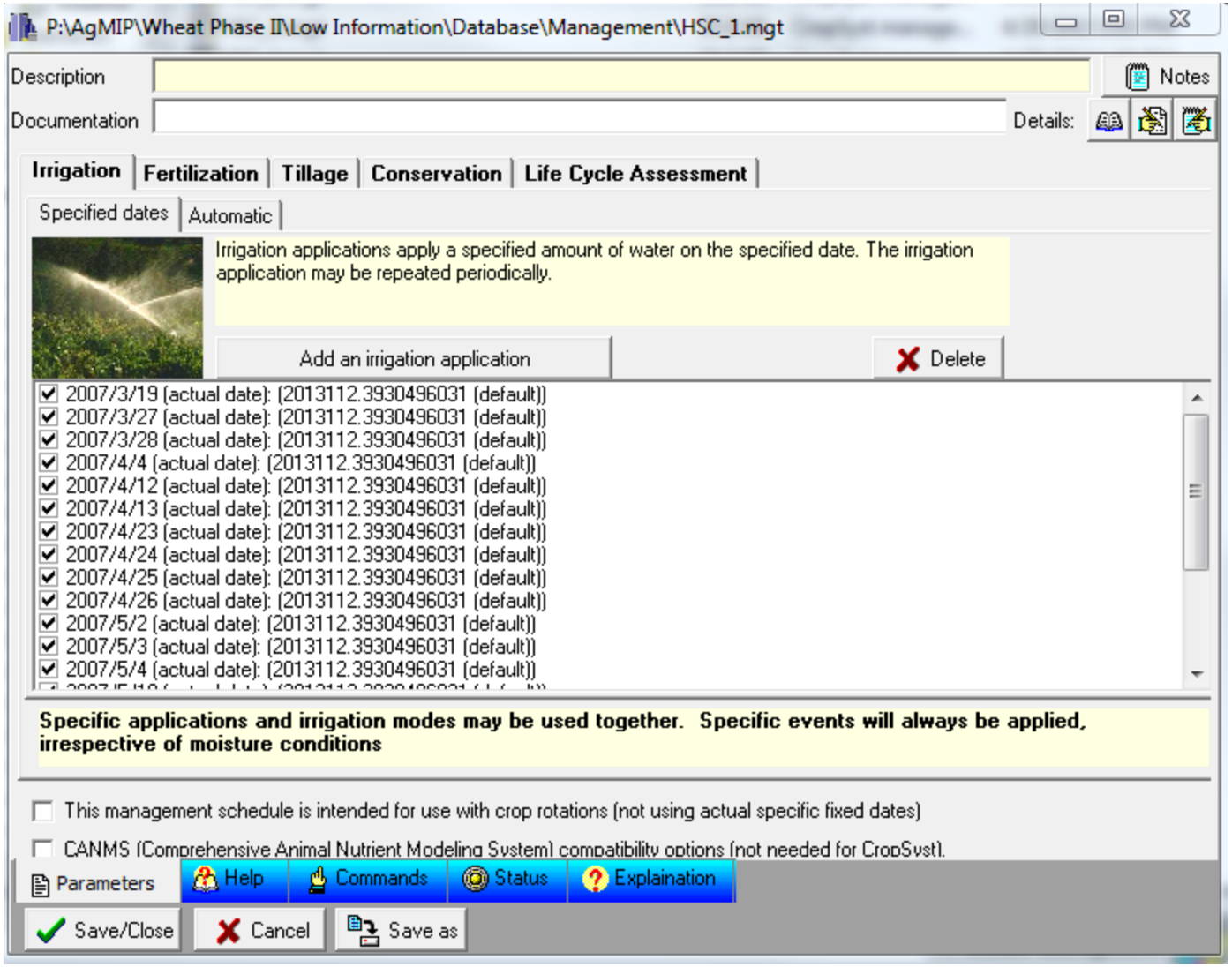
Description

Documentation

Profile | Surface | Runoff | Erosion | Other

Texture | Hydraulic properties | Chemistry | <-- Focus to column

Layers 11	Thickness m	Sand %	Clay %	Silt %	Layer bypass 0-1	Permanent wilt point m³/m³	Field capacity	Bulk density	Water pot at FC kPa	Saturated hydr.conc. m/day	Air entry potential J/kg	Campbell b	Saturation m³/m³ (Computed)	Cation exchange	pH
1	0.050	35.000	34.000	31.00	0.300	0.190	0.323	1.310	-38.424	0.072	-1.340	7.157	0.506	255.000	7.00
2	0.100	35.000	34.000	31.00	0.300	0.191	0.326	1.270	-38.424	0.097	-1.155	7.157	0.521	255.000	7.00
3	0.150	35.000	34.000	31.00	0.300	0.191	0.326	1.270	-38.424	0.097	-1.155	7.157	0.521	255.000	7.00
4	0.200	35.000	34.000	31.00	0.300	0.190	0.324	1.300	-38.424	0.078	-1.292	7.157	0.509	245.000	7.00
5	0.100	35.000	34.000	31.00	0.300	0.180	0.307	1.470	-38.424	0.017	-2.329	7.157	0.445	235.000	7.00
6	0.100	35.000	34.000	31.00	0.300	0.180	0.307	1.470	-38.424	0.017	-2.329	7.157	0.445	235.000	7.00
7	0.200	45.000	30.000	25.00	0.300	0.157	0.266	1.570	-36.693	0.011	-1.474	7.255	0.408	207.000	7.00
8	0.200	55.000	25.000	20.00	0.300	0.140	0.238	1.570	-34.171	0.027	-0.701	7.162	0.408	173.000	7.00
9	0.100	55.000	25.000	20.00	0.300	0.150	0.255	1.403	-34.171	0.105	-0.409	7.162	0.470	173.000	7.00
10	0.100	55.000	25.000	20.00	0.300	0.150	0.255	1.403	-34.171	0.105	-0.409	7.162	0.470	173.000	7.00
11	0.200	60.000	20.000	20.00	0.300	0.122	0.220	1.570	-31.084	0.071	-0.579	6.536	0.408	138.000	7.00



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P:\AgMIP\Wheat Phase II\Low Information\Database\Crop\Spring Wheat Yecora Rojo DailyTT.crp

Description: Wheat - winter (Triticum aestivum)

Notes

Documentation: http://en.wikipedia.org/wiki/Common_wheat

Details:

Root | Photo-period | Harvest | Dormancy/Seasonal | Senescence | Hardiness | Residue | Nitrogen | Salinity | CO2 | Adjustments

Defaults | Classification | Emergence | Thermal time accumulation | Transpiration | Attainable growth | Canopy growth | Phenology | Vernalization

Thermal time to reach:

☐ Clipping resets active growth

Emergence	85	°C-days
Maximum root depth	840	°C-days
End canopy growth	840	°C-days
Begin flowering	940	°C-days
Begin filling (seed filling, or orchard fruit filling, or tuber bulking)	1050	°C-days
Begin senescence (thermal time)	1100	°C-days
☑ Maturity is significant	(applicable to annual crop and fruit trees and not perennials)	
Physiological maturity	1510	°C-days
Adjustment factor for phenologic response to stress	1.00	0-1

Parameters | Help | Commands | Status | Explaination | Translation

Save/Close | Cancel | Save as

☐ Advanced

P:\AgMIP\Wheat Phase II\Low Information\Scenarios\CS02low\Output

Description

Scenario results | Report generation

Fast graph

Schedule

Harvest report

Reports that can be generated

Available reports

- Soil
- daily.xls
- season.xls

Soil profile reports

- ammonium.xls
- cum_water_depth....
- NH4_mineralizati...
- nitrate.xls
- Root_fraction.xls
- water_content.xls
- water_depth.xls

Fast Graph: P:\AgMIP\Wheat Phase II\Low Information\Scenarios\CS02low\Output\daily.ued

Weather | Evapotranspiration | 2007/1/1

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

☑	Precipitation	0 - 15 mm
☑	Runoff	0 - 15 mm
☑	Solar radiation	0 - 35 MJ/m²
☑	Temperature	°C

Plant

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

☑	Biomass	0 - 10000 kg/h
☑	Leaf Area Index	0 - 8
☑	Green Area Index	0 - 8
☑	Water stress	(index) 1 - 0
☑	Temperature stress	(index) 1 - 0
☑	Nitrogen stress	(index) 1 - 0
☑	Root depth	m

Soil: Plant Available Water | Temperature | Nitrogen | Salinity

Plant Available Water

Red = 0.0 (dry) Blue = 100 (Wet)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

☑	Water table depth	m

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Daily report		Version:	4.17.08											
2			Build date:	May 15 2013											
3			Run date:	May 16 2013											
4															
5					Growing	Above	Leaf		Total					Soil	Soil
6				Growth	degree	ground	area	Root	nitrogen	Potential	Actual	Potential	Actual	evaporation	evaporation
7	Year	Month	Day	stage	days	biomass	index	depth	uptake	ET	ET	transpiration	transpiration	pot.	act.
8						(kg/ha)	(m2/m2)	(m)	(kgN/ha)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
18	2007	3	21	Preemergence	17.500	0.000	0.000	0.200	0.000	6.779	6.7792	0.0000	0.0000	6.7792	6.7792
19	2007	3	22	Preemergence	32.400	0.000	0.000	0.200	0.000	3.749	3.7491	0.0000	0.0000	3.7491	3.7491
20	2007	3	23	Preemergence	44.650	0.000	0.000	0.200	0.000	3.203	3.2030	0.0000	0.0000	3.2030	3.2030
21	2007	3	24	Preemergence	58.150	0.000	0.000	0.200	0.000	3.467	3.4671	0.0000	0.0000	3.4671	3.4671
22	2007	3	25	Preemergence	73.500	0.000	0.000	0.200	0.000	4.327	4.3273	0.0000	0.0000	4.3273	4.3273
23	2007	3	26	Active growth	90.200	22.727	0.050	0.200	0.000	4.553	1.3791	0.0000	0.0000	4.5531	1.3791
24	2007	3	27	Active growth	104.450	29.782	0.065	0.200	0.532	6.819	6.8186	0.1400	0.1400	6.6786	6.6786
25	2007	3	28	Active growth	113.450	35.639	0.078	0.227	0.969	4.930	4.9304	0.1012	0.1012	4.8292	4.8292
26	2007	3	29	Active growth	122.550	42.203	0.092	0.244	1.423	4.569	4.5689	0.1225	0.1225	4.4464	4.4464
27	2007	3	30	Active growth	134.400	50.118	0.110	0.261	1.966	4.710	1.3528	0.1507	0.1507	4.5597	1.2020

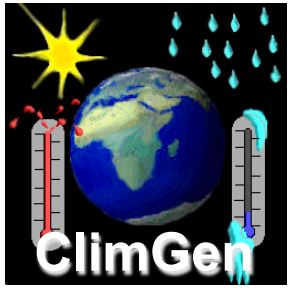
Simulation-based Estimation and Projection

Soil

Weather

Cropping systems

Management



Arc GIS – CropSyst Cooperator

Biomass

Yield

ΔSOC

GHG emissions

Water, N, C balance

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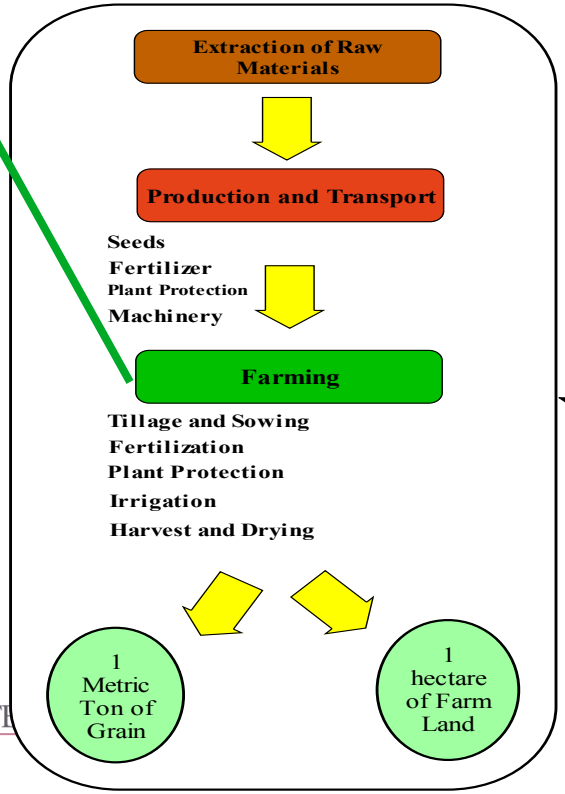
CropSyst- Farm LCA Interaction

Biomass

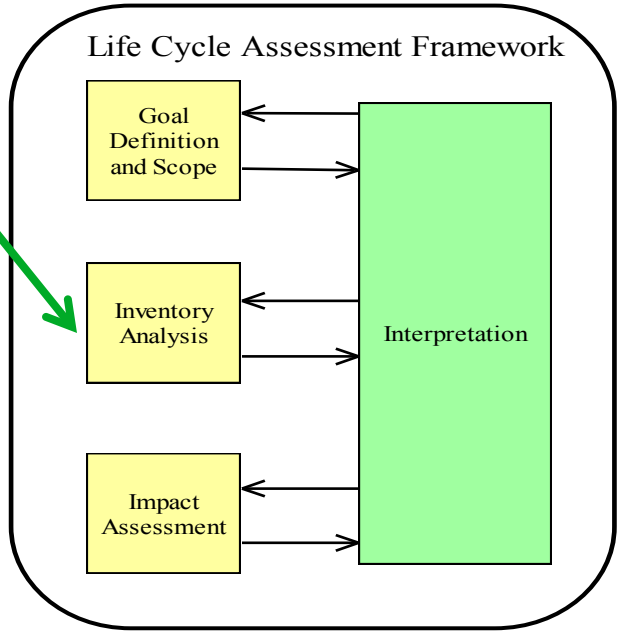
Yield

ΔSOC

GHG emissions



System Boundary



LCA Software

CropSyst, from Crop Growth to Agricultural Systems Modeling

- New demands for computer simulation tools and applications have led to upgrades of CropSyst capabilities and functionalities in the last decade
- Integration into larger modeling frameworks and spatial scales
- Upgrades to run simulations under multiple platforms, in addition to MS-Windows, such as Linux based high-performance computer clusters and supercomputers.
- Specialized tools to inform policy makers and stakeholders such as CropSyst-IST (Irrigation Strategies Tool), a tool to address responses to water shortages, OFoot, an organic farm management model, and CAFE Dairy, a farm energy and nutrient design and management system.

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Land Allocation Decision Support System

LADSS Portal Home
Decision Support Home
Rationale
Development
Components
Site Characterisation
Themes
Papers/Publications
Reference Materials
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Oracle Database
Land Use Planning
Smallworld GIS
CropSyst
Livestock
Impact Assessments

CropSyst

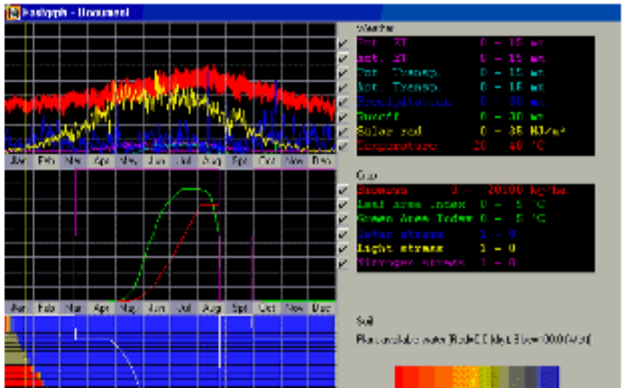
CropSyst is a is a multi-year multi-crop daily time step simulation model which has been developed to study the effect of cropping systems management on productivity and the environment. The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion. Management options include: cultivar selection, crop rotation (including fallow years), irrigation, nitrogen fertilization, tillage operations, and residue management.

The People Involved

CropSyst has been developed by a team at the Biological Systems Engineering Department of Washington State University. Heading the team is Dr Claudio Stöckle. Software development has been carried out by Roger Nelson. For more information see the CropSyst website.

LADSS - CropSyst Integration

The integration of CropSyst facilitates the representation of a wide range of crop-based land-uses within LADSS. The integration has required a substantial amount of structural alterations to both LADSS and CropSyst, not least the



MARS ies JRC EUROPEAN COMMISSION

Biophysical Models Applications

BioMA

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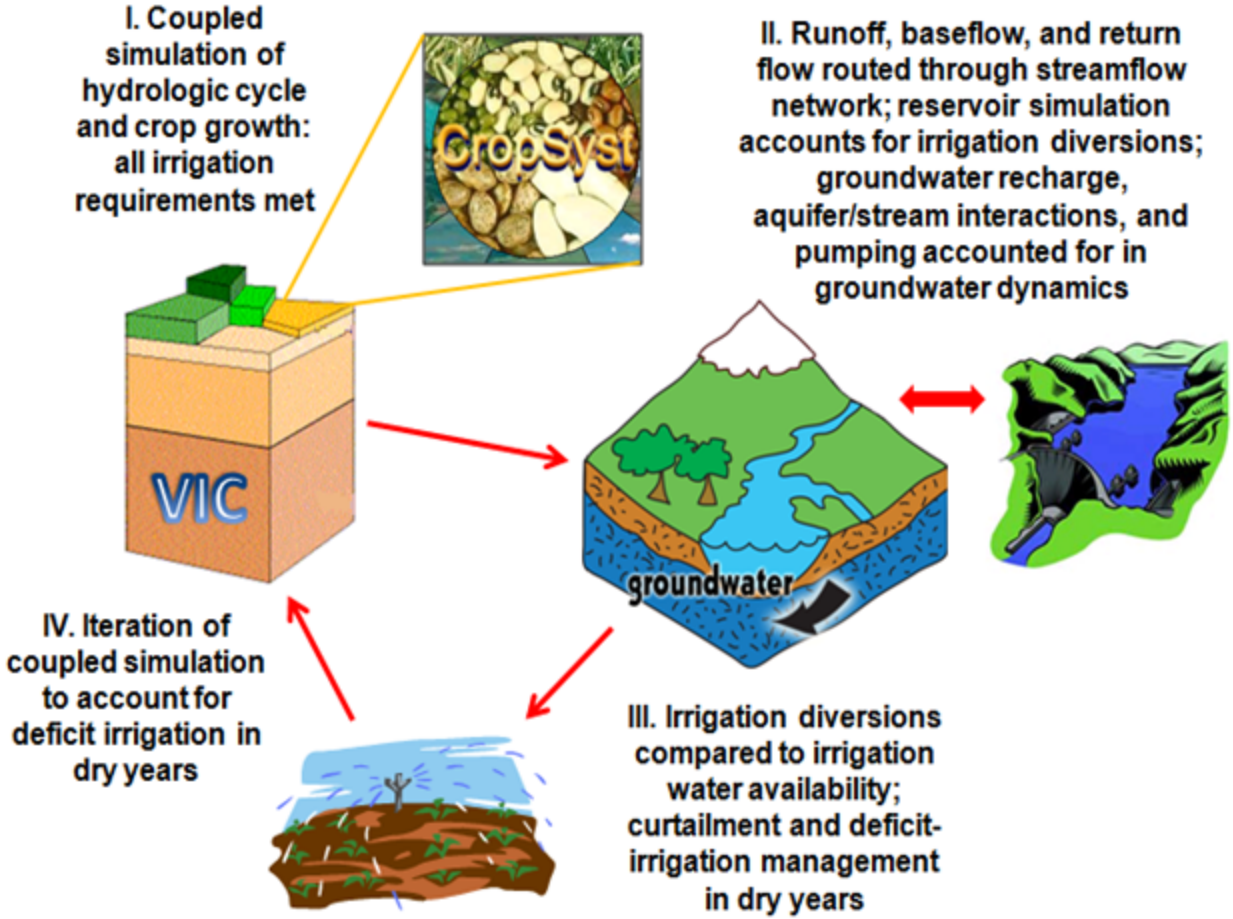
VIC-CropSyst



BioEarth

Biosphere-relevant earth system model

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Crop Growth Models in Agriculture

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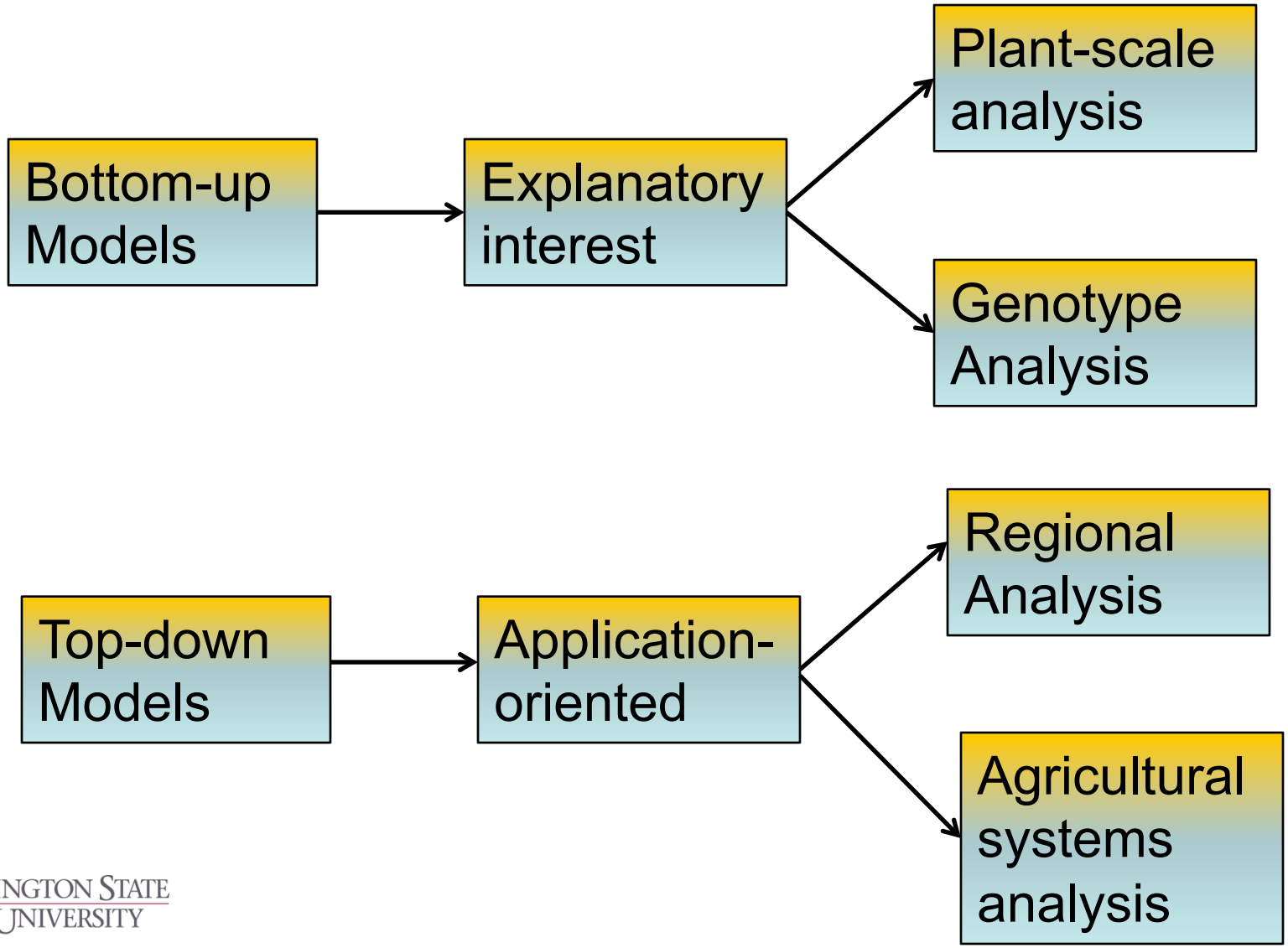
What is the model objective?



The CTP model

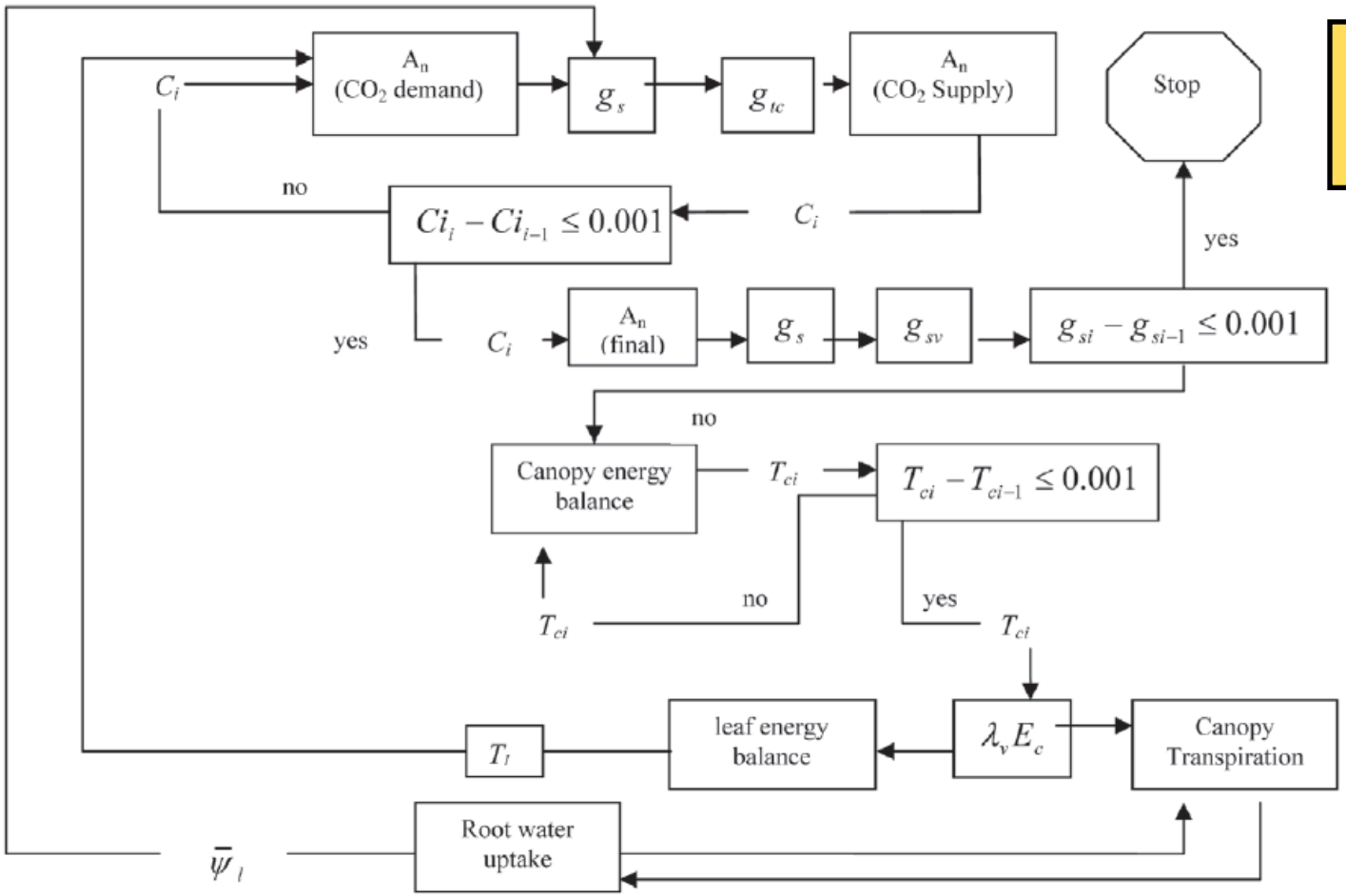


Fig. 6–1. Model diagram of main equations and their iterative solution, where A_n is the leaf net photosynthesis, T_c and T_l are canopy and leaf temperature, g_s, g_{tc}, and g_{sv} are the average leaf stomatal conductance for CO_2, leaf conductance to CO_2 and water vapor, $\bar{\psi}_l$ is the average leaf water potential, $\lambda_v E_c$ is the canopy latent heat, i is an index indicating time step, and C_i is the internal CO_2.

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A mix of top-down and bottom-up approach

Average sunlit and shaded leaf photosynthesis

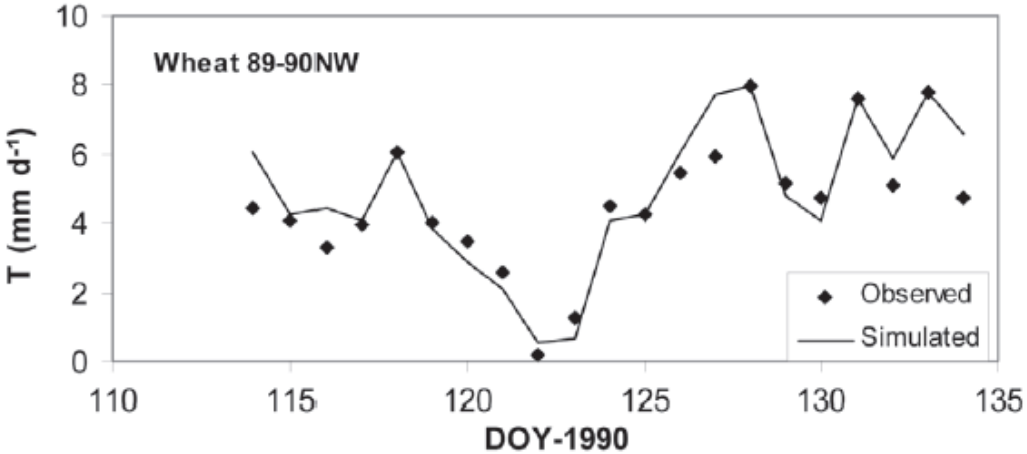
Table 6–1. List of input parameters used for model simulations.

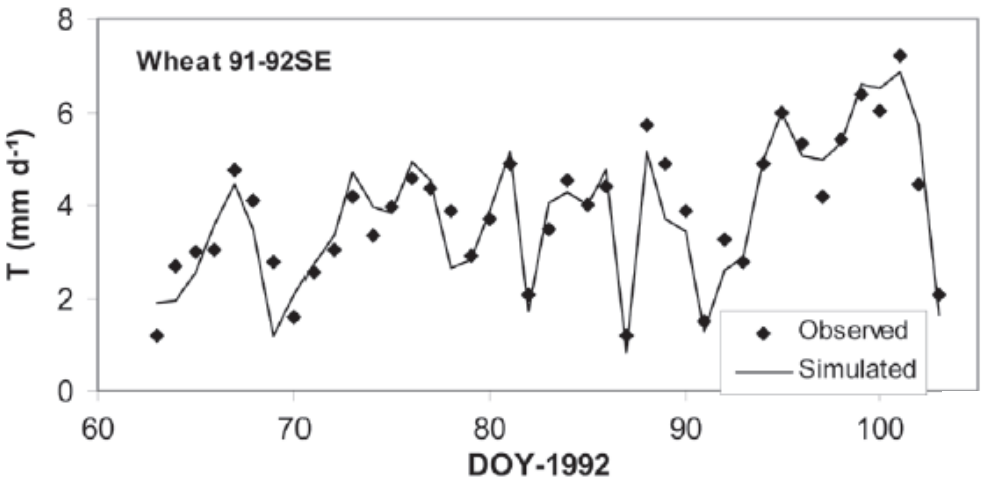
Parameters	Units	Maize	Wheat	Equation number
K_c	μmol mol^{-1}		237	9
K_o	μmol mol^{-1}		328	9
δ	μmol mol^{-1}		0.08	7
V_m	μmol m^{-2} s^{-1}	51.5	135	9, 13
u	mol m^{-2} s^{-1}	1.038		12
$\delta\gamma$	–	0.067		11
g_{Dl}^{0}	mol m^{-2} s^{-1}	0.87	2.31	18
D_o	kPa	0.66	0.40	18
g_s^{max}	mol m^{-2} s^{-1}	0.4	0.5	21
$\psi_{1/2}$	J kg^{-1}	–1660	–1600	24
n	–	7	10	24

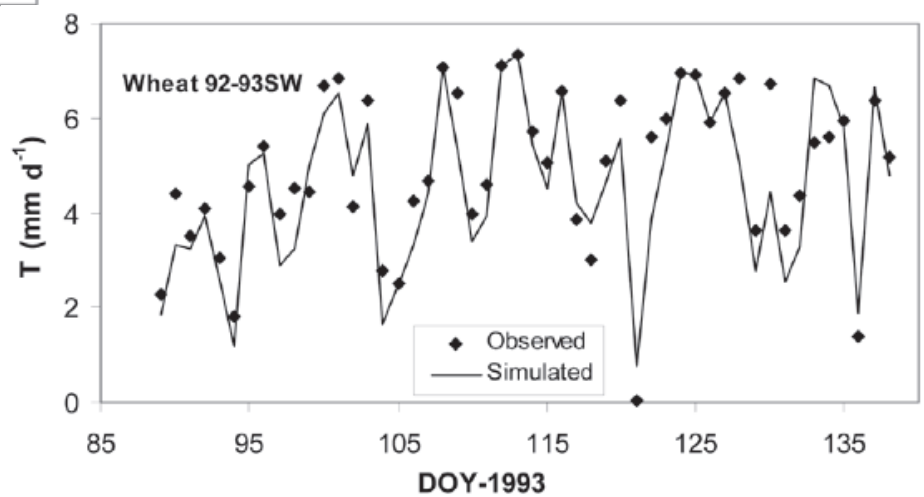
More Processes and Parameters

- Canopy structure
- Canopy radiation
- Leaf photosynthesis
- Stomatal regulation (CO2, VPD, water)
- Canopy energy balance
- Root water uptake
- Canopy transpiration
- Biomass accretion (respiration, partitioning)

CTP simulation of transpiration (lysimeter data from Bushland TX)







Kremer et al., 2008

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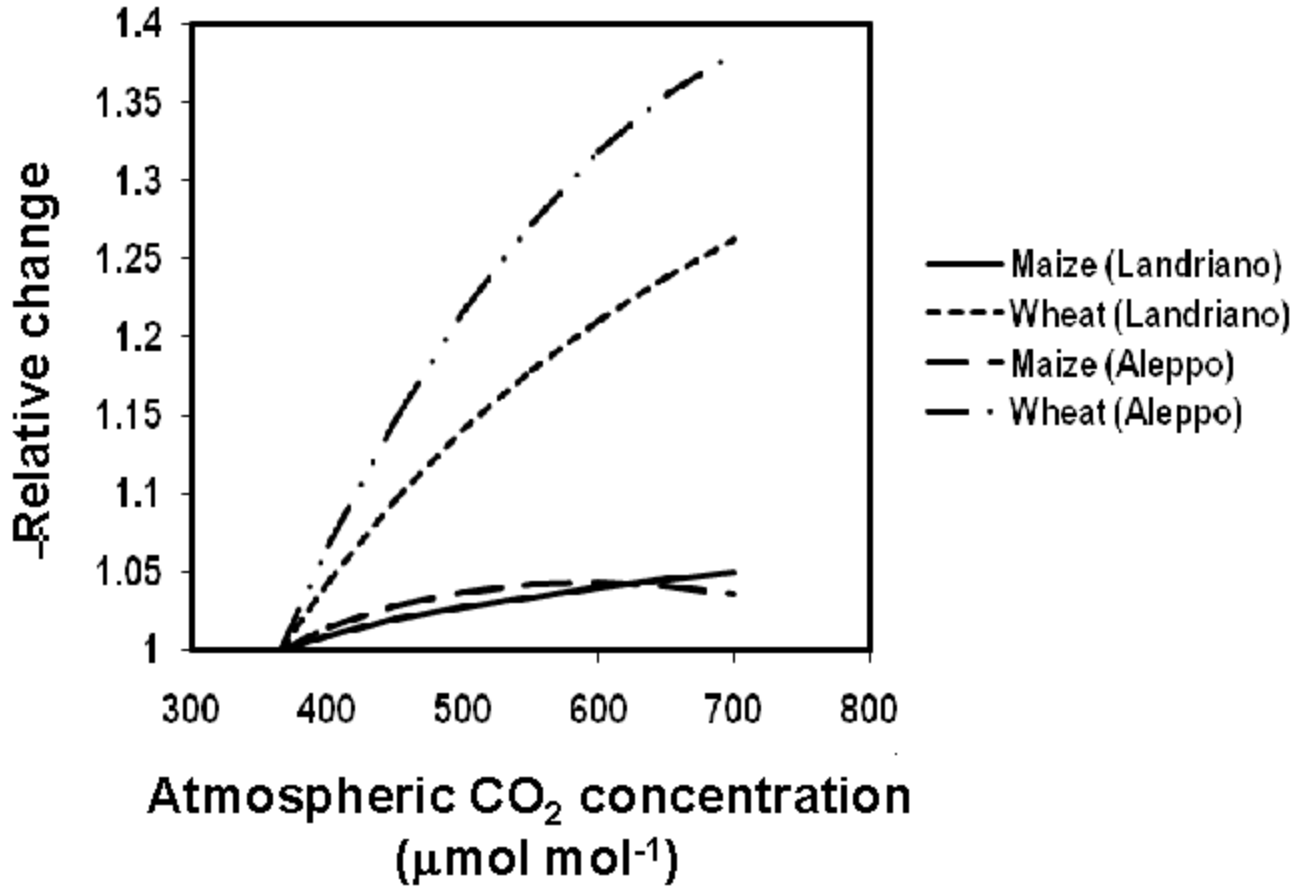
CTP model output



Stöckle and Kemanian, 2009

CropSyst, a Process-oriented Top-Down Model

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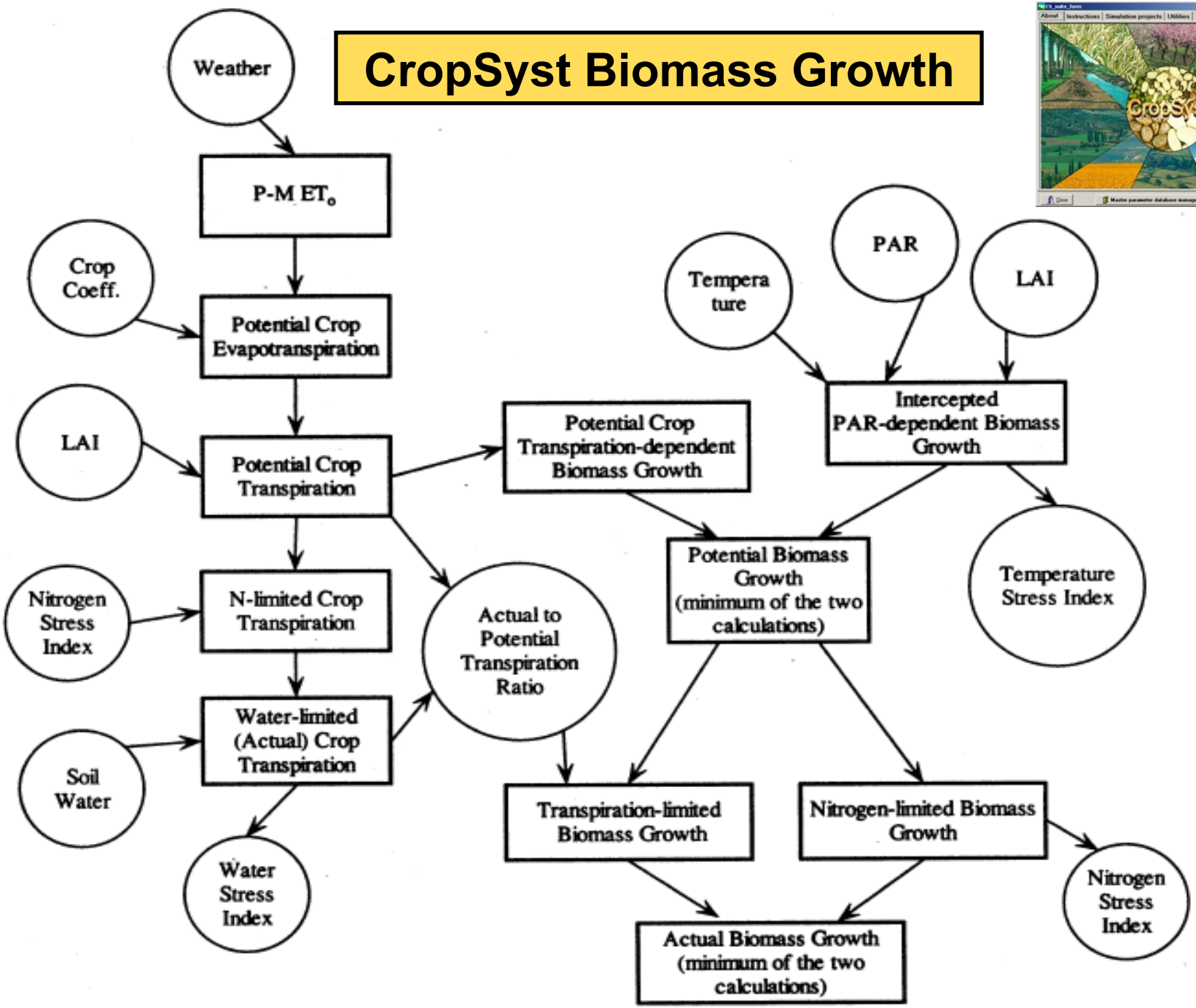
CropSyst, a Process-oriented Top-Down Agricultural Systems Model

- Top-down resource-capture modeling approach
- Plant transpiration (T)
  - Atmospheric water demand
  - Soil water and roots
  - Stomatal control
  - Daily and hourly water uptake
  - Water stress
- Biomass accretion (BA)
  - Radiation-use efficiency (RUE)
  - Transpiration-use efficiency (TUE)
- Interaction CO2 x T X BA
  - Changes in stomatal conductance
  - Changes in transpiration
  - Changes in RUE and TUE

CropSyst Biomass Growth



CropSyst, a Process-oriented Top-Down Model

First, let us take a look at transpiration and water uptake modeling

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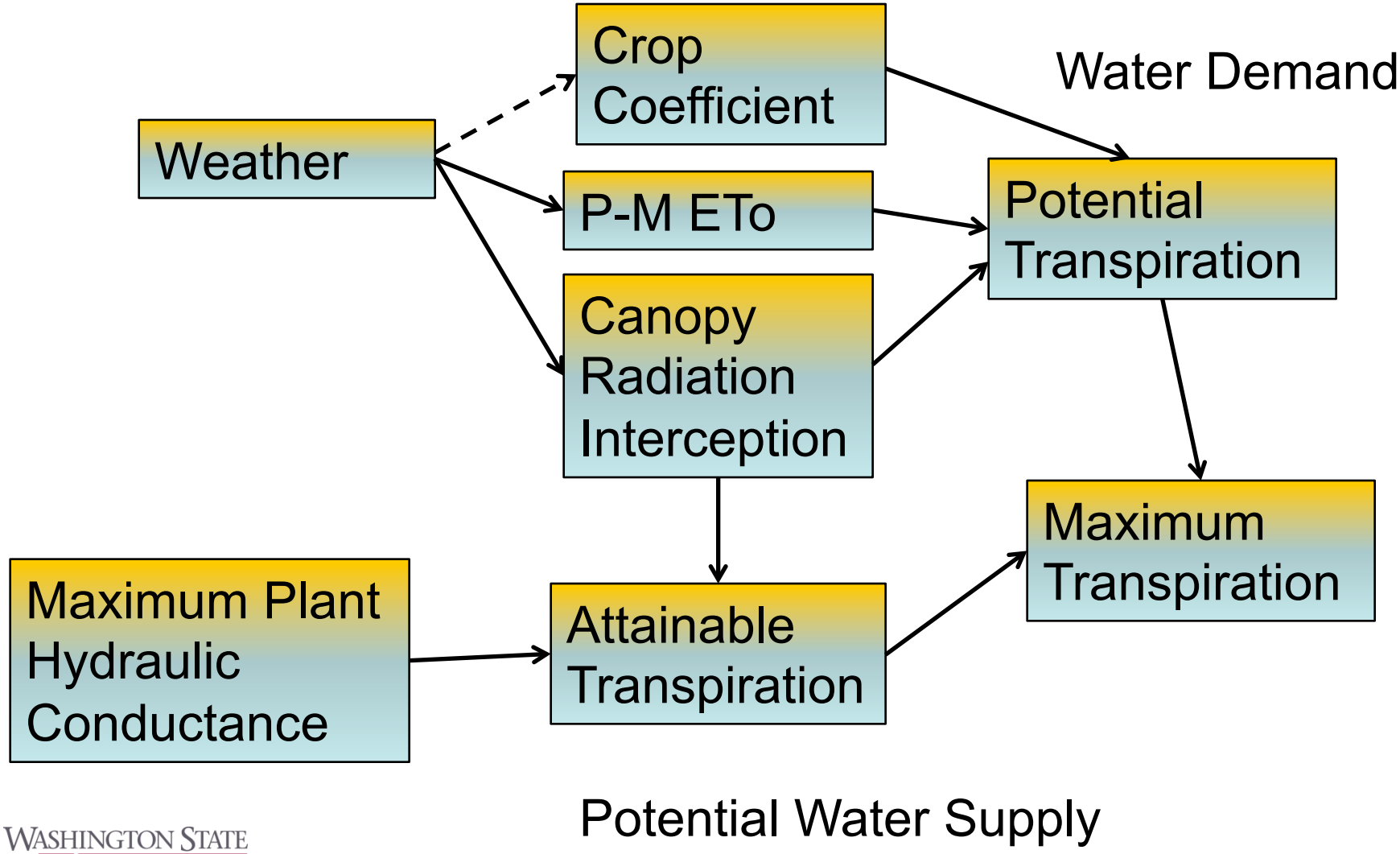
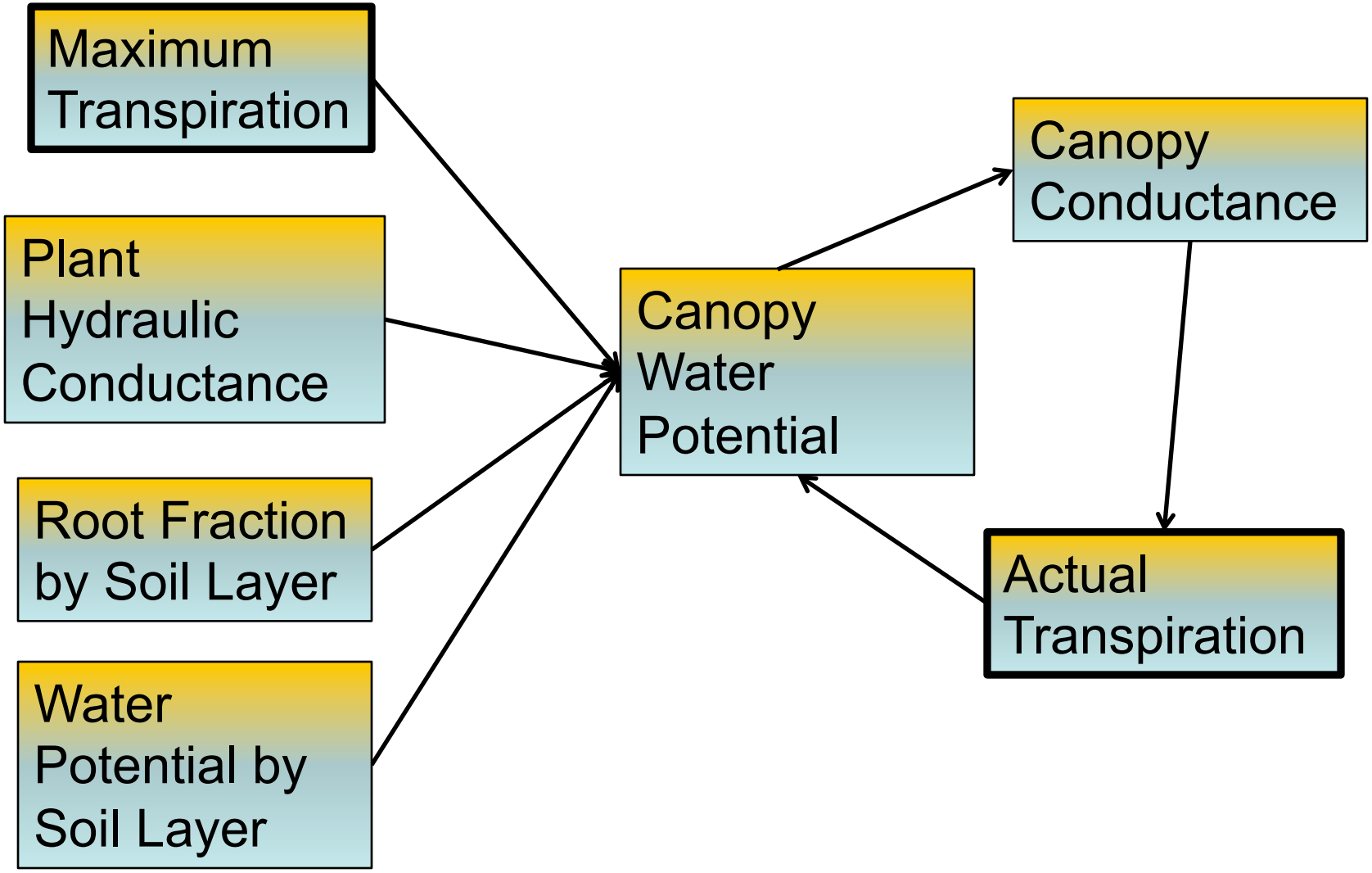
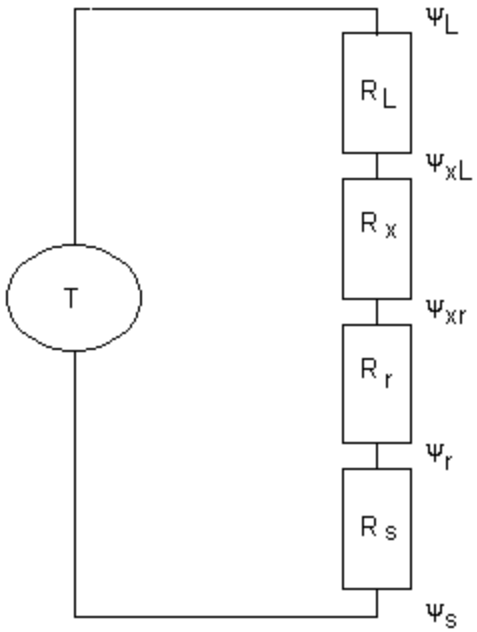
Maximum Transpiration

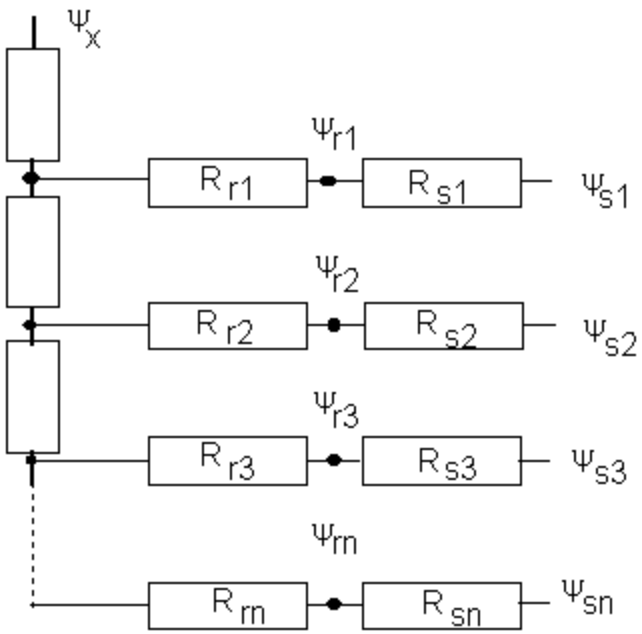


Water Uptake = Actual Transpiration





Electrical analog of liquid water transport through the plant showing the potentials resistances from the bulk soil to the intercellular spaces in the leaf.



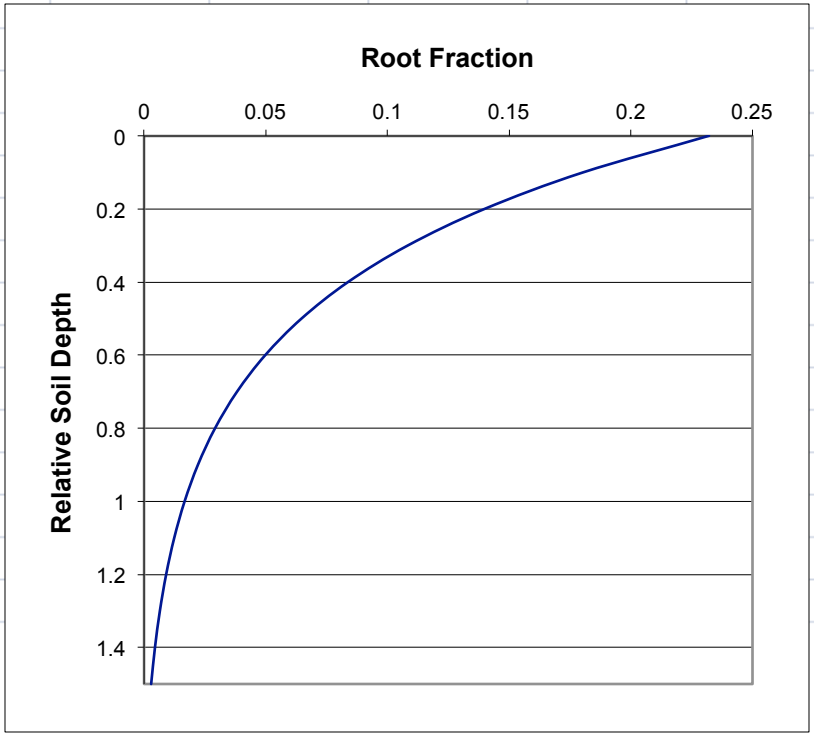
Electrical analog of the soil-root system showing water potential with depth in the soil and soil and root resistances to water uptake.

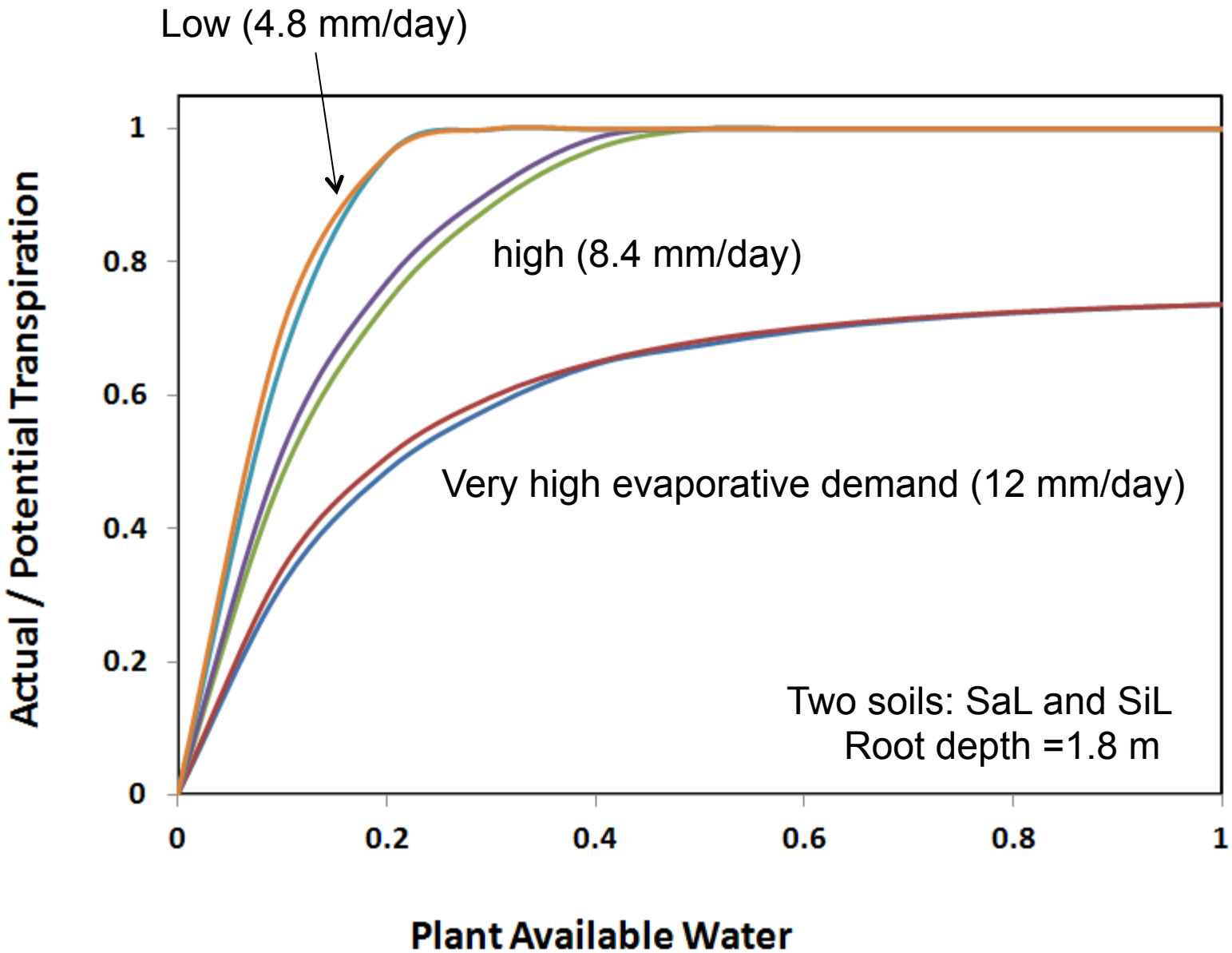
	A	B	C	D	E	F
1	Crop Water Uptake					
2					RUN	
3	Atmospheric Parameters					
4	10	Potential Crop ET (mm/day)				
5	1.2	Crop Coefficient Full Canopy				
6	Crop Parameters					
7	1.8	root depth (m)				
8	-1000	leaf water potential at the onset of stomatal closure (J/kg)				
9	-1500	leaf water potential at wilting (zero transpiration) (J/kg)				
10	10	maximum full cover transpiration rate (mm/day)				
11	0.8	Fractional Canopy Interception				
12						
13	Soil Parameters					
14	10	Number of soil layers				
15	Layer	thick (m)	Bulk Dens	Air Entry	b	WC
16			(Mg/m3)	Pot (J/kg)		(m3/m3)
17	1	0.2	1.3	-5	3.9	0.294
18	2	0.2	1.3	-5	3.9	0.270
19	3	0.2	1.3	-5	3.9	0.254

Summary of Daily Crop Water Uptake

9.6	Potential Crop Transpiration (mm/day) (as given by atmospheric demand)
8	Maximum Water Uptake (mm/day) (as given by crop characteristics)
8	Attainable Transpiration (mm/day) (minimum of potential transpiration and maximum water uptake)
7.02274	Actual Transpiration (mm/day) (assumed equal to actual water uptake)
0.87784	Stress Index (actual to potential transpiration ratio)

Layer Number	Root Fraction	Water Uptake (mm/day)	
1	0.210	1.474	
2	0.185	1.301	
3	0.160	1.127	
4	0.136	0.954	
5	0.111	0.780	
6	0.086	0.607	
7	0.062	0.434	
8	0.037	0.260	
9	0.012	0.087	
10	0.000	0.000	
	1.000	7.023	Total Uptake (mm/day)





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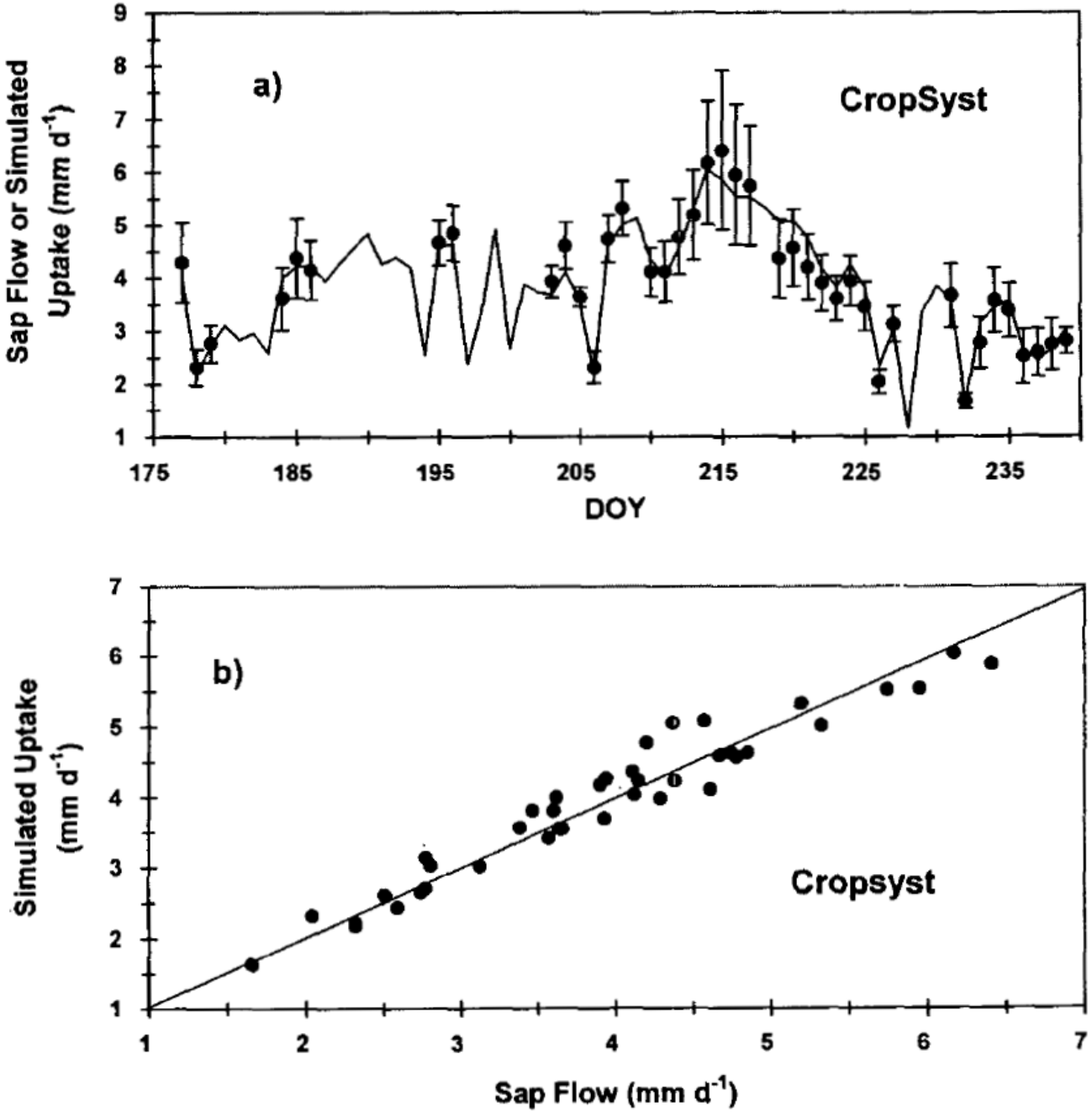
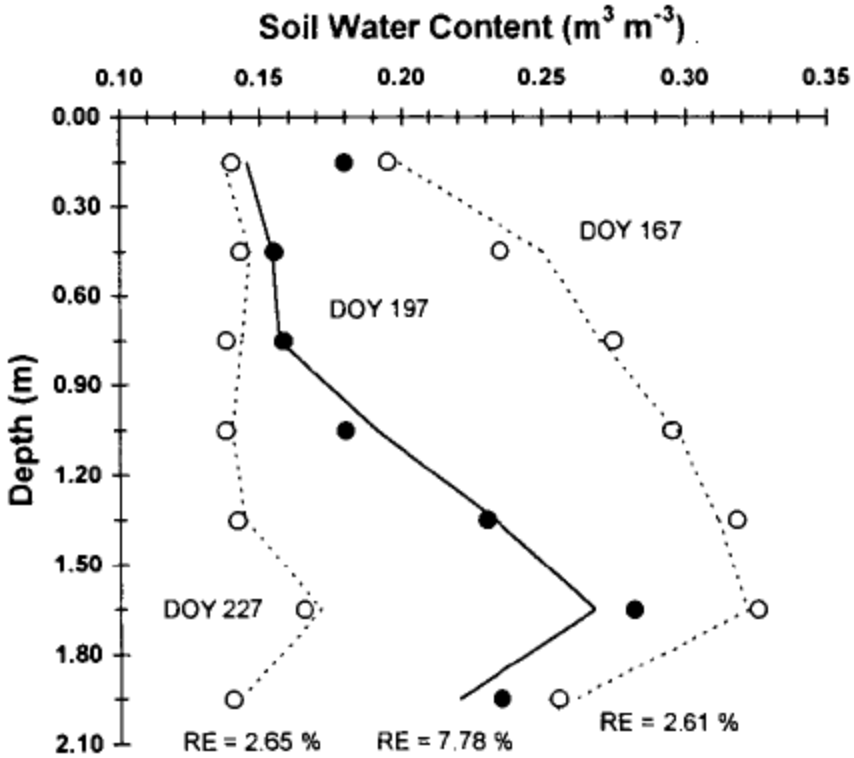
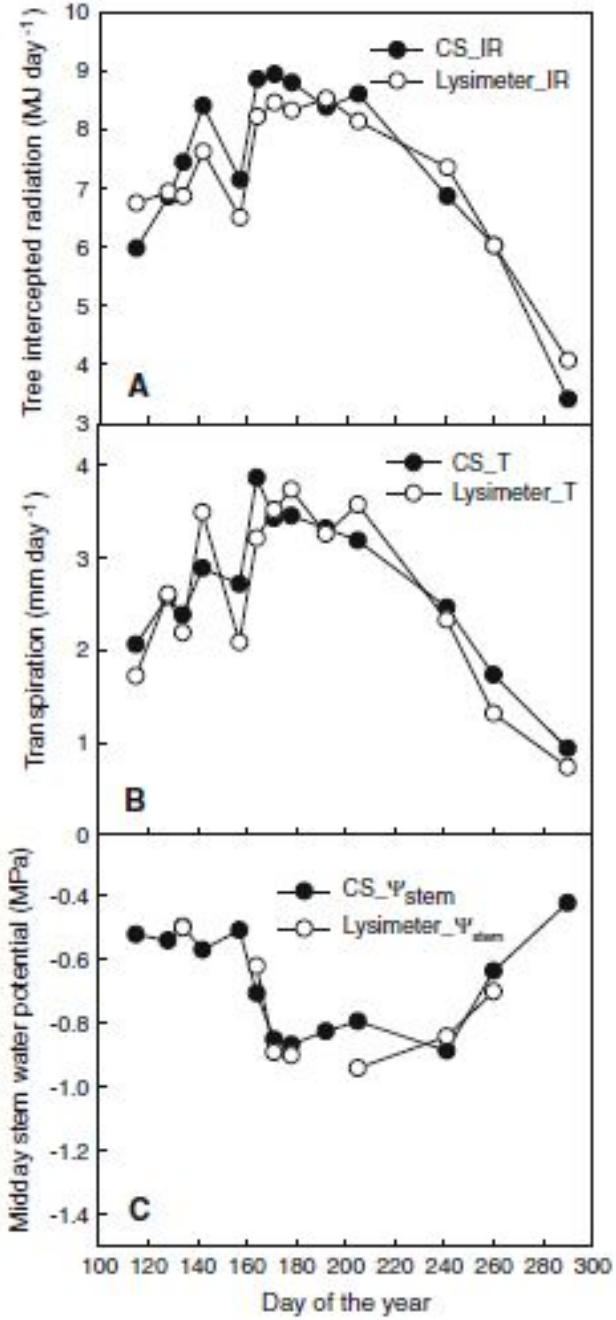


Jara and Stöckle, 1999



Water uptake simulation, non-irrigated maize, fully recharged deep soil (data from Davis CA)

Jara and Stöckle, 1999



Pears (data from Lleida, Spain)

Marsal and Stockle, 2012

ET simulation with varying degrees of water stress

Statistical comparisons of observed and simulated seasonal evapotranspiration for four crops and two locations (Stöckle et al., 1997; Pala et al., 1996)

Crop	Location	N	Obs mean (mm)	Sim mean (mm)	RMSE (mm)	RMSE/Obs mean	d
Wheat (Cham 1)[a]	Northern Syria	16	311	298	29	0.090	0.950
Wheat (Hourani)[a]		16	319	314	30	0.090	0.950
Sorghum	Auzeville, France	5	372	409	54	0.144	0.786
Soybean		6	412	443	42	0.102	0.956
Maize		6	416	414	13	0.031	0.997

N, number of data point; Obs, observed value; Sim, simulated value; RMSE, root mean square error; d, index of agreement.
[a] Cham 1 and Hourani correspond to improved and local varieties, respectively.

Stockle et al., 2003

Biomass and yield simulation with varying degrees of water stress

Statistical comparisons of observed and simulated responses to water treatments for four crops and four locations (Stöckle et al., 1994, 1997)

Crop	Location		N	Obs mean (kg/ha)	Sim mean (kg/ha)	RMSE (kg/ha)	RMSE / Obs mean	d
Maize	Davis, CA and Ft Collins, CO	Grain yield	28	9831	9026	724	0.081	0.950
		Biomass	28	16 460	16 808	1246	0.076	0.954
	Auzeville, France	Grain yield	9	8026	7847	1707	0.213	0.963
		Biomass	9	19 038	18 358	2921	0.153	0.966
Wheat	Logan, UT	Grain yield	18	4100	4261	443	0.108	0.979
		Biomass	18	8033	8460	1121	0.140	0.961
Sorghum	Auzeville, France	Grain yield	8	7601	8055	896	0.118	0.967
		Biomass	8	16 684	17 358	1139	0.068	0.985
Soybean	Auzeville, France	Grain yield	9	2828	2804	381	0.135	0.970

N, number of data point; Obs, observed value; Sim, simulated value; RMSE, root mean square error; d, index of agreement.

Stockle et al., 2003

Biomass Accretion

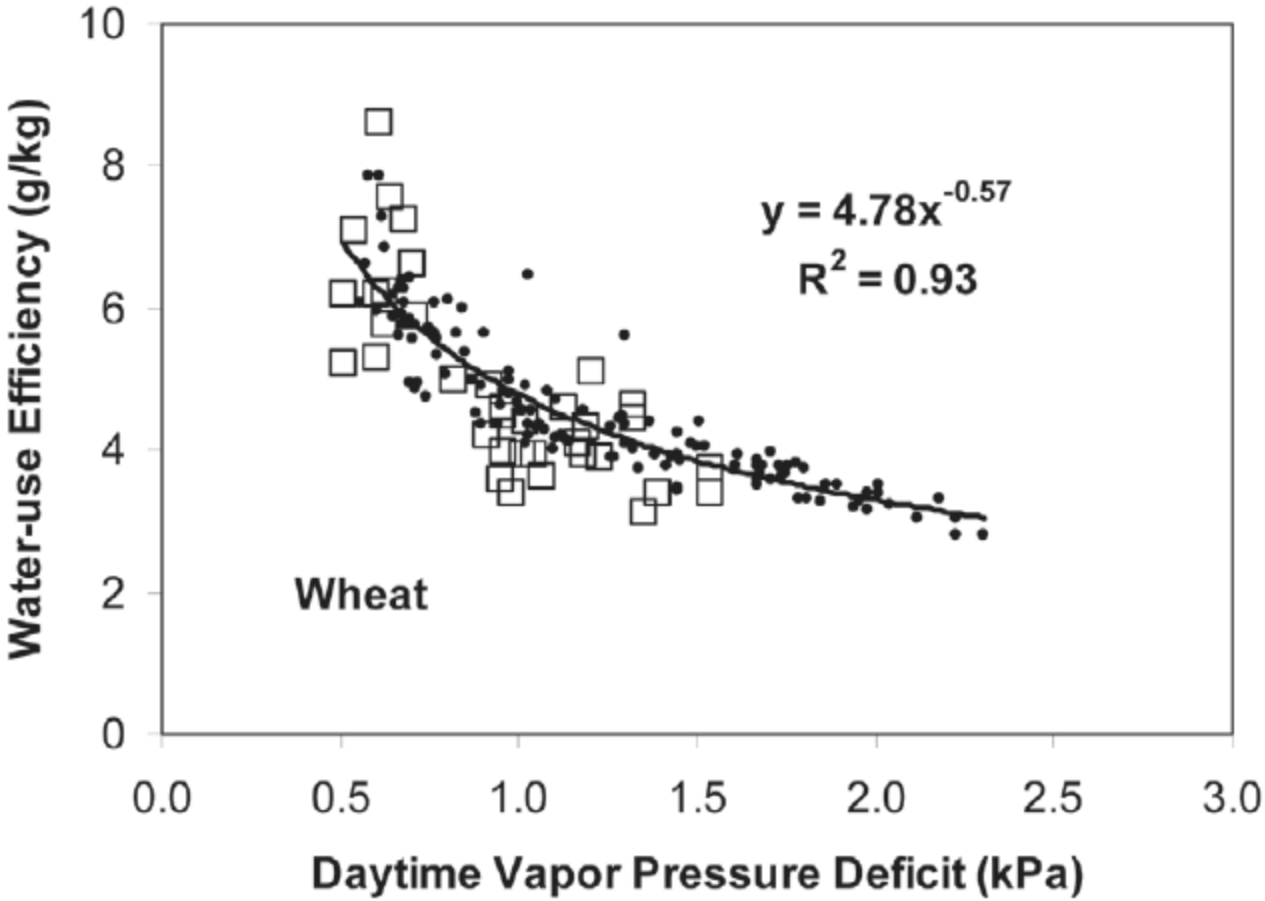
Dual Approach

Radiation-use efficiency at low D_a (upper limit)

$$B = ef_i S_t$$

Modified transpiration-use efficiency

$$B = \frac{\alpha T}{D_a^{\beta}}$$



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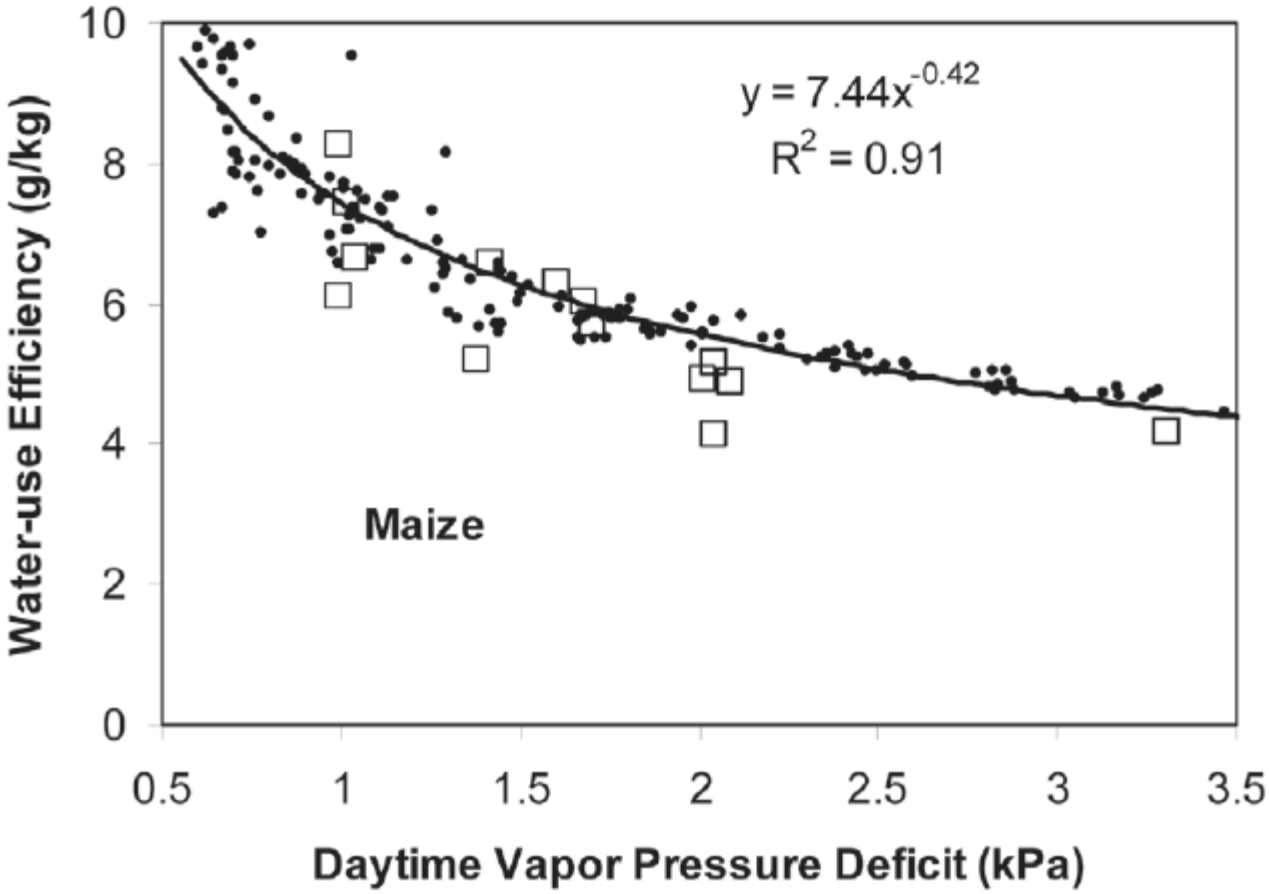

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Biomass Accretion under Elevated CO_2

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The implementation relies on experimental evidence of crop growth responses to CO_2. These experiments report the ratio (r_e) of biomass production for a specified elevated CO_2 concentration (C_e) to the production for a baseline concentration (C_b).

With this information, the biomass growth ratio at any CO2 concentration relative to the baseline (r_{CO_2}) can be obtained by assuming that r_{CO_2} and [CO2] are related by a Michaelis-Menten type of expression:

$$r_{CO_2} = \frac{r_F\,[CO_2]}{\mathrm{K} + [CO_2]}$$

$$K = \frac{C_e C_b (1 - r_e)}{r_e C_b - C_e}$$

$$r_F = \frac{K + \mathrm{C_b}}{C_b}$$

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The future values of TUE and RUE at any CO_2 concentration must be adjusted with respect to the values at the specified [CO_2] (C_S) at which they were determined, which is not necessarily the baseline [CO_2] defined for biomass response to elevated carbon dioxide.

$$r_{Sp} = \frac{r_{CO_2}(K + C_S)}{r_F C_S}$$

$$RUE_{CO_2} = r_{Sp}\, RUE_{C_S}$$

The determination of TUE_{CO2} is more involved given that biomass production, canopy resistance to vapor transfer, and transpiration will change with elevated [CO_2].

Experimental data for a number of C3 and C4 crops reported by Morison (1985) showed a linear reduction of canopy conductance as a function of increasing [CO_2] with a slope (S) of 0.00121per ppm of [CO_2].

The [CO2] adjusted canopy resistance is given by the following equation, where $r_{c_{FAO}}$ is the FAO Irrigation and Drainage Paper #56 (Allen et al., 1998) standardized canopy resistance (0.00081 d/m) for use with the FAO version of the Penman-Monteith reference ET, C_c is current [CO2], C_{FAO} is [CO2] when the FAO56 was published (~359 ppm), and S was defined previously.

$$r_{c_{adj}} = \frac{r_{c_{FAO}}}{1-(C_c - C_{FAO})S}$$

Given the change of canopy resistance as a function of [CO2], crop transpiration calculated based on the standard FAO56 PM-ETo must be multiplied by the following adjustment factor (FT).

$$F_T = \frac{\Delta + \gamma(r_{c_{FAO}} + r_a)/r_a}{\Delta + \gamma(r_{c_{adj}} + r_a)/r_a}$$

Finally, TUE_{CO2} is given by

$$TUE_{CO2} = \frac{TUE_{C_S}\ r_{Sp}}{F_T}$$

(Actually, only α in

$$B = \frac{\alpha\, T}{D_a^{\beta}}$$

is adjusted)

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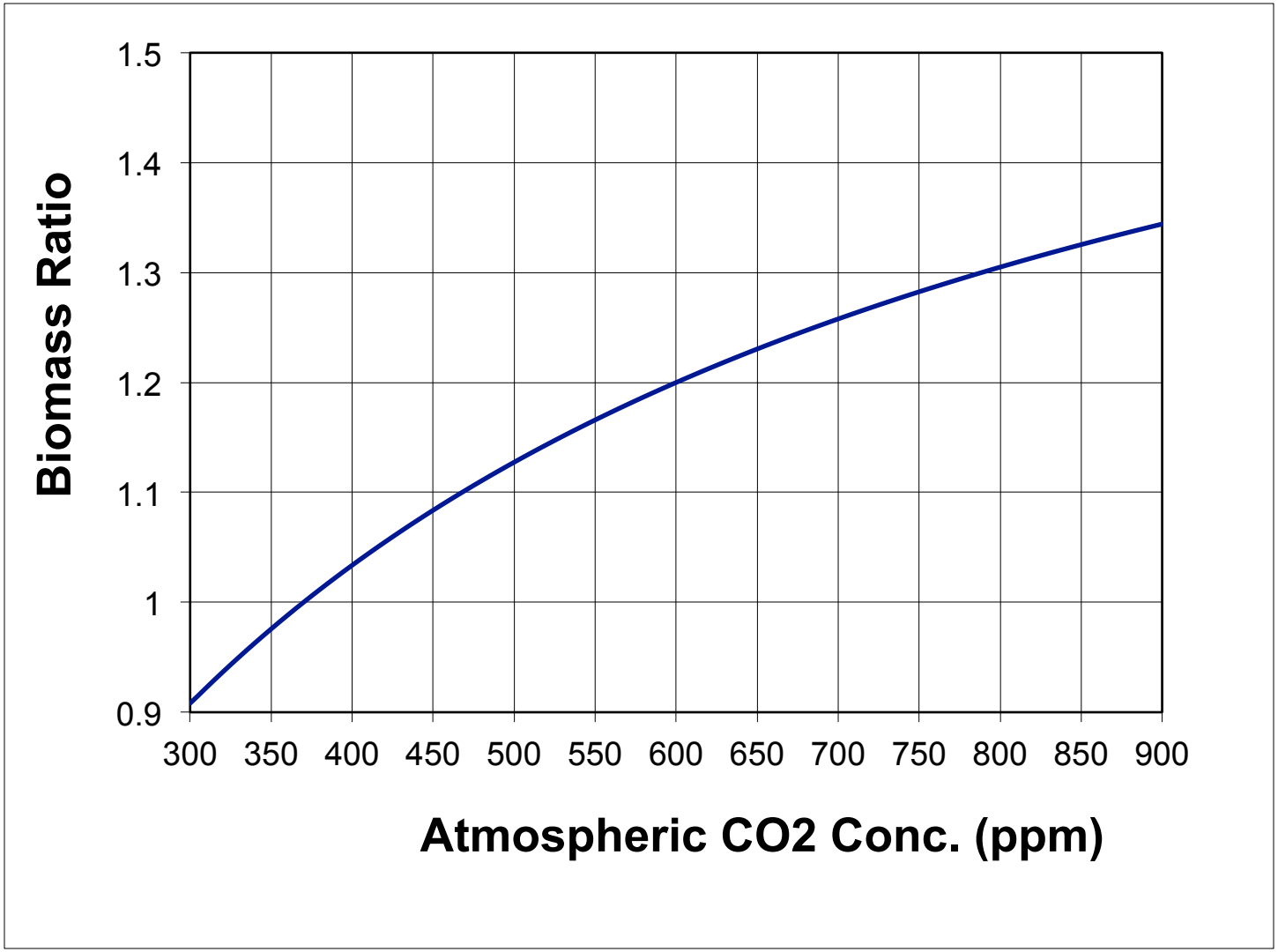
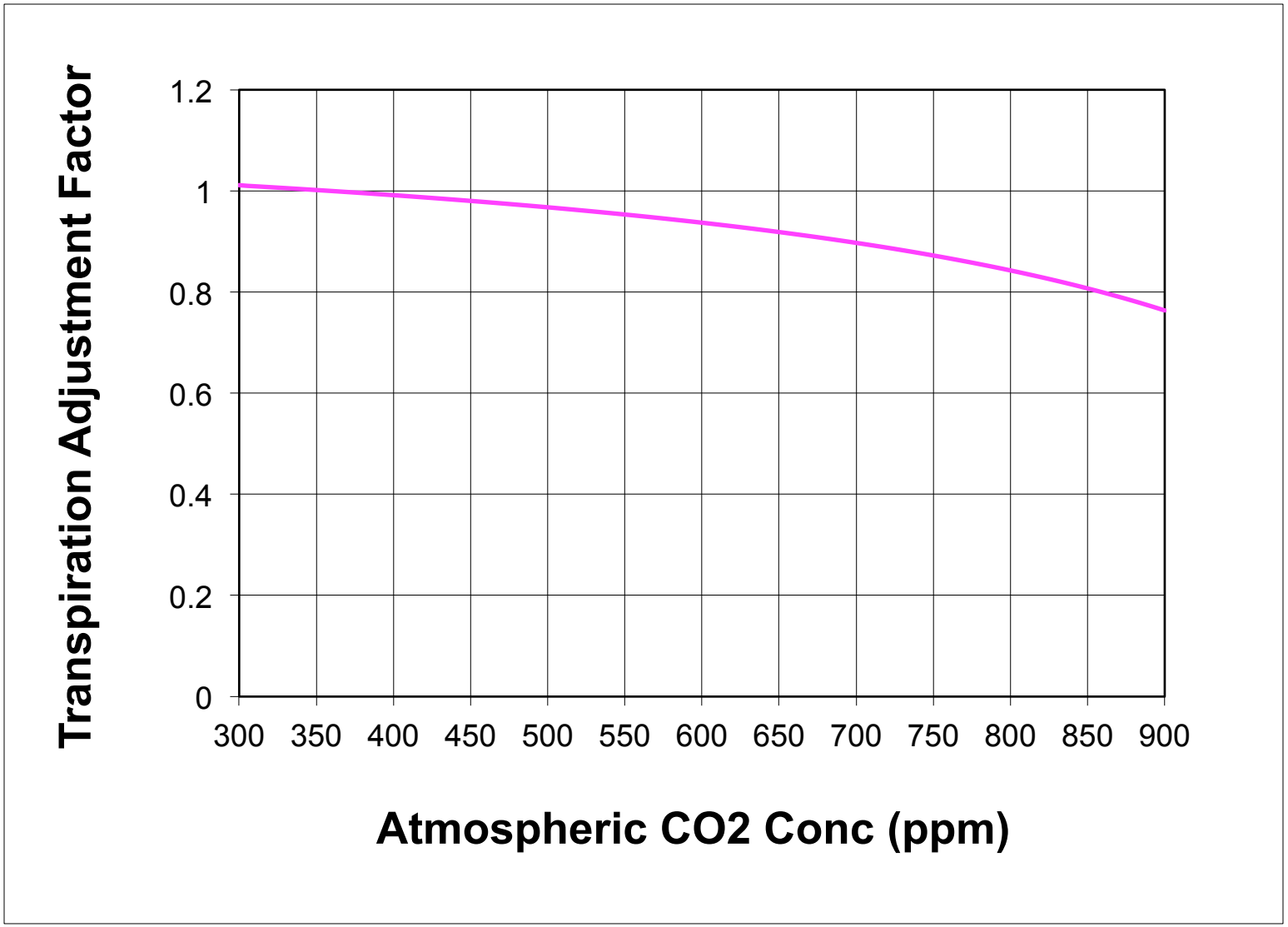
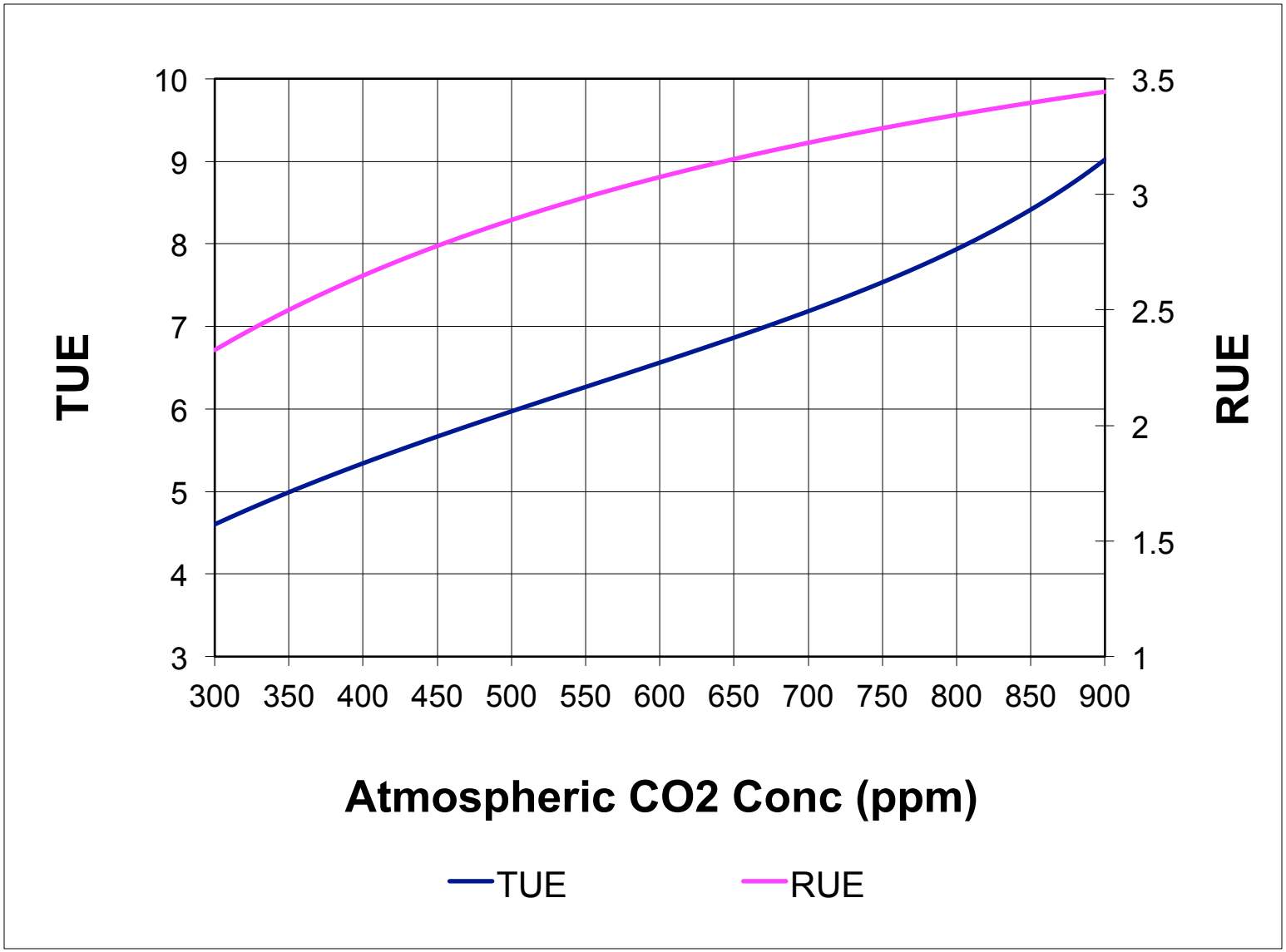

Biomass Ratio
1.5
1.4
1.3
1.2
1.1
1
0.9
300
350
400
450
500
550
600
650
700
750
800
850
900
Atmospheric CO2 Conc. (ppm)

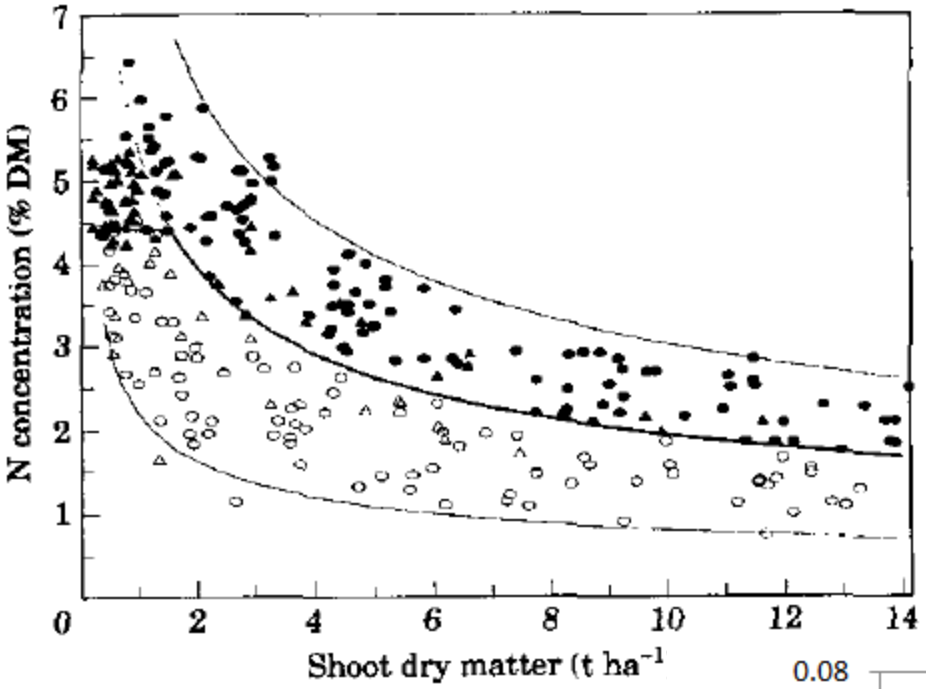

Transpiration Adjustment Factor
1.2
1
0.8
0.6
0.4
0.2
0
300
350
400
450
500
550
600
650
700
750
800
850
900
Atmospheric CO2 Conc (ppm)

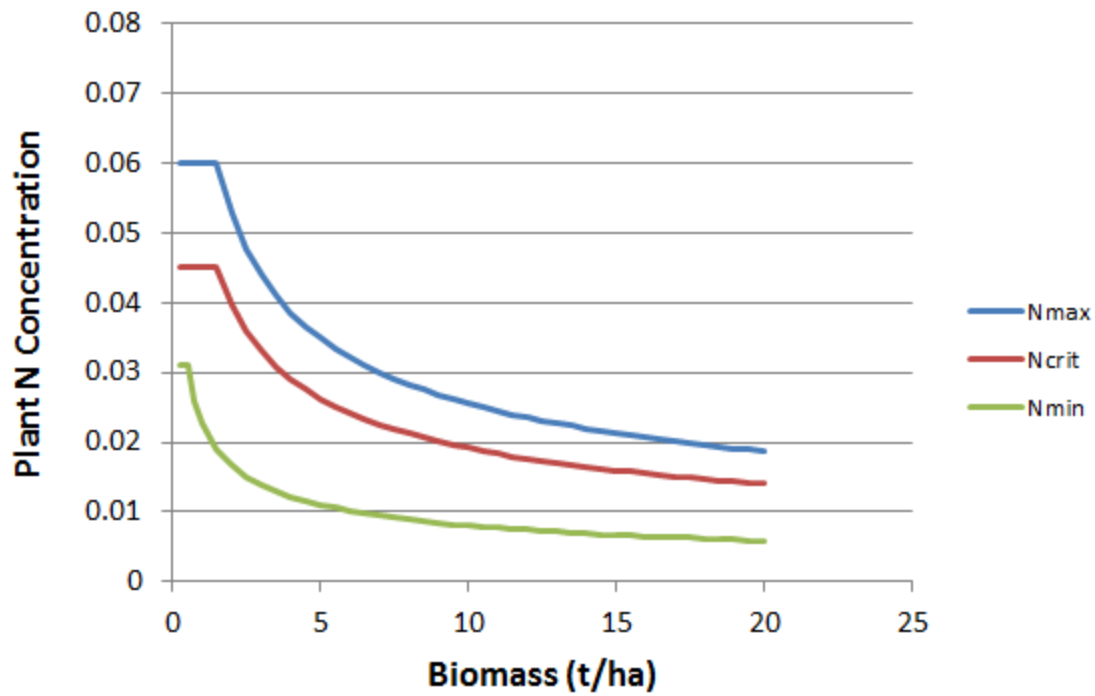

TUE
RUE
10
9
8
7
6
5
4
3
3.5
3
2.5
2
1.5
1
300 350 400 450 500 550 600 650 700 750 800 850 900
Atmospheric CO2 Conc (ppm)
TUE
RUE

Carbon and Nitrogen Budgets

- Calculated daily for all soil layers
- Carbon and nitrogen cycling are interactive
- Crop residues and all types of organic materials are considered in cycling calculations
- Nitrogen demand and uptake included
- Phosphorus not yet fully implemented

Nitrogen Demand





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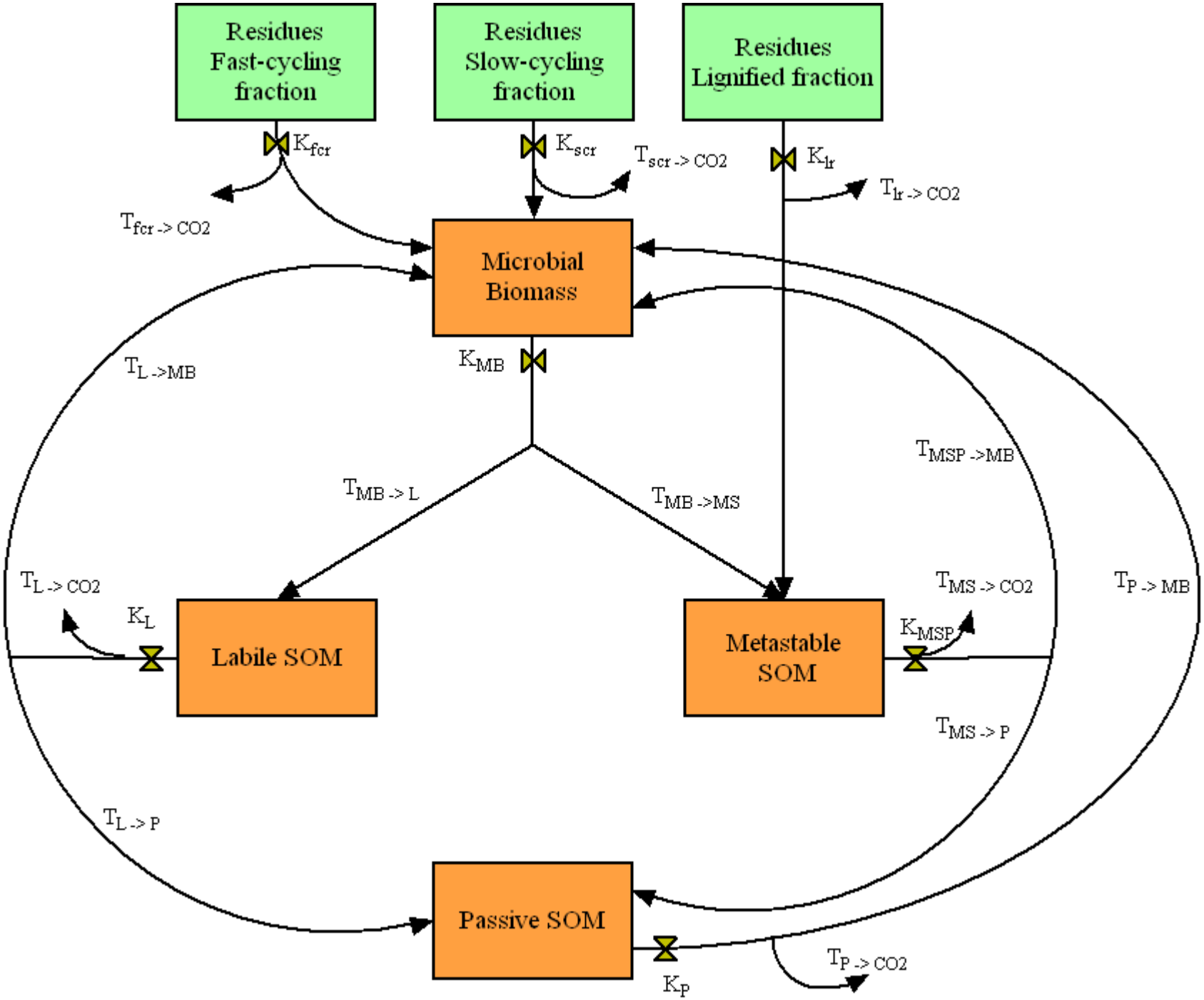
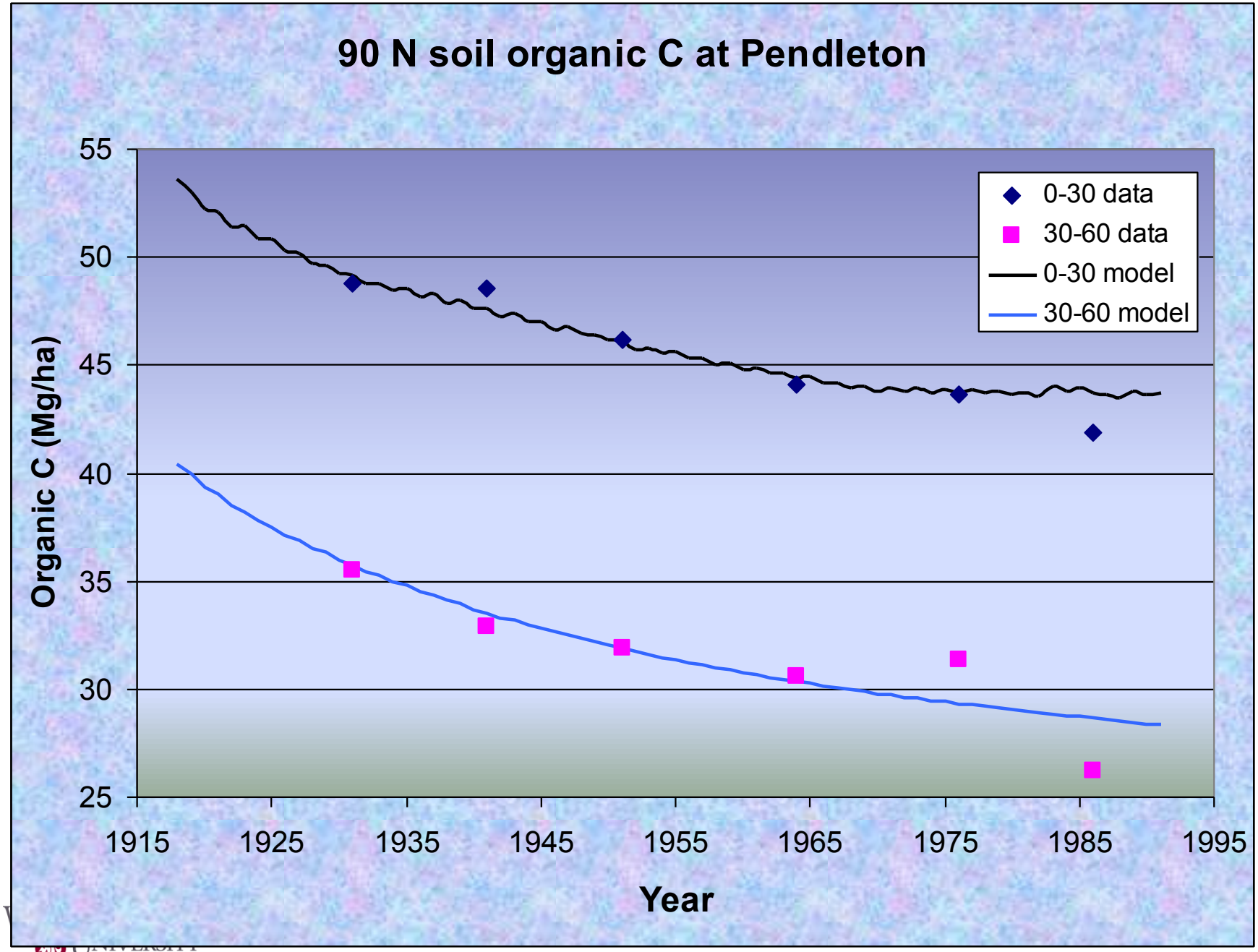
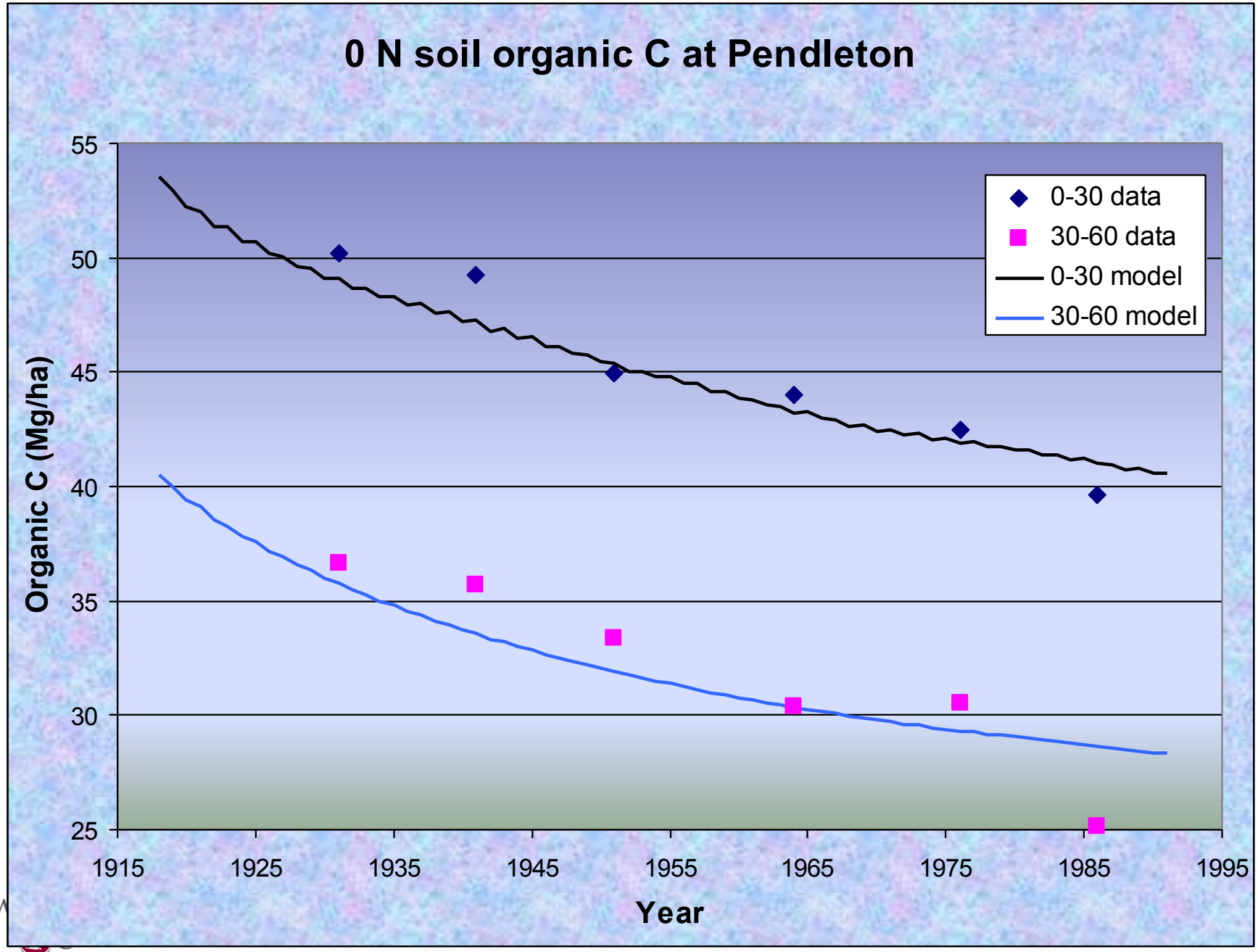
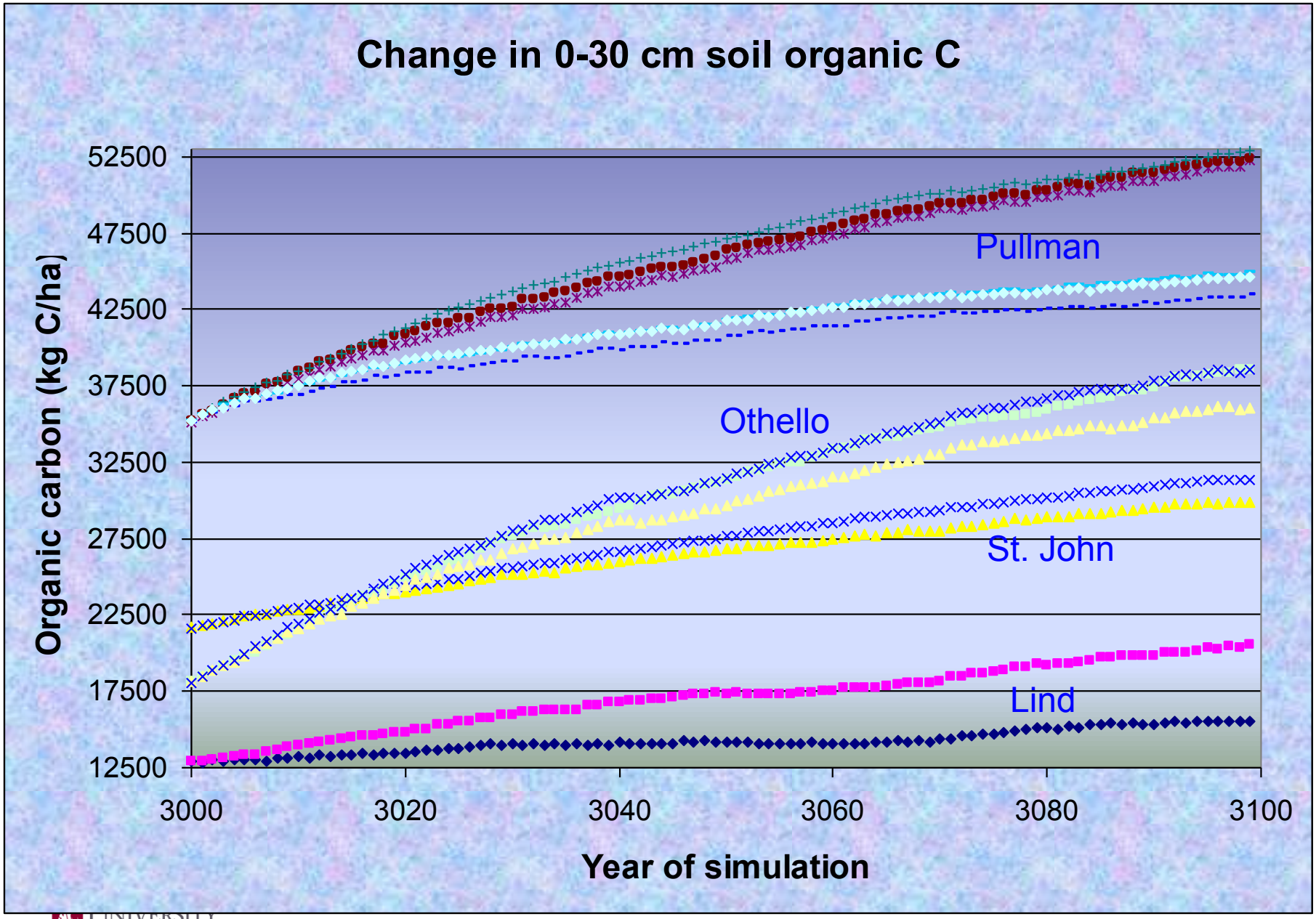

Residues Fast-cycling fraction
Residues Slow-cycling fraction
Residues Lignified fraction
Kfcr
Kscr
Tscr -> CO2
Klr
Tlr -> CO2
Tfcr -> CO2
Microbial Biomass
TL ->MB
KMB
TMSP ->MB
TMB -> L
TMB ->MS
TL -> CO2
KL
Labile SOM
Metastable SOM
TMS -> CO2
TP -> MB
KMSP
TMS -> P
TL -> P
Passive SOM
TP -> CO2
KP


90 N soil organic C at Pendleton
Organic C (Mg/ha)
55
50
45
40
35
30
25
1915
1925
1935
1945
1955
1965
1975
1985
1995
Year
0-30 data
30-60 data
0-30 model
30-60 model


0 N soil organic C at Pendleton
Organic C (Mg/ha)
55
50
45
40
35
30
25
1915
1925
1935
1945
1955
1965
1975
1985
1995
Year
0-30 data
30-60 data
0-30 model
30-60 model


Change in 0-30 cm soil organic C
Organic carbon (kg C/ha)
52500
47500
42500
37500
32500
27500
22500
17500
12500
3000
3020
3040
3060
3080
3100
Year of simulation
Pullman
Othello
St. John
Lind

Simulated annual nitrous oxide emission

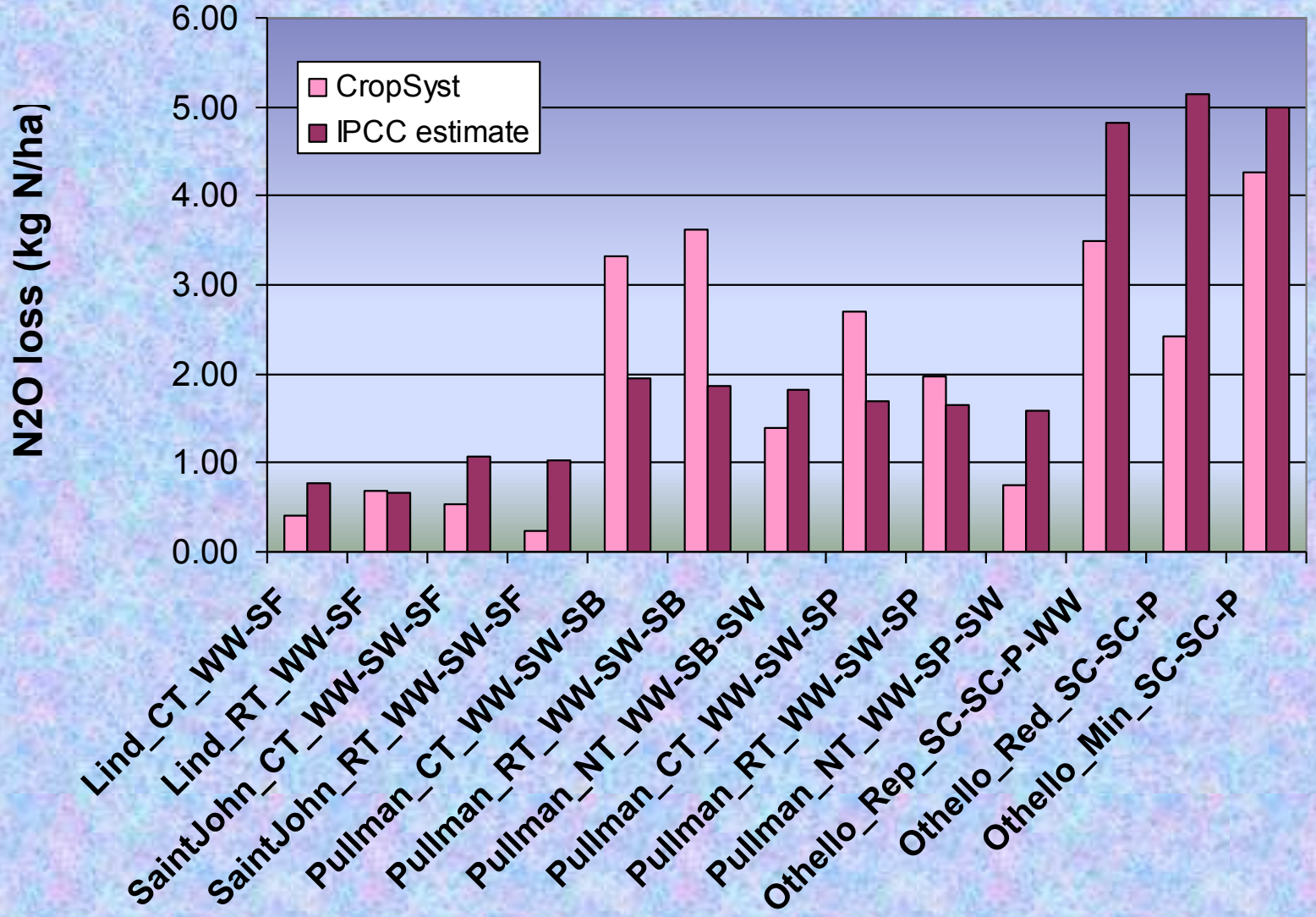
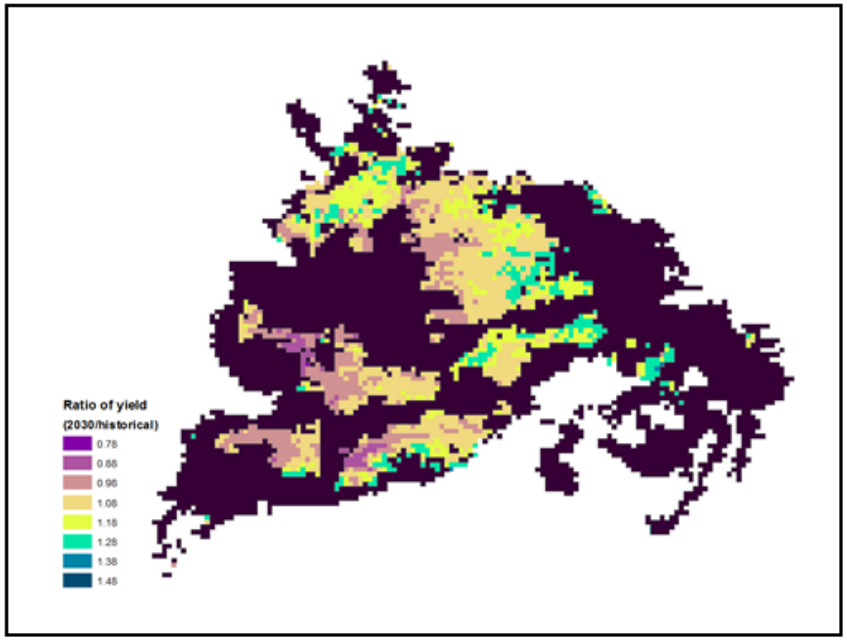
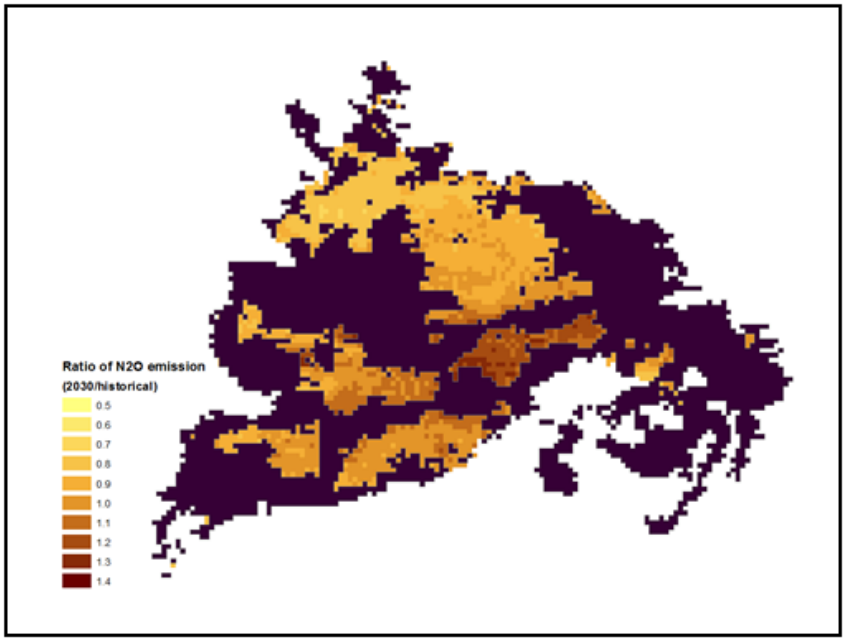


Fig.1. Regional ratios of future (2030s) to historic yields and N_2O emissions





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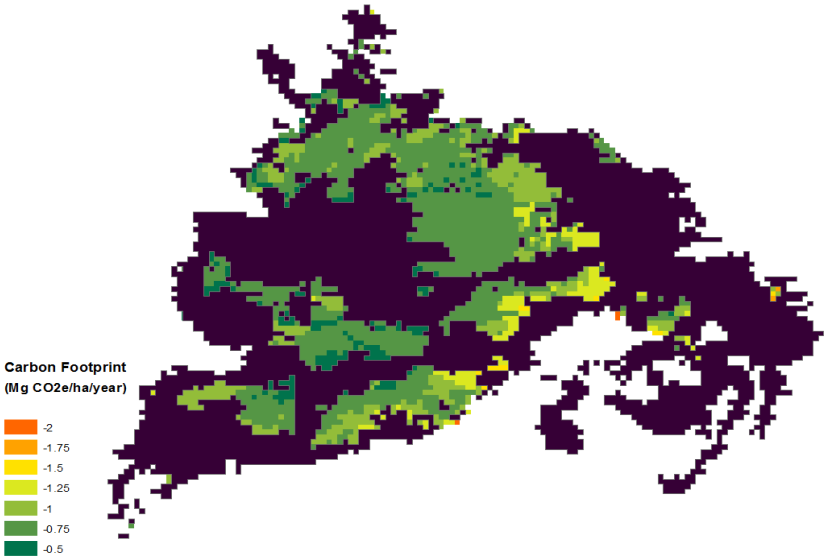

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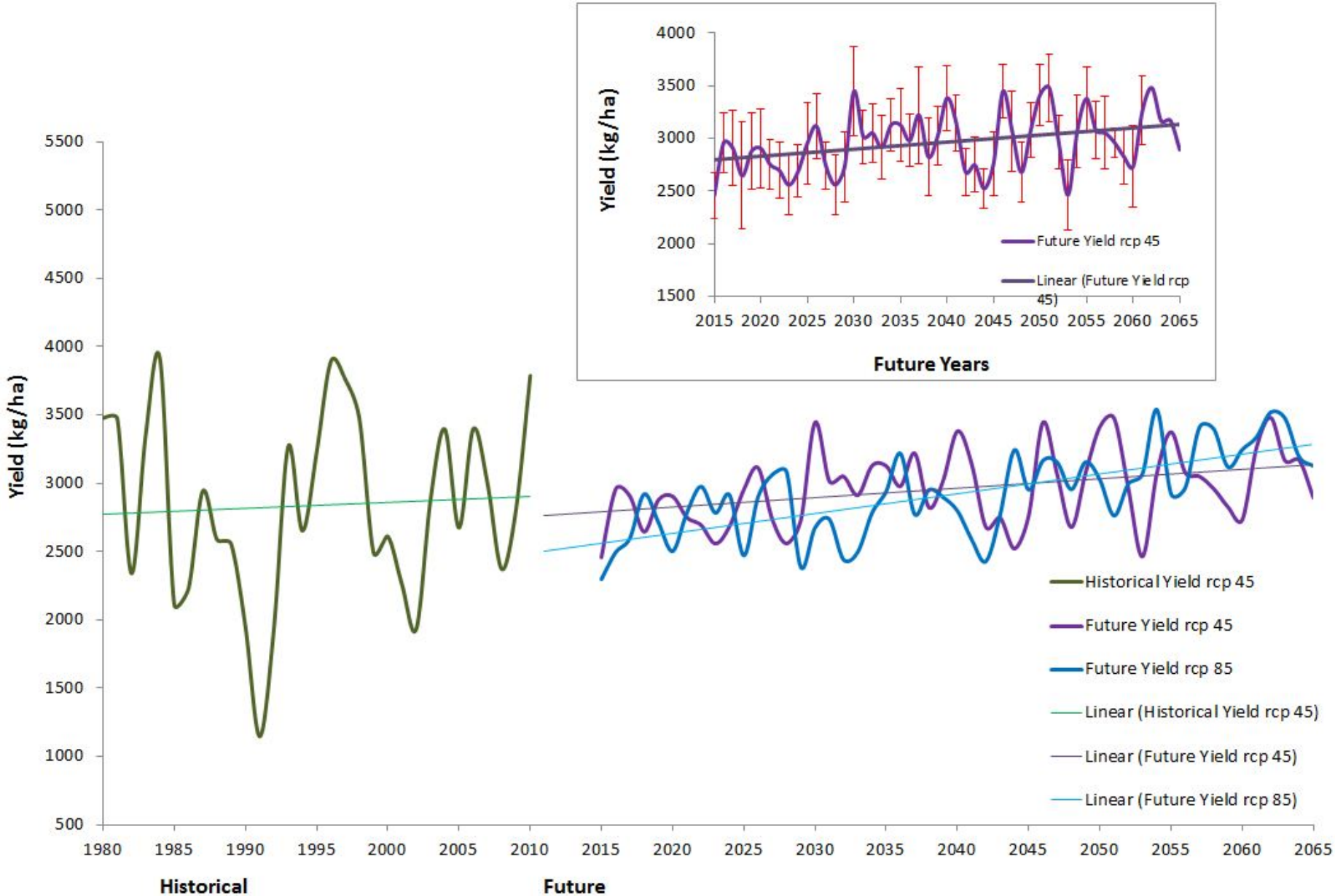
Yield (kg/ha)
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
Historical
Future
Historical Yield rcp 45
Future Yield rcp 45
Future Yield rcp 85
Linear (Historical Yield rcp 45)
Linear (Future Yield rcp 45)
Linear (Future Yield rcp 85)
Yield (kg/ha)
4000
3500
3000
2500
2000
1500
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
Future Years
Future Yield rcp 45
Linear (Future Yield rcp 45)

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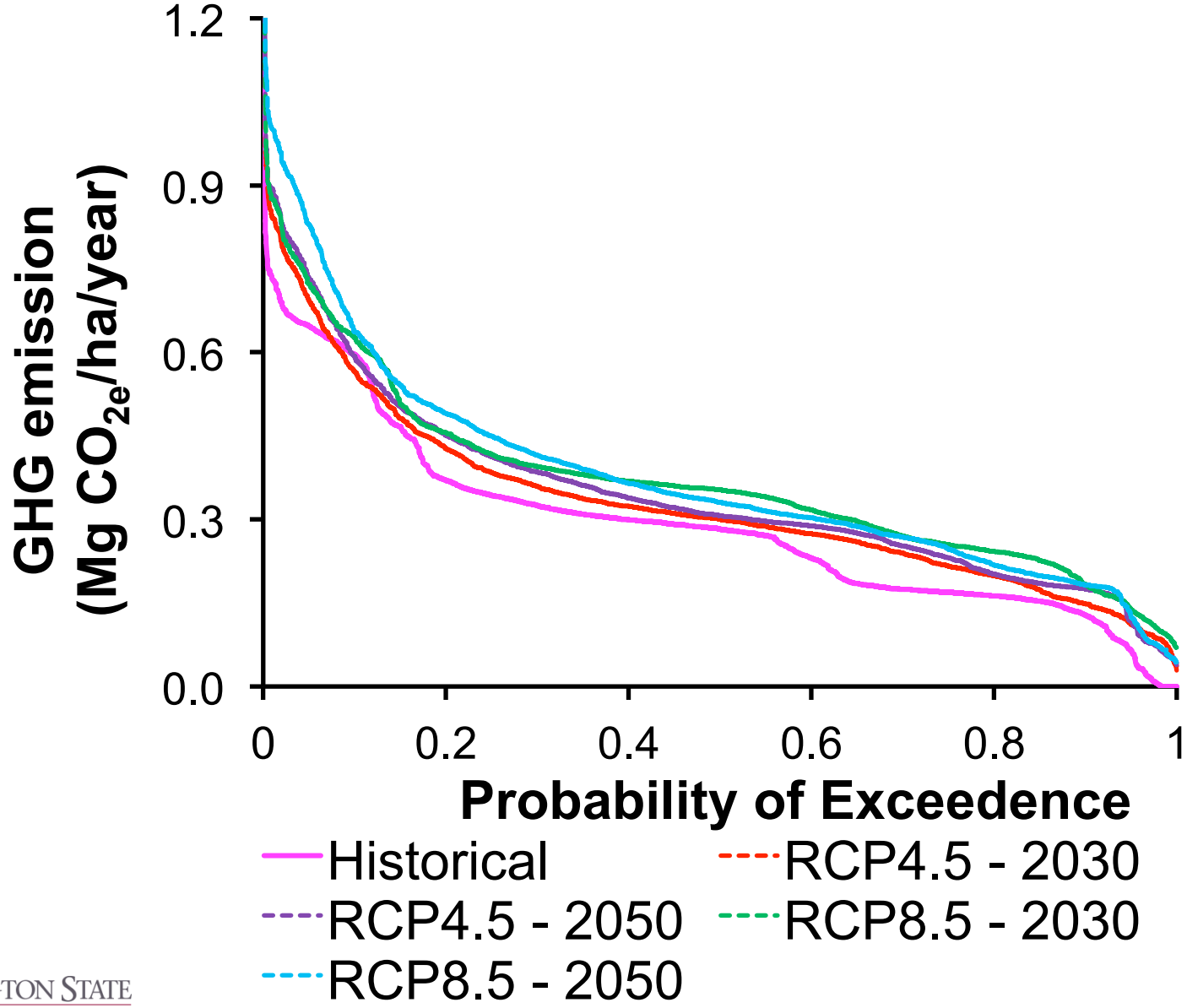

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