Can crop models capture water stress and waterlogging effects on crop yields

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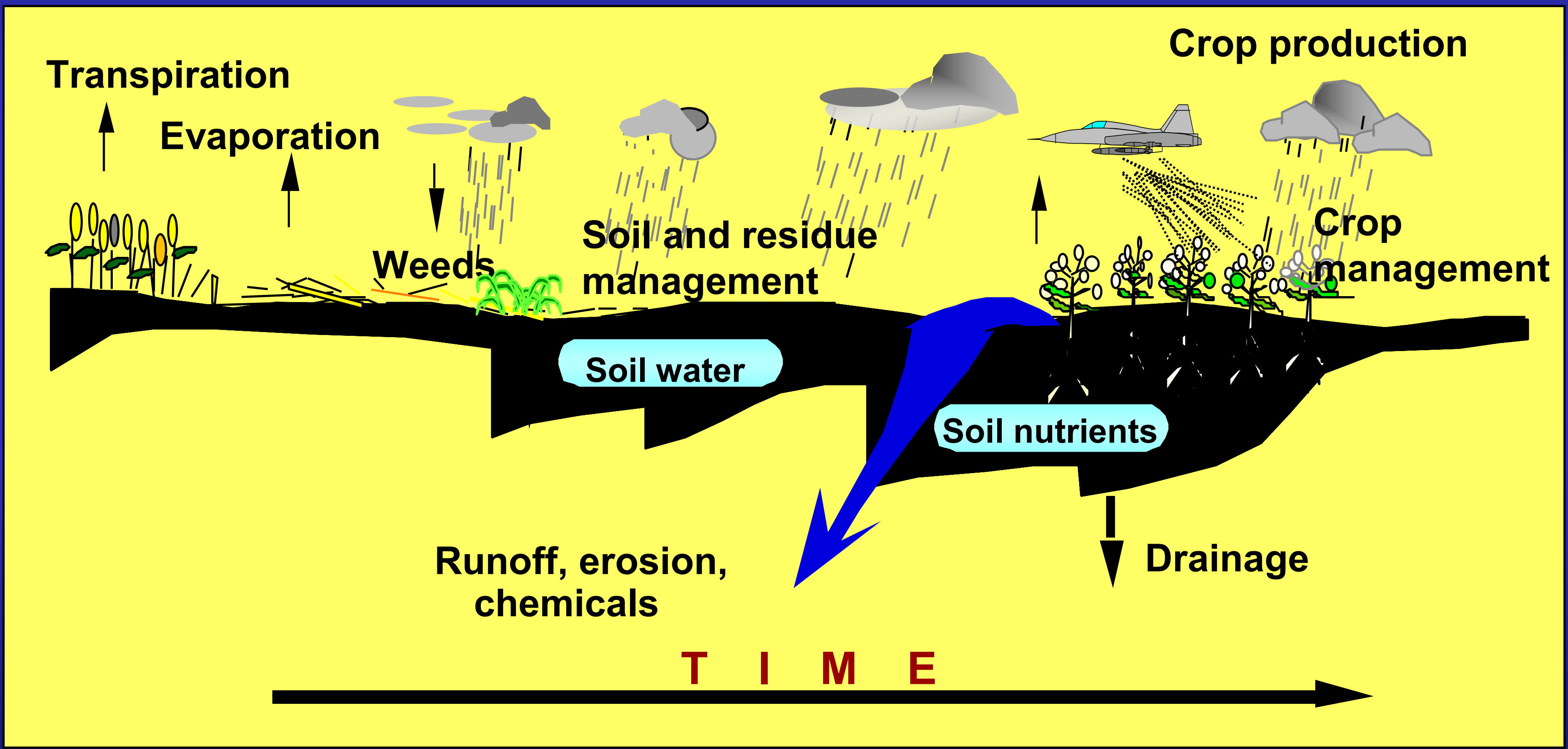
Layout of presentation

- Aim
- Water stress
  .. water balance models
- crop models (simple v detailed)
  .. crop growth
  .. crop yield
- Waterlogging
- Conclusions

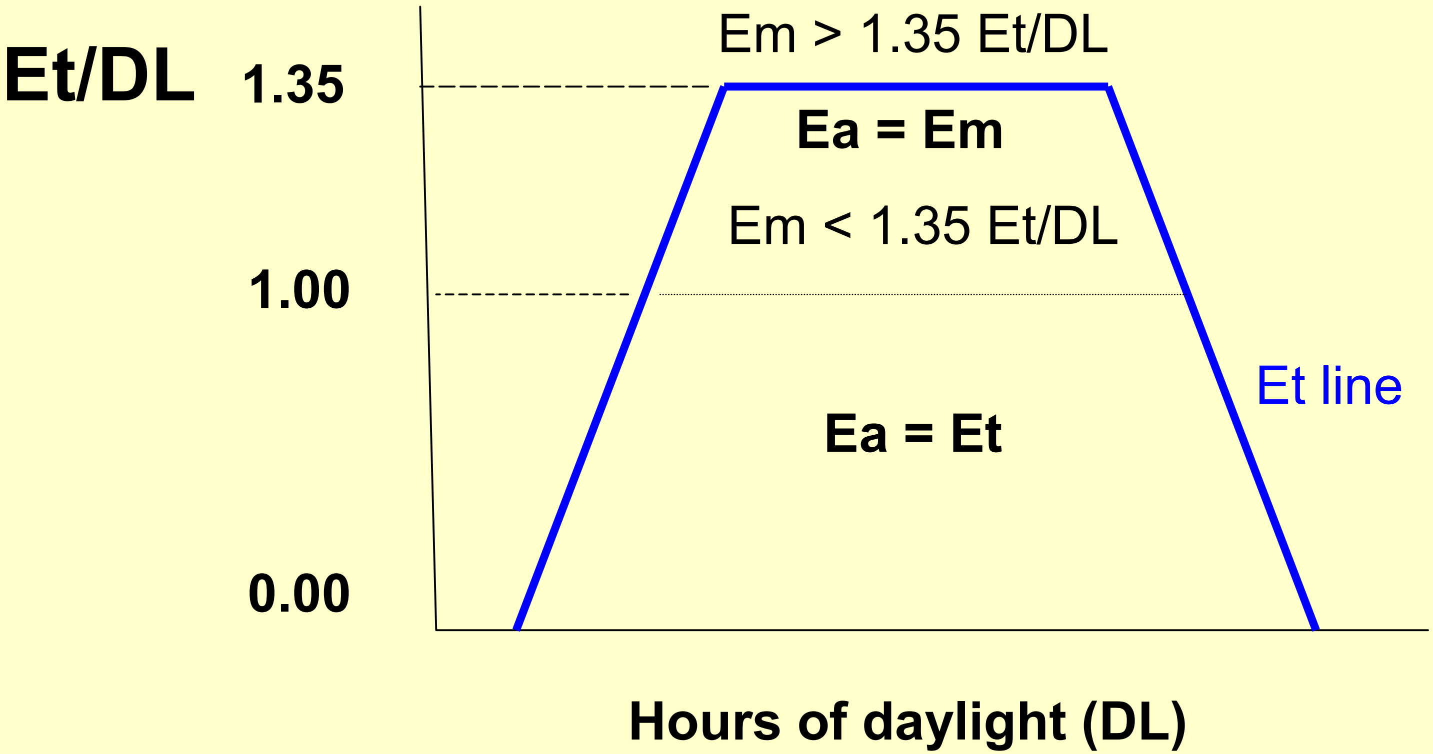
Aim of study

To provide a comprehensive written literature review that critically assesses the capability of crop models to simulate the physiological impact (particularly crop yield) of periodic water stress or waterlogging.

Why model water balance ?

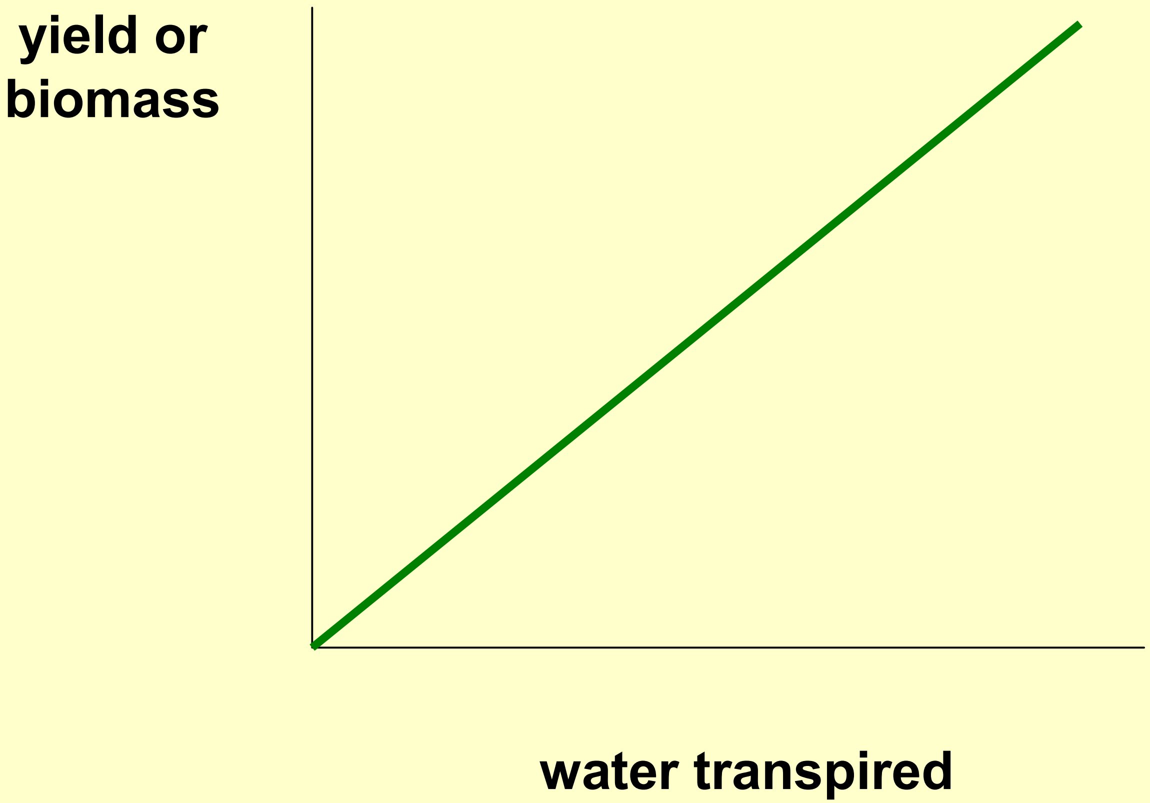


Evaporation distribution function for overcast days (Fleming 1984)

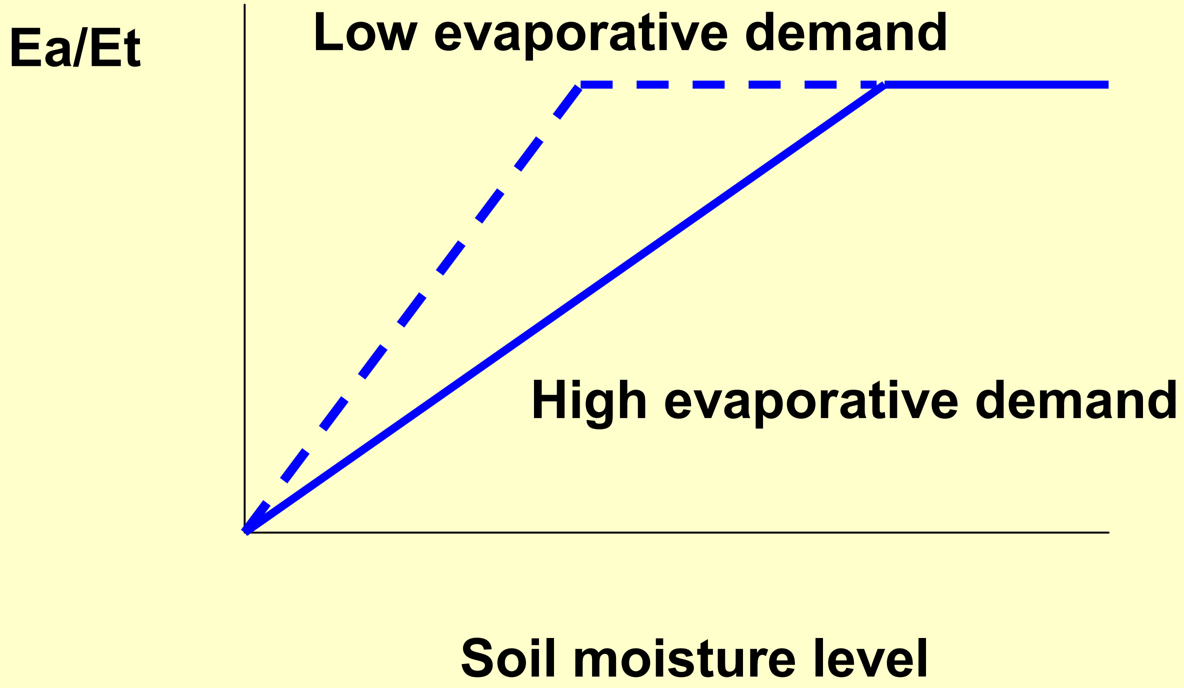


Et = potential evapotranspiration rate
Em = maximum transmission rate

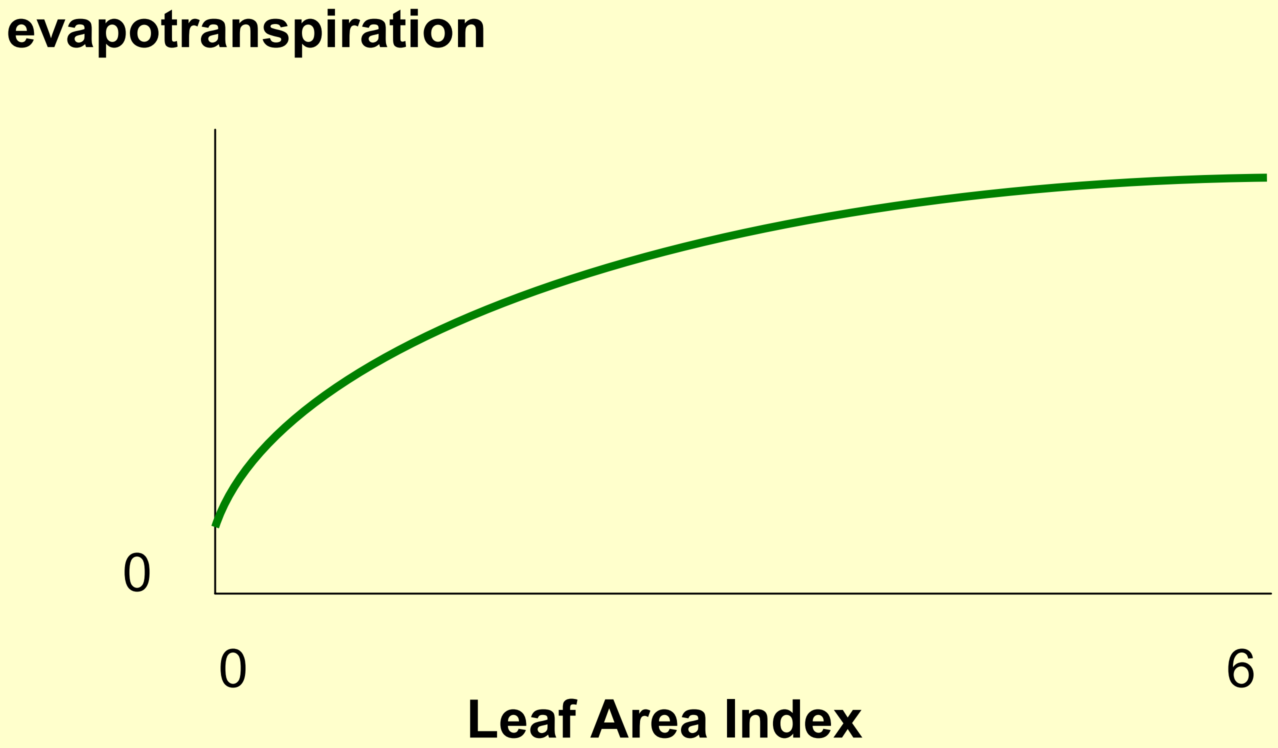
Relationship between growth or yield and water transpired



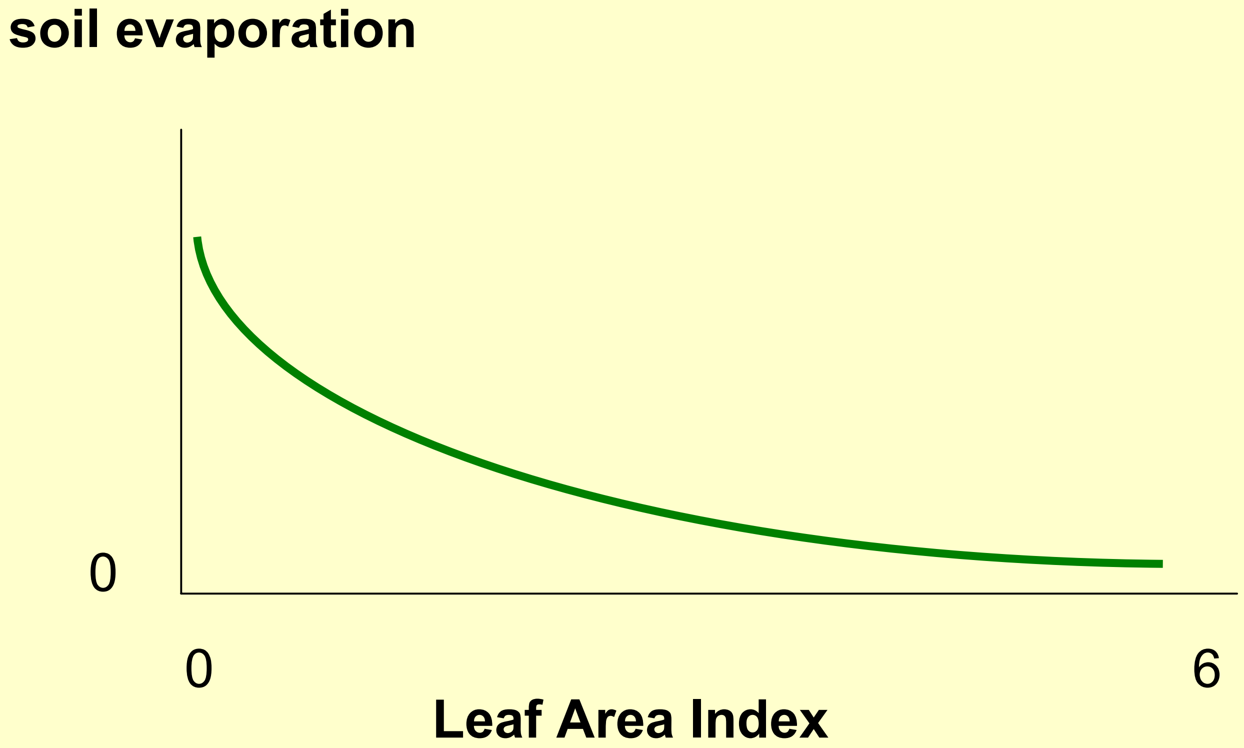
Predicted relationships between the ratio of actual (Ea) to potential (Et) evapotranspiration and the level of soil moisture



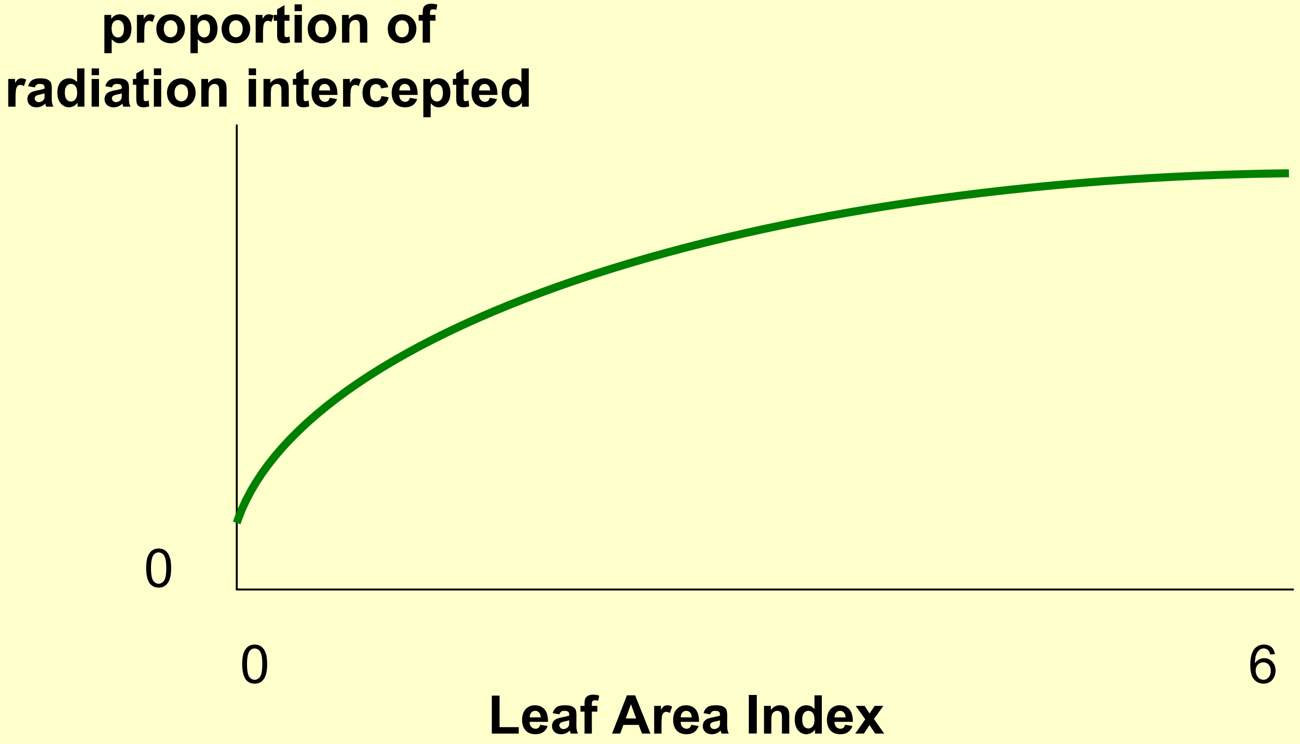
Relationship between leaf area index and evapotranspiration



Relationship between leaf area index and soil evaporation



Relationship between leaf area index and radiation intercepted



Water balance

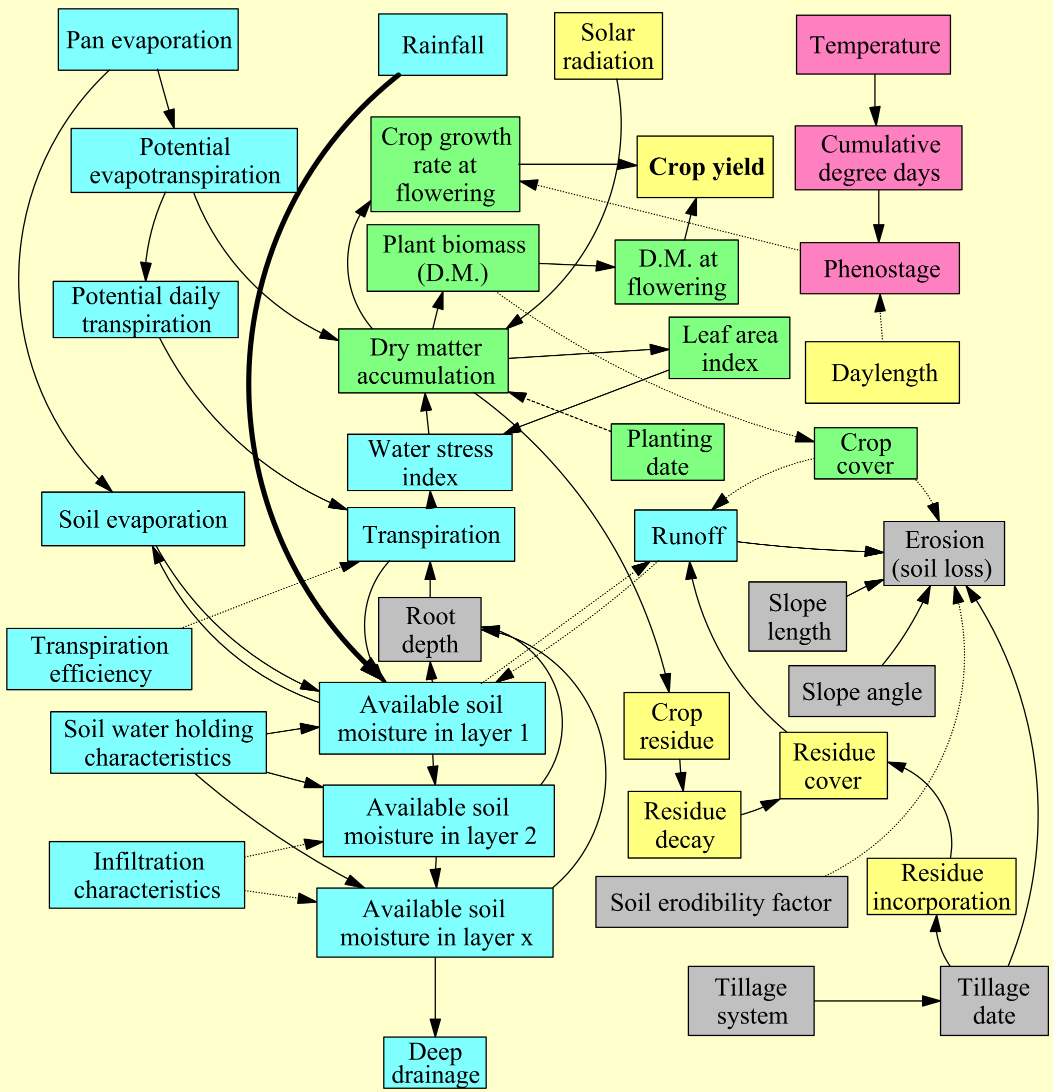
- Cascade (tipping bucket)

- SWIM (Richards equation)
  - Soil Water Infiltration & Movement

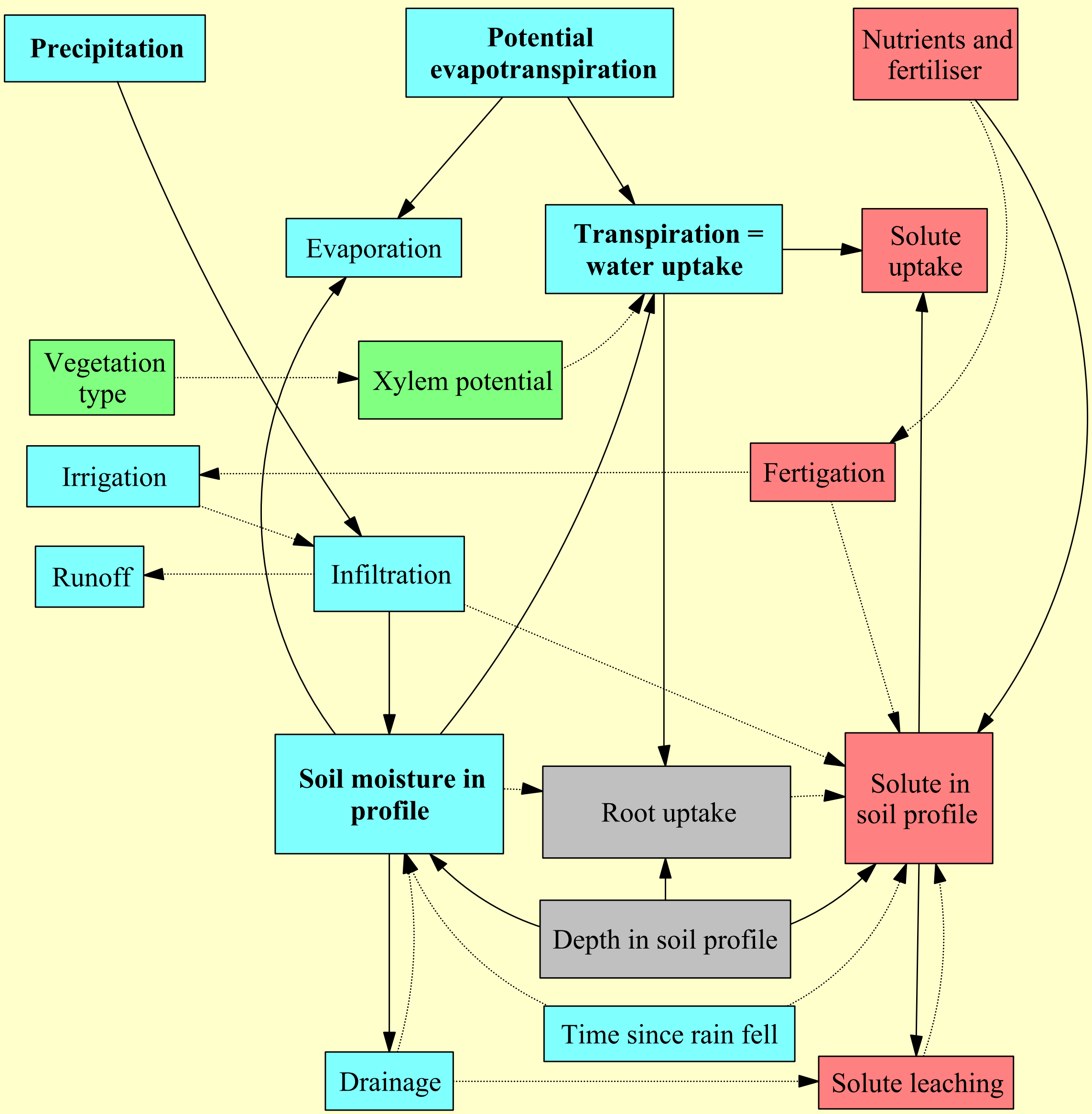
- WAVES - Water Atmosphere
  Vegetation Energy Solute

PERFECT: Productivity, Erosion and Runoff Functions to Evaluate Conservation Techniques

- includes dynamic crop models for wheat, sorghum and sunflower

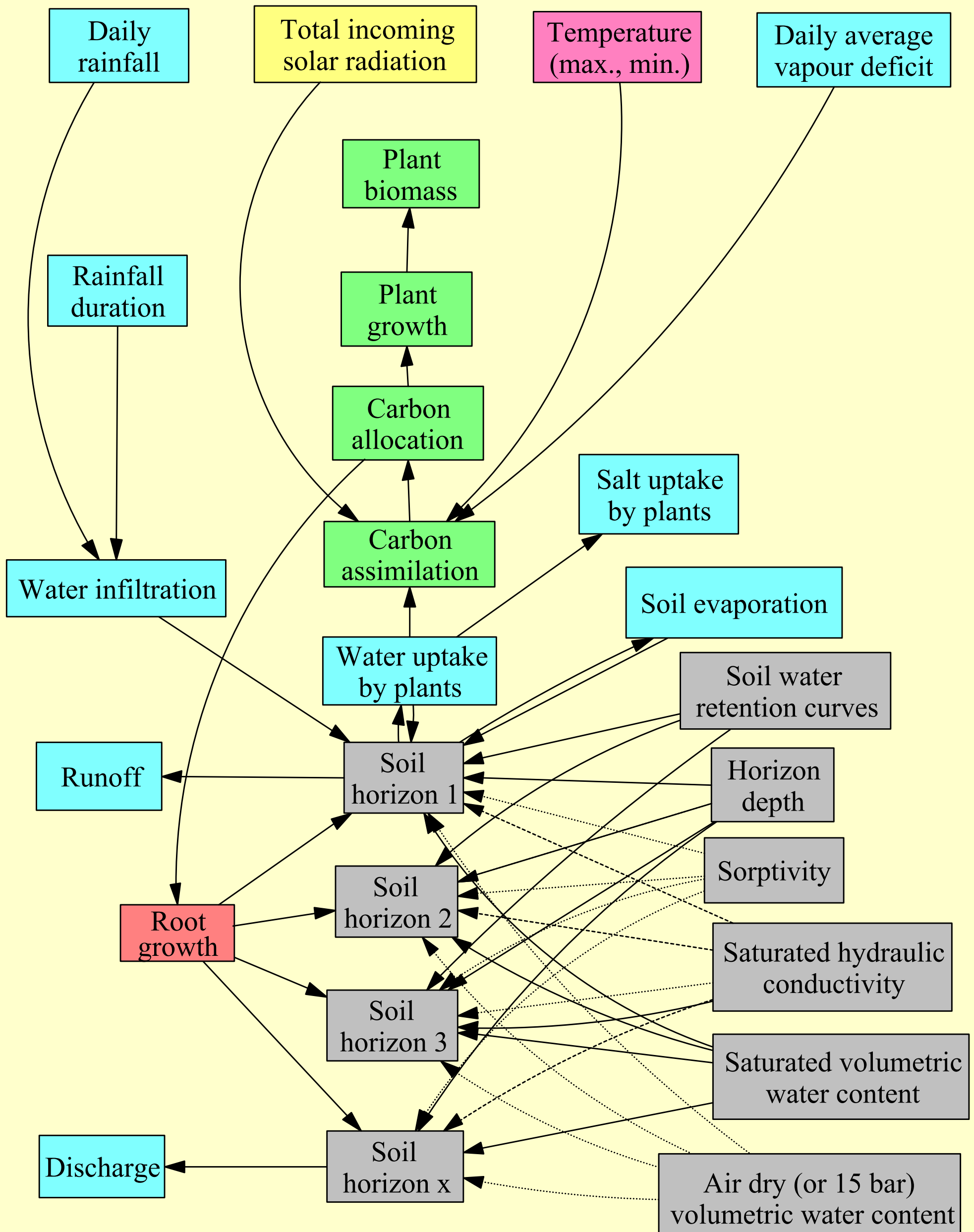


SWIM: Soil Water Infiltration and Movement



WAVES: Water Atmosphere Vegetation Energy Solute

Growth of trees, crops, C3 and C4 grasses can be modelled



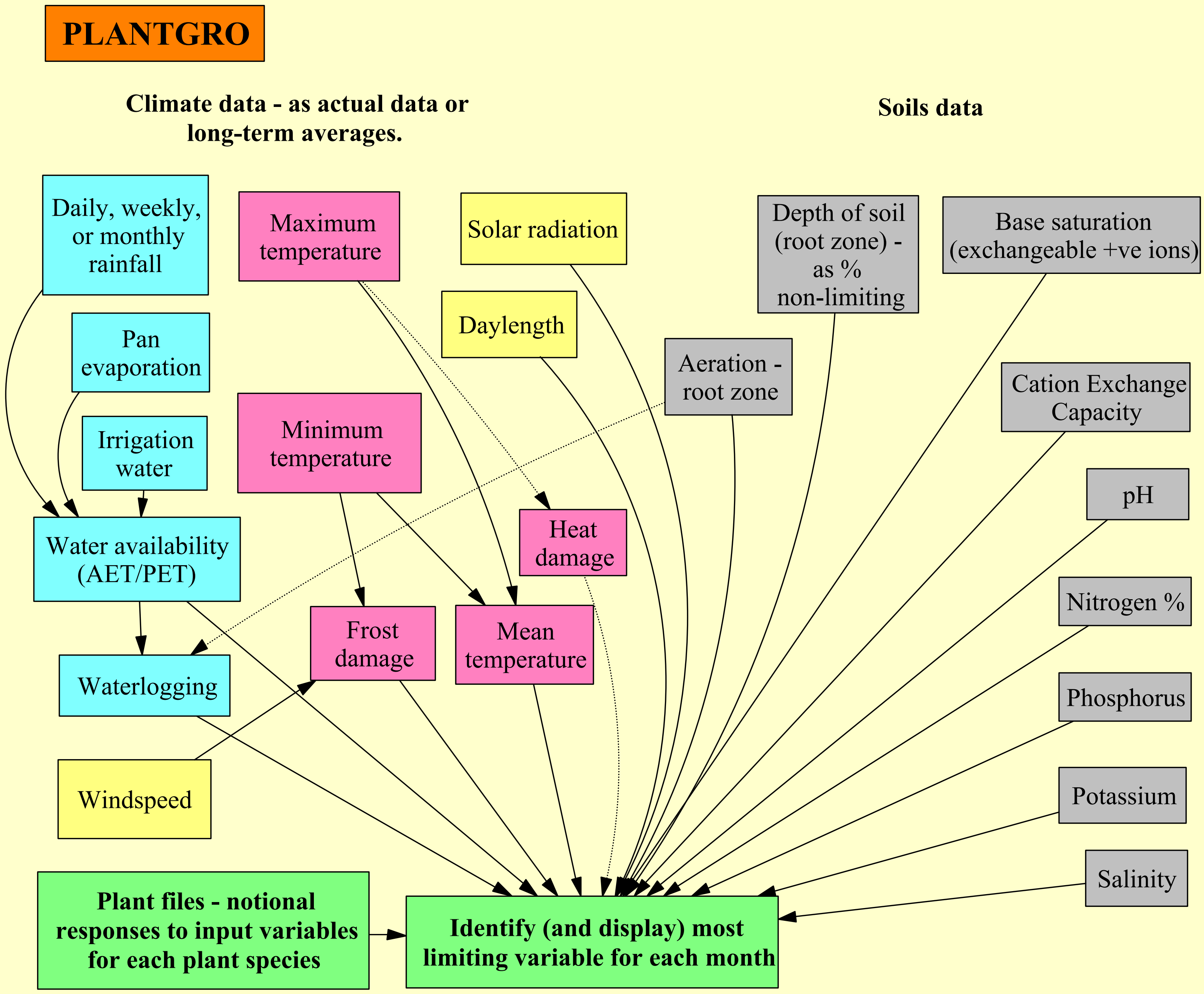
Determinants of crop growth

- Soil moisture, LAI..-> evapotranspiration
- Solar radiation -> intercepted
- Transpiration efficiency
- Radiation use efficiency
- Growth = minimum of:

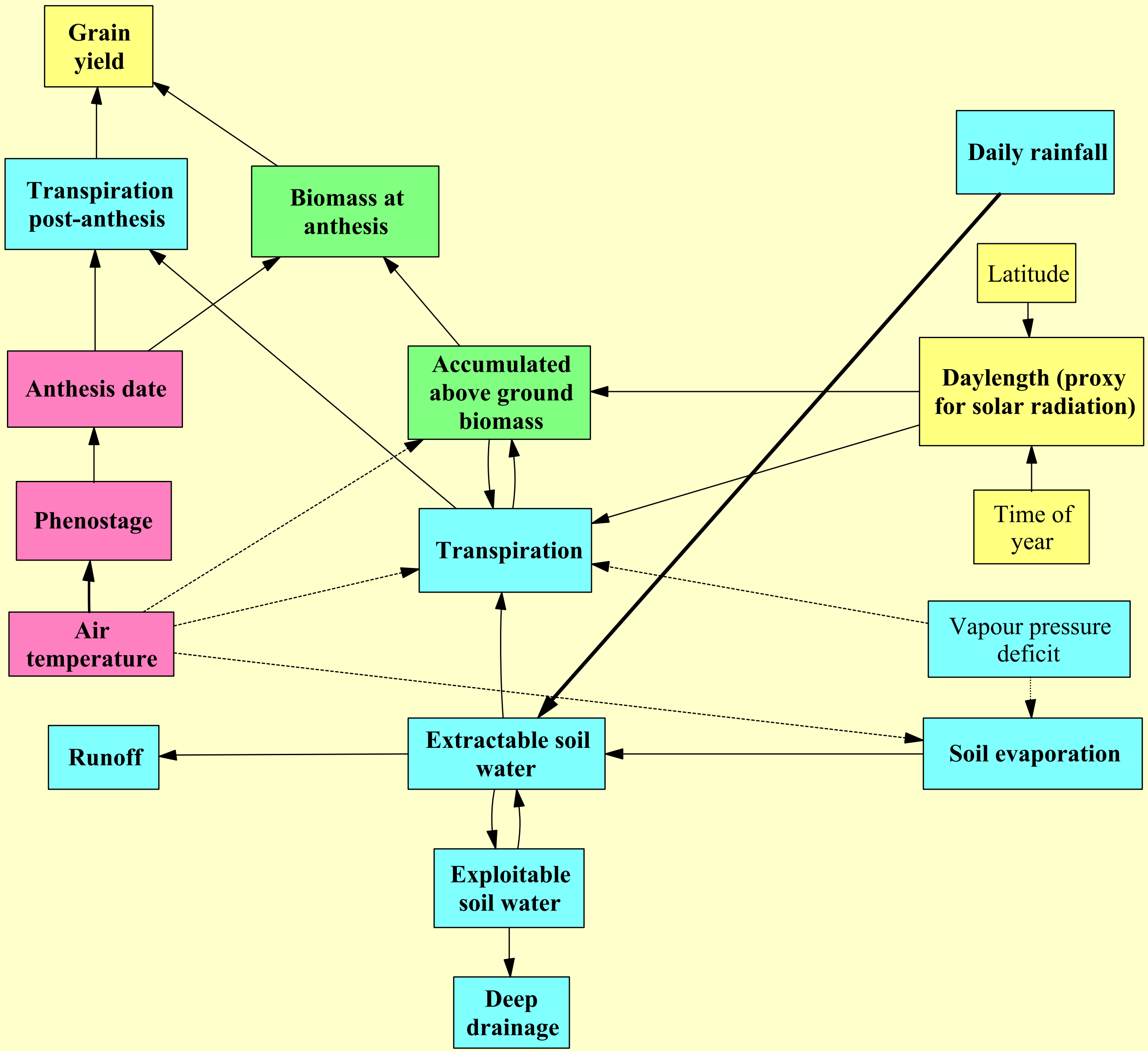
  water-limited dry matter production, and
  radiation-limited dry matter production

Minimal crop models

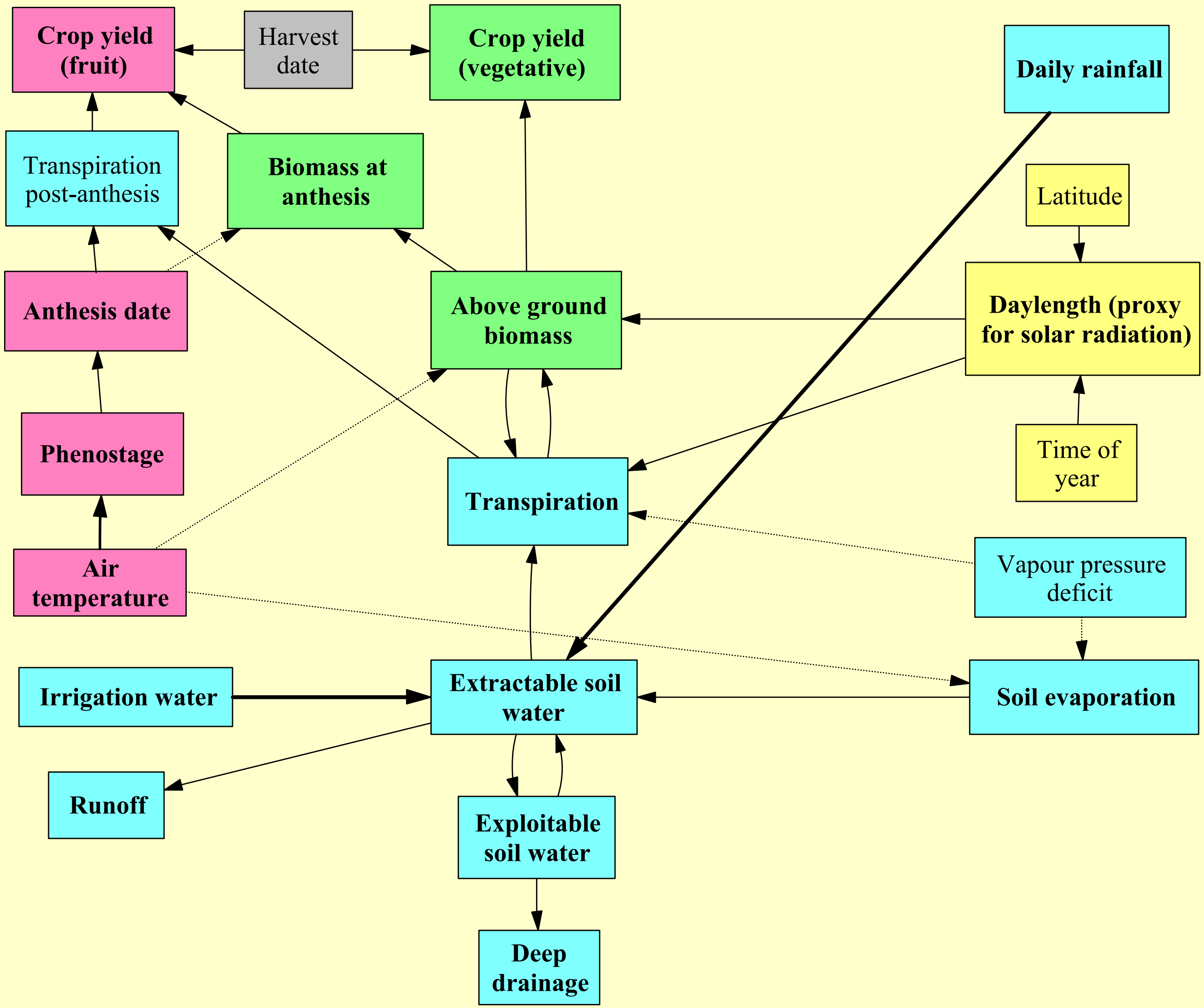
- PLANTGRO
- Minimal agricultural crop model
- Minimal horticultural model
- Minimal orchard model


PLANTGRO
Climate data - as actual data or long-term averages.
Soils data
Daily, weekly, or monthly rainfall
Maximum temperature
Solar radiation
Depth of soil (root zone) - as % non-limiting
Base saturation (exchangeable +ve ions)
Pan evaporation
Daylength
Aeration - root zone
Cation Exchange Capacity
Irrigation water
Minimum temperature
pH
Heat damage
Water availability (AET/PET)
Nitrogen %
Frost damage
Mean temperature
Waterlogging
Phosphorus
Windspeed
Potassium
Salinity
Plant files - notional responses to input variables for each plant species
Identify (and display) most limiting variable for each month

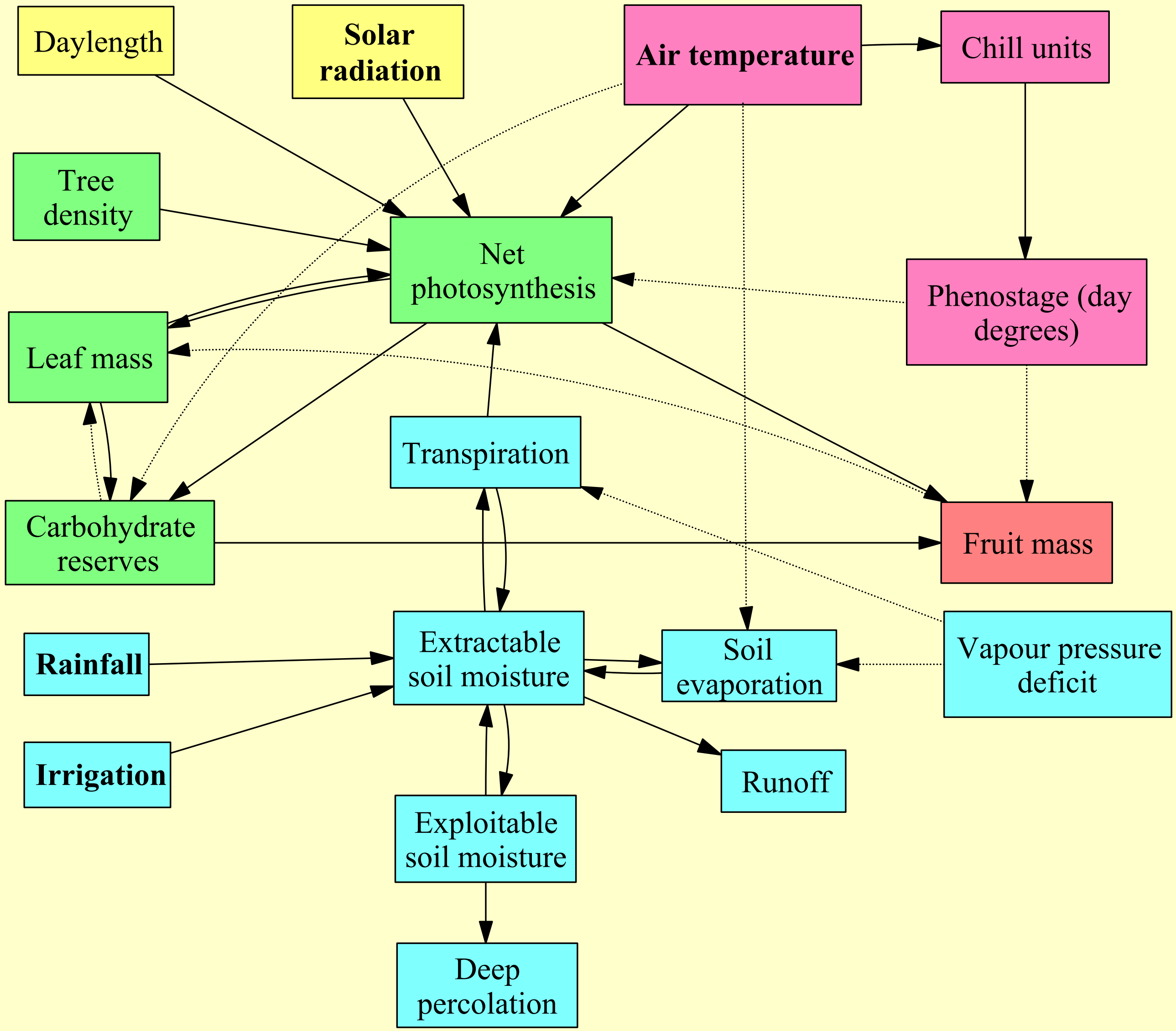
Minimal crop model



Minimal horticultural model



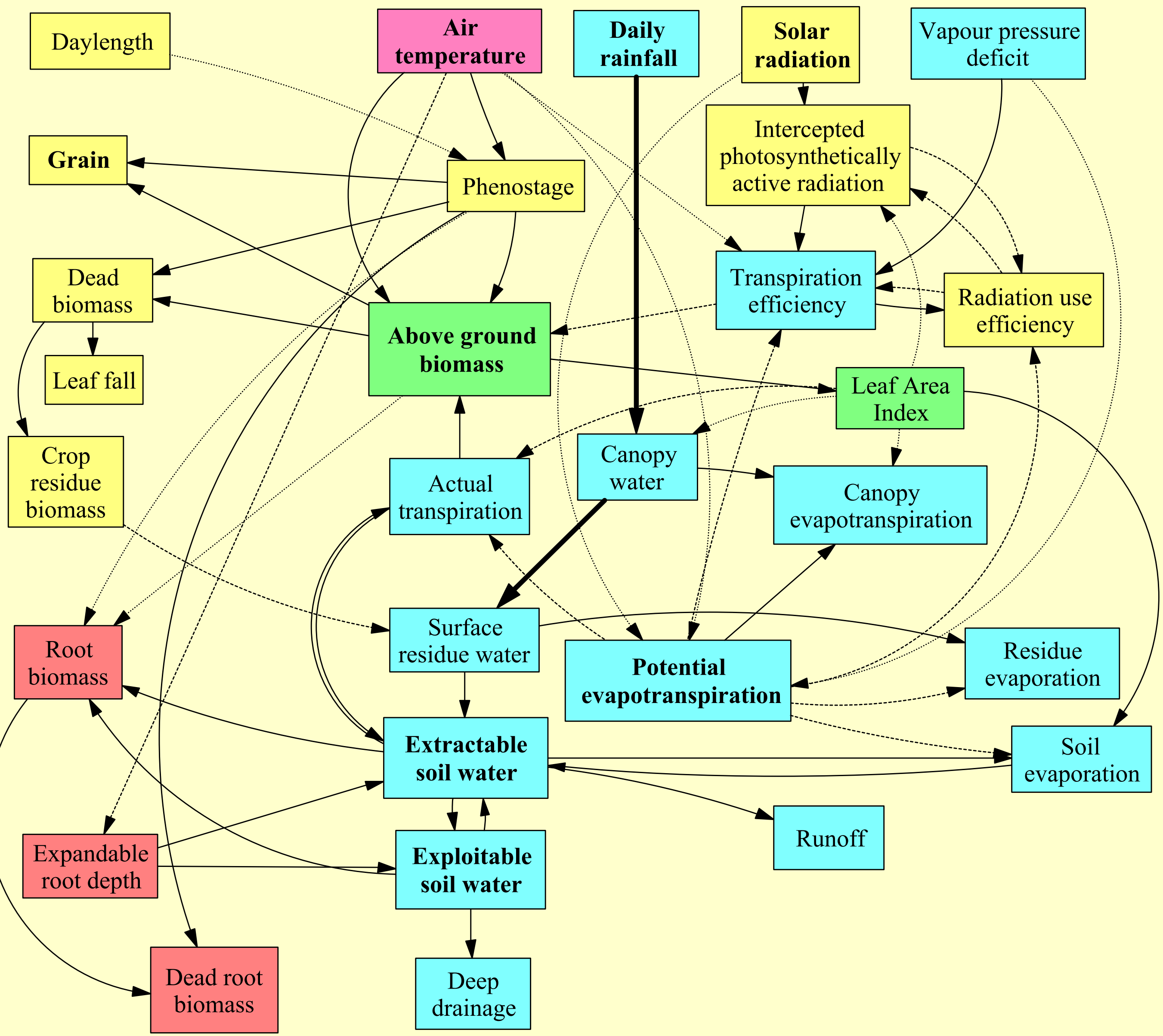
Minimal orchard yield model



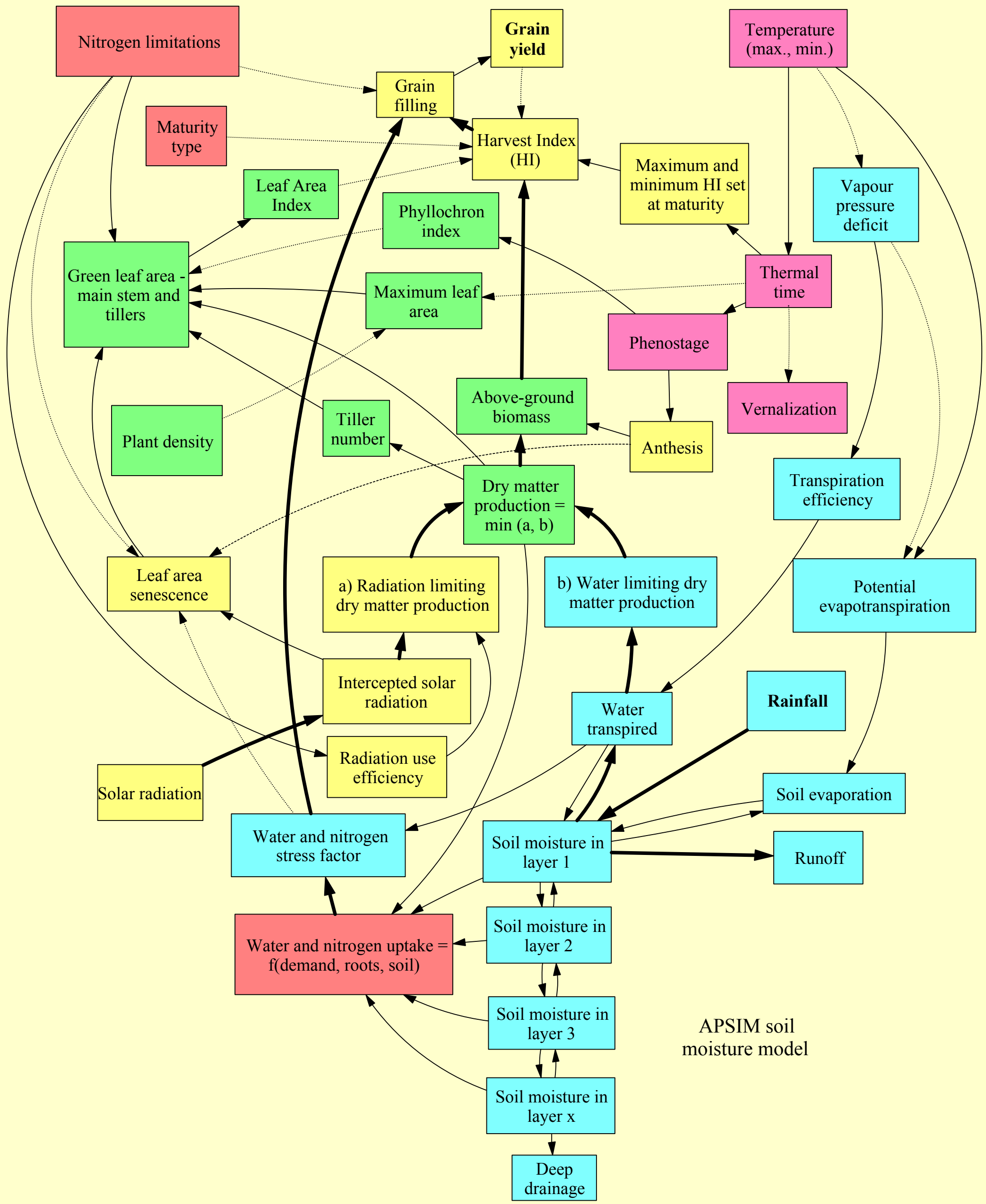
Crop physiology models

- Cereal models
- Oilseed (sunflower) model
- Cotton model
- Tomato model
- Apple model

O'Leary and Connor wheat model



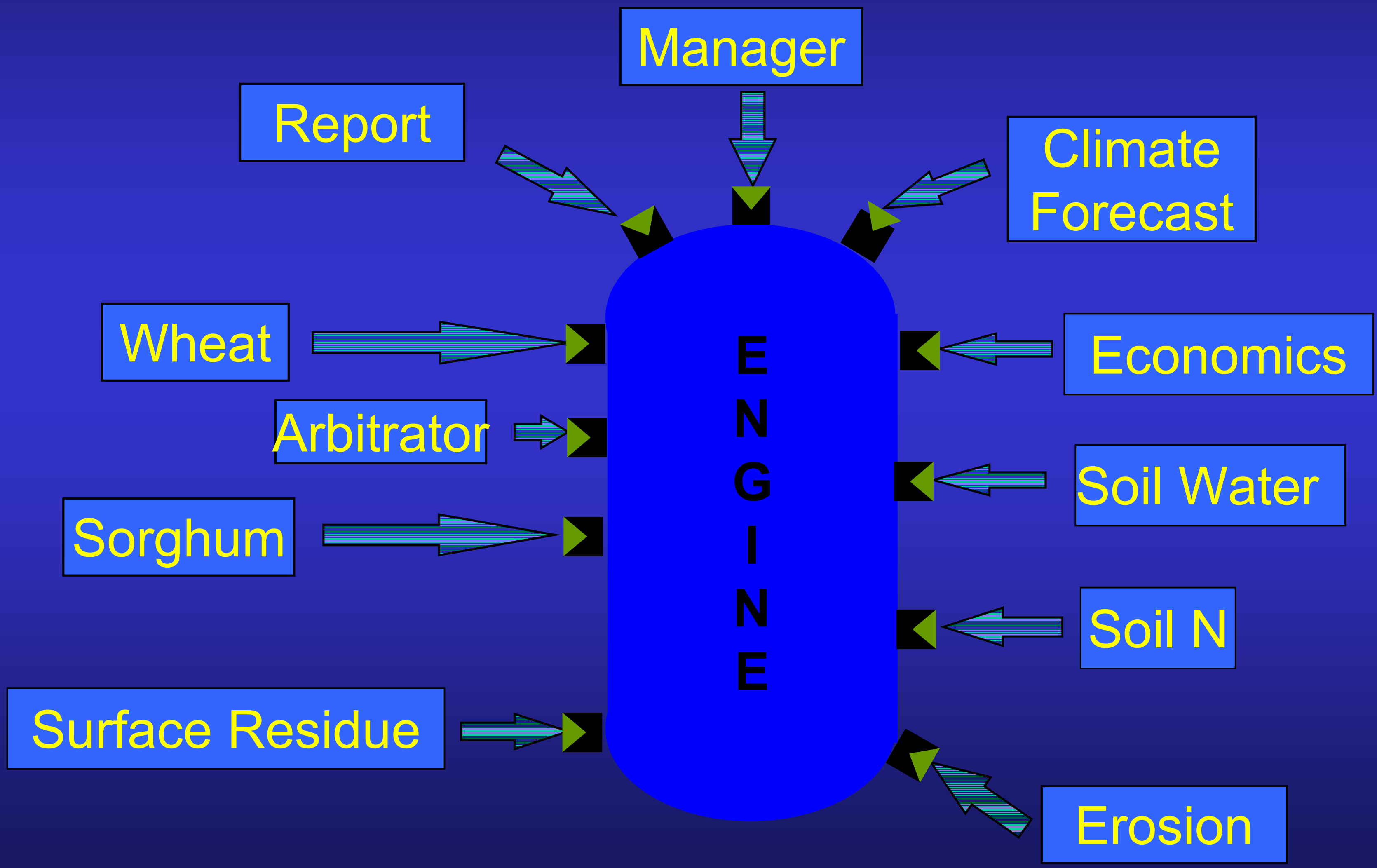
I_WHEAT model (Meinke)



Determinants of grain yield

- Biomass at anthesis
- Translocation post-anthesis
- Harvest Index = Grain yield/biomass
- Significance of root depth often ignored
- Kernel number important - wheat, barley
- Grain weight more important in maize

APSIM - Plug-in / Pull-out modularity



Agricultural Production Systems Simulator (APSIM)

Simulates

- yield of crops and pastures
- key soil processes (water, N, carbon)
- surface residue dynamics & erosion
- range of management options
- crop rotations + fallowing
- short or long term effects
- BUT, not pests nor diseases

Current APSIM sorghum model

- **temperature determines canopy size and potential radiation interception;**
- **root extent determines the soil water and N supply potential**
- **radiation use efficiency (RUE) and transpiration efficiency (TE) 'switch' daily Crop Growth Rate between radiation-limited and water-limited**

Testing proposed new crop N modelling framework

		HighN/Irrig		LowN/Irrig		HighN/Dry		LowN/Dry	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Biomass at Anthesis (kg/m2)	Observed	547.51	676.58	335.02	597.32	443.46	560.87	419.02	577.85
	Predicted	561.39	653.81	398.48	436.48	426.91	485.93	321.44	572.86
Biomass at Maturity (kg/m2)	Observed	1278.79	1537.63	707.87	911.89	517.77	649.23	524.52	645.95
	Predicted	1274.48	1544.64	889.24	1009.71	581.13	642.34	522.15	808.76
LAI at Anthesis	Observed	2.64	4.00	1.56	2.17	1.61	2.77	1.55	2.71
	Predicted	3.20	3.95	2.10	2.50	3.03	3.35	2.63	3.72
Total N at Anthesis (kg/m2)	Observed	6.87	9.61	2.58	4.22	4.66	8.78	4.31	8.61
	Predicted	8.65	11.01	3.26	3.68	7.33	8.36	3.67	9.36
Total N at Maturity (kg/m2)	Observed	14.96	18.48	6.51	4.29	4.56	9.90	5.05	8.62
	Predicted	17.29	20.83	6.12	6.46	8.70	10.28	5.13	12.74
Grain N at Maturity (kg/m2)	Observed	10.46	13.48	4.48	2.72	3.45	4.87	3.66	3.06
	Predicted	11.90	15.37	4.38	4.99	3.54	5.14	2.15	6.33
SLN at Anthesis	Observed	1.34	1.29	0.75	0.87	1.26	1.43	1.24	1.50
	Predicted	1.51	1.51	1.04	0.99	1.54	1.61	0.98	1.51

- Test runs on detailed water*N experiments

Model Testing – Liverpool Plains

Treatments:

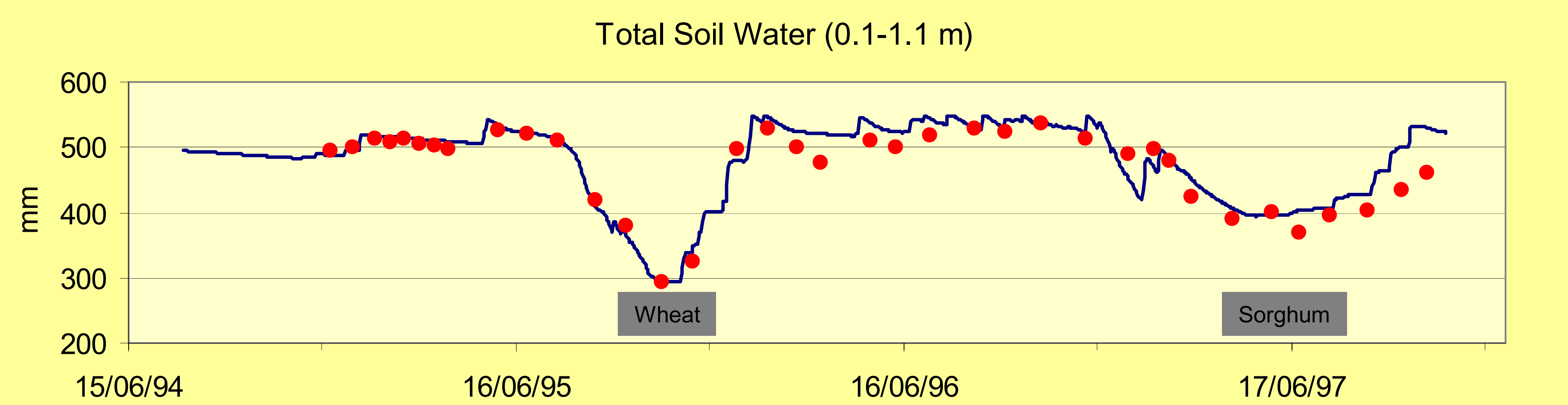
- Wheat & sorghum in long fallow systems
- Continuous wheat and barley
- Opportunity Cropping
  - » Wheat/barley - Mungbeans
  - » Sorghum - Chickpea/fababeans
- Lucerne

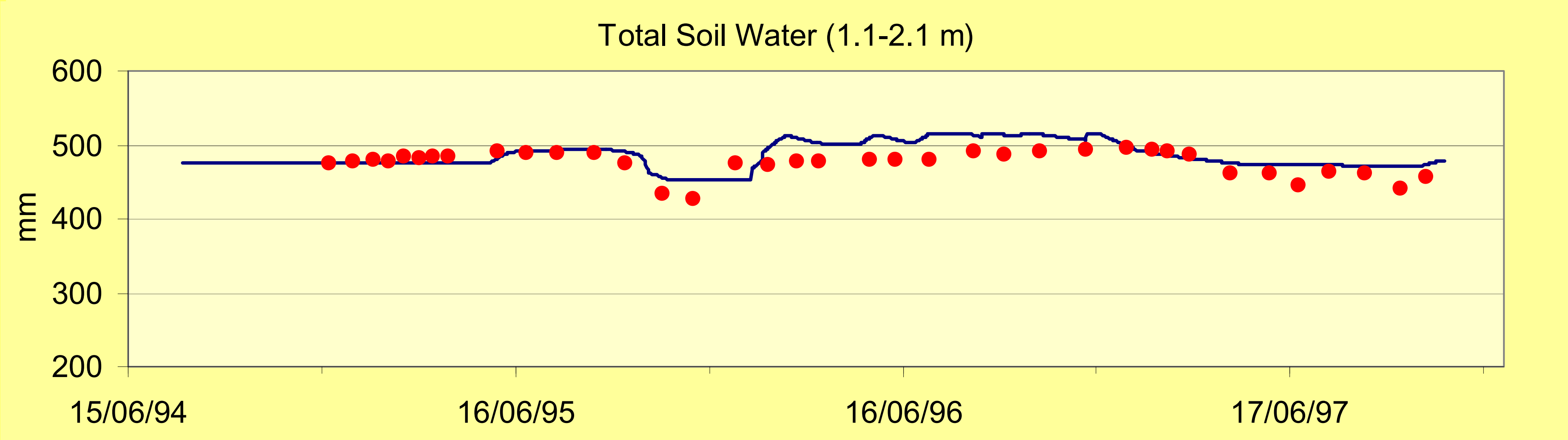
Some overall research objectives

- Assess crop management options at the paddock-scale that
  - maintain or raise profitability
  - maximise water use
    - restrict deep drainage
    - reduce runoff

- Provide input to catchment scale studies on water balance issues

Wheat-Sorghum Long Fallow - Soil Water

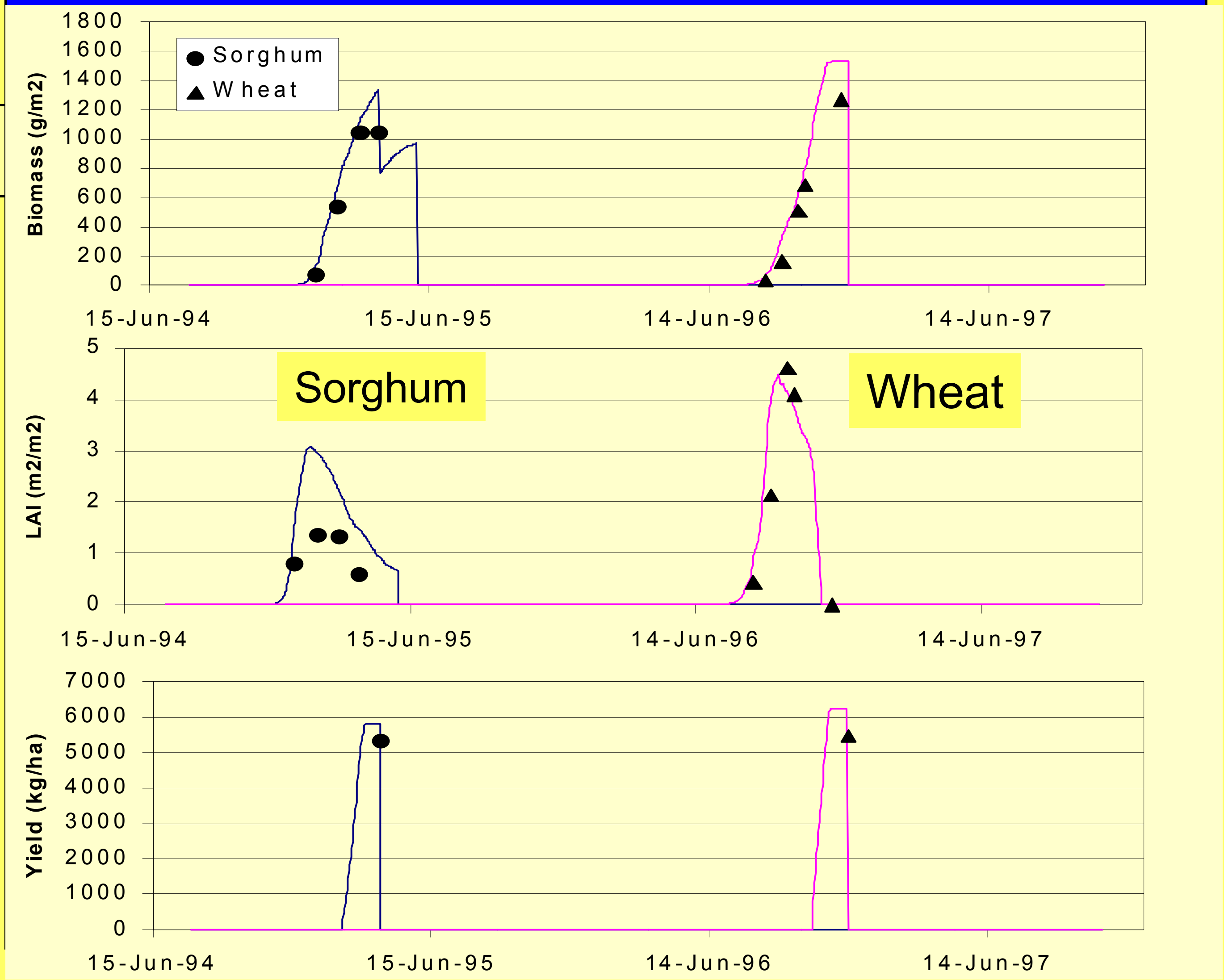




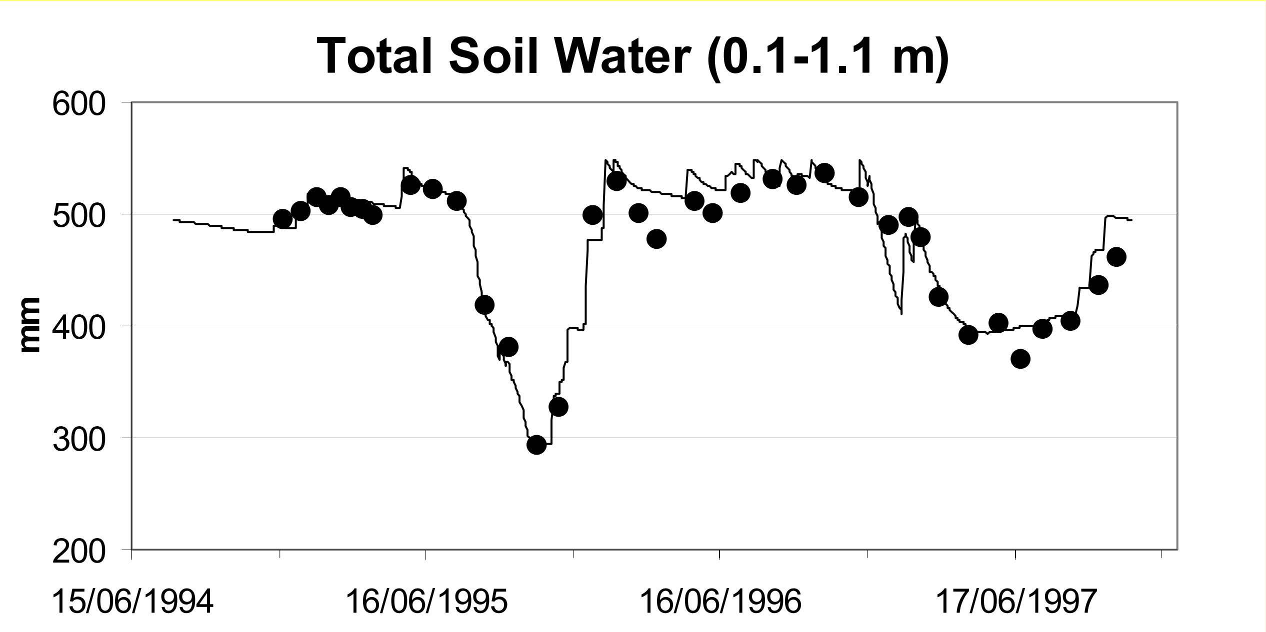
Wheat-Sorghum Long Fallow - Crop performance

Lines = predicted

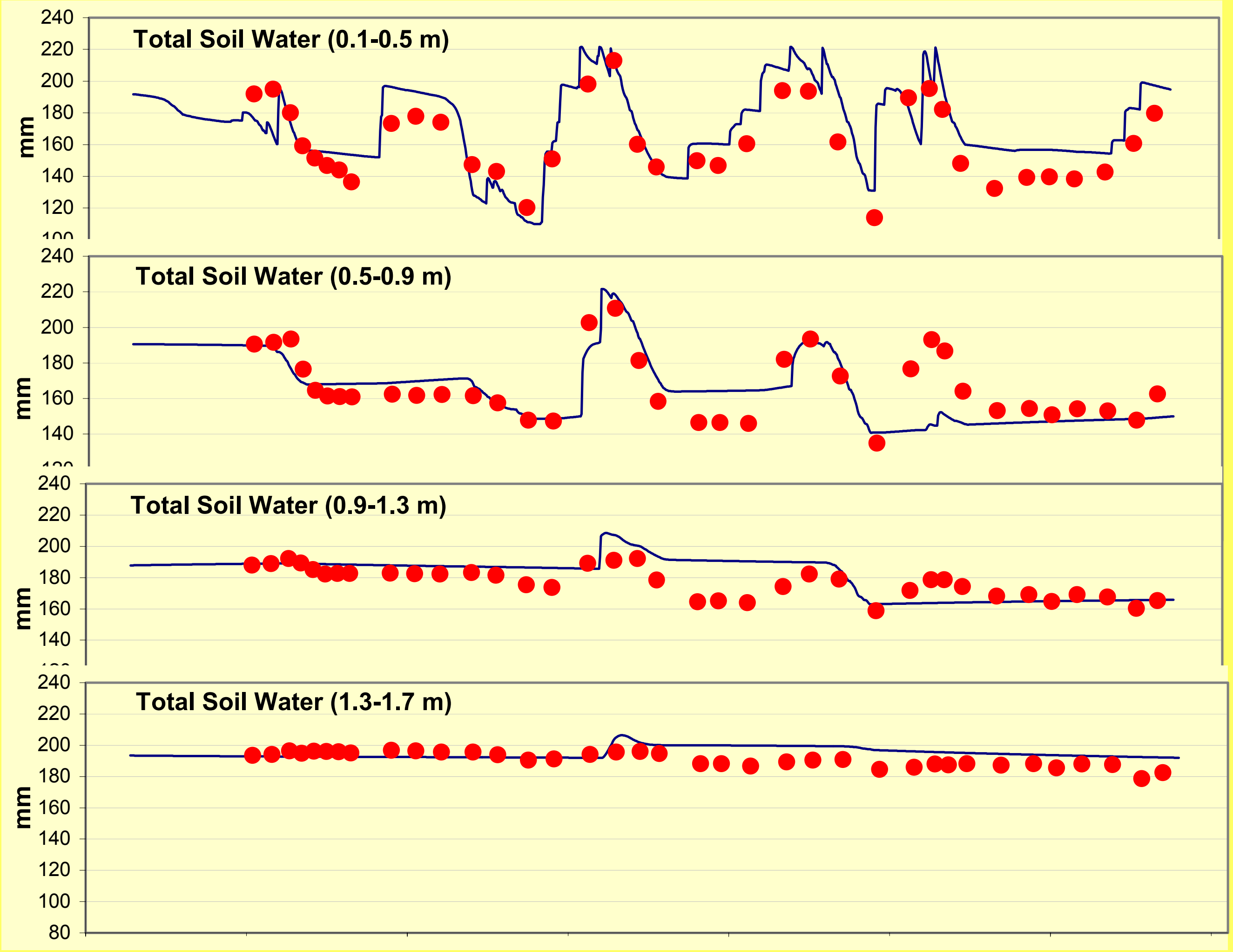
Symbols = observed



Effect of sorghum regrowth on soil water extraction



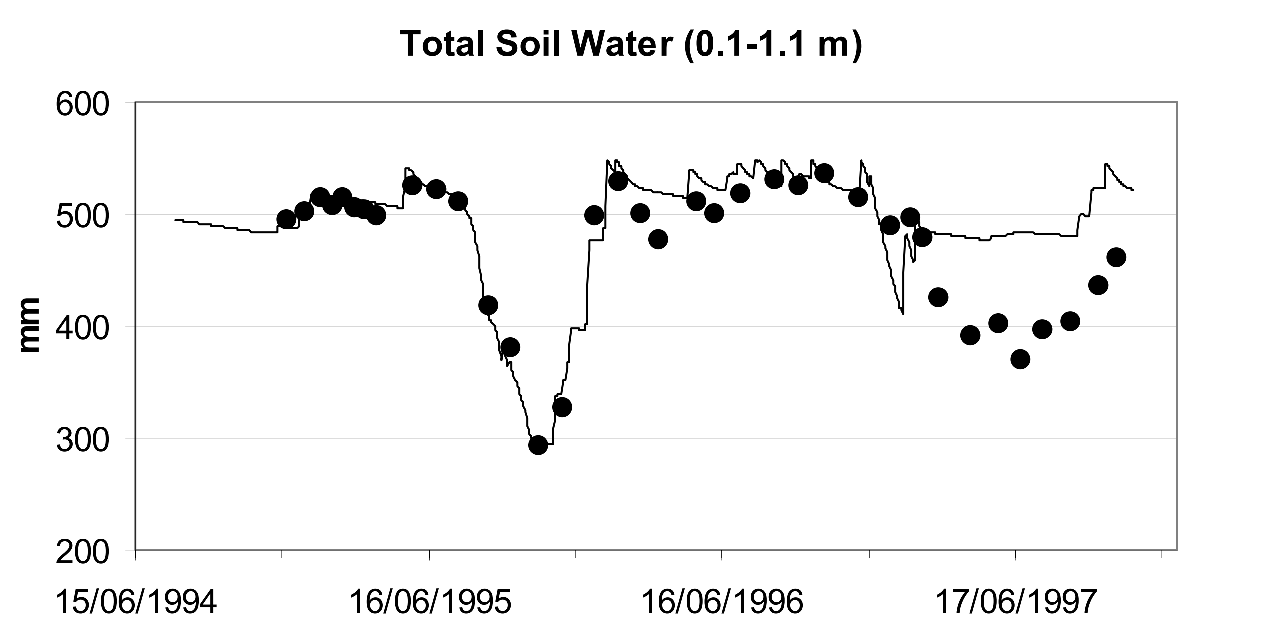
Modeling - Soil water dynamics Opportunity Cropping



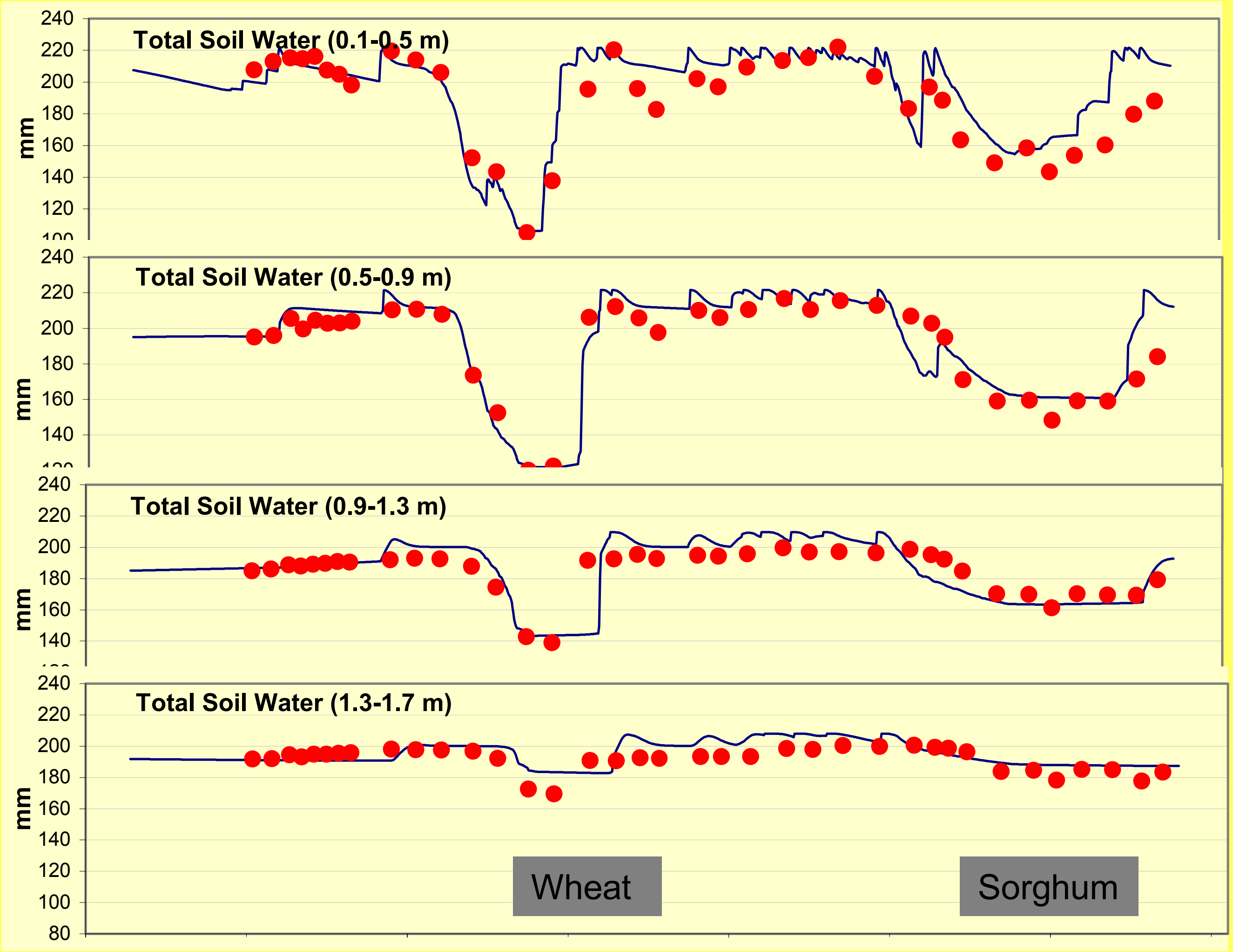
Model enhancement - the sorghum “regrowth” issue

- Originally, sorghum model leaf area was killed at harvest
- Crop continued to grow in field experiment
- Big effect on soil water extraction
- Model was enhanced to enable this effect to be simulated

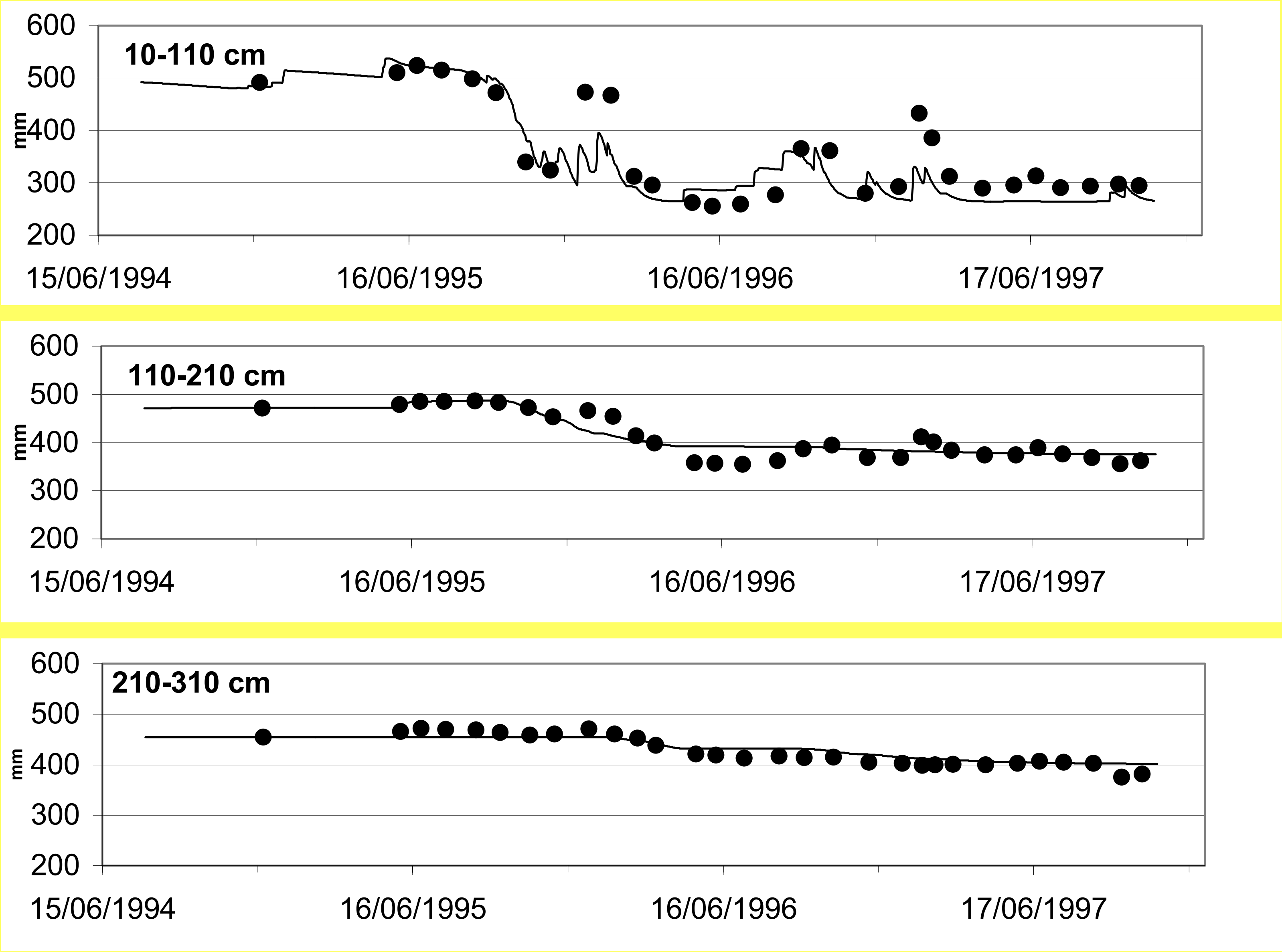
Effect of sorghum regrowth on soil water extraction



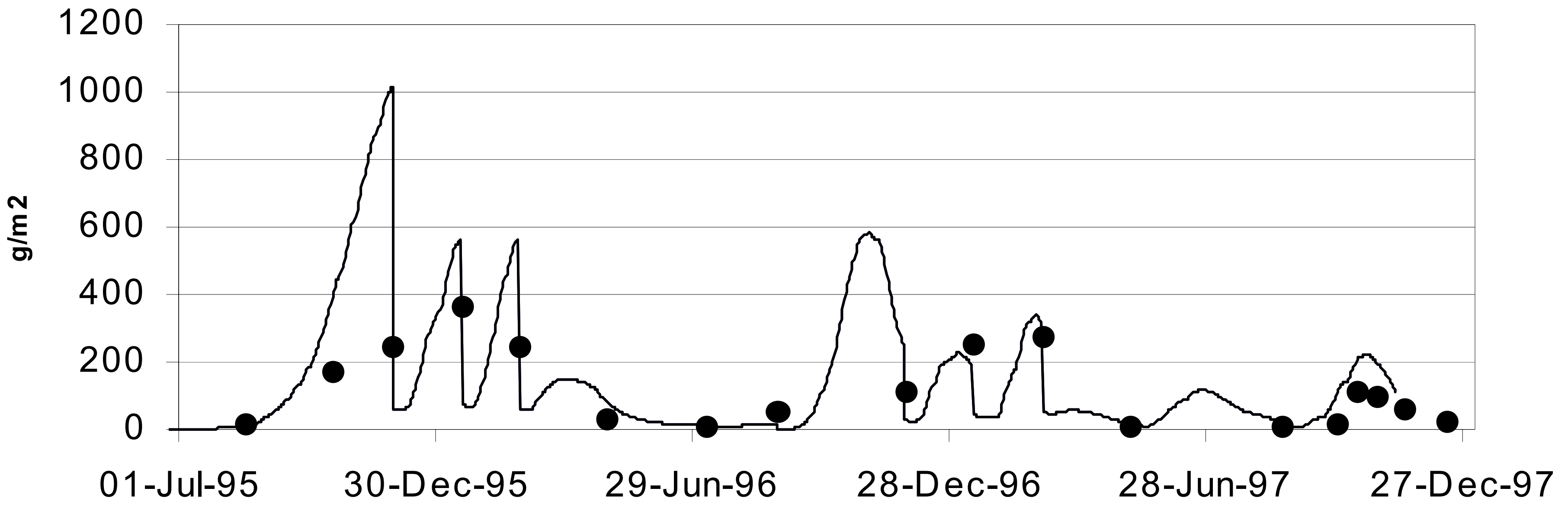
Modeling - Soil water dynamics
Long fallow systems



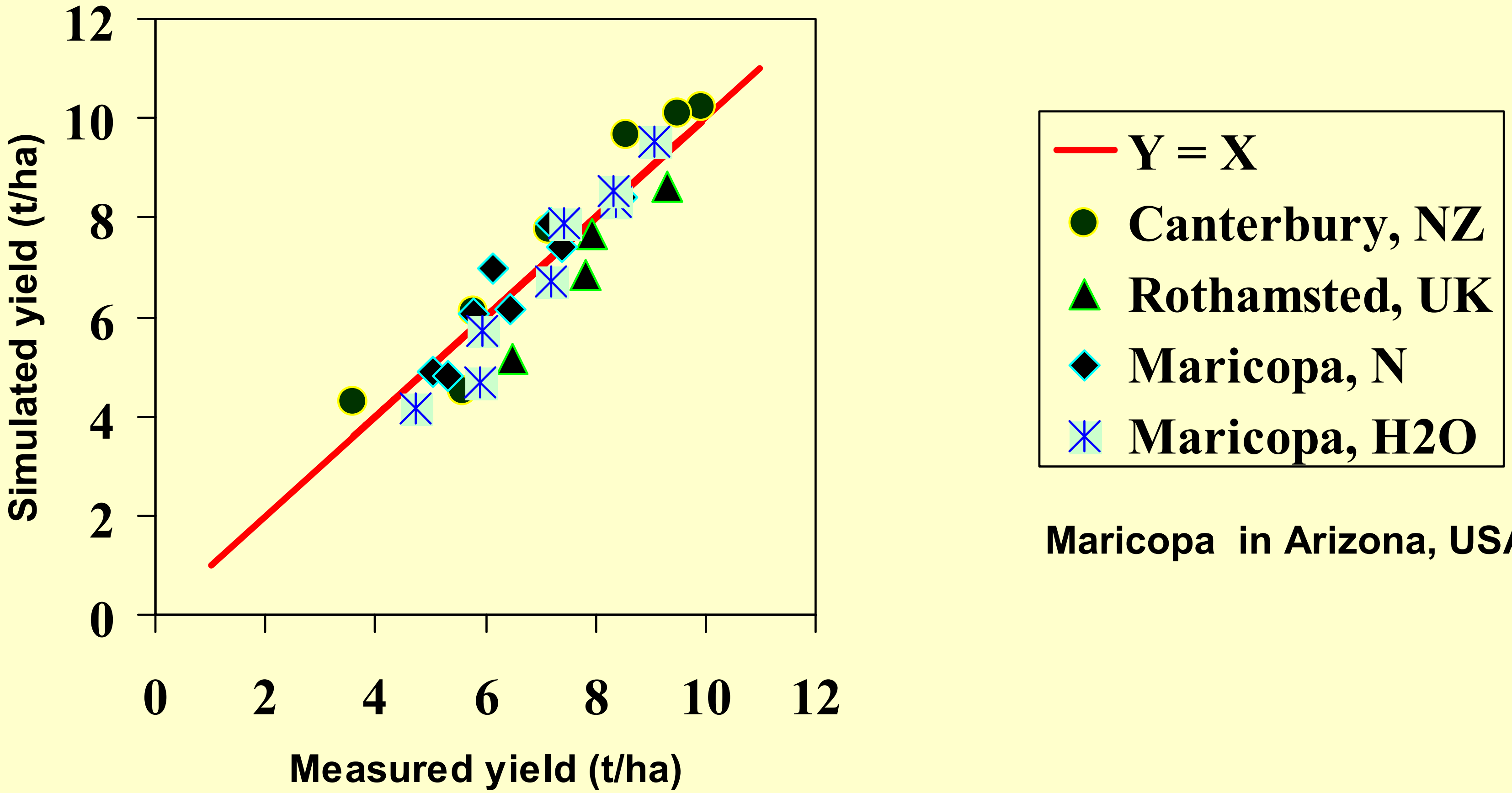
Lucerne - Soil water dynamics



Lucerne – above-ground dry weight



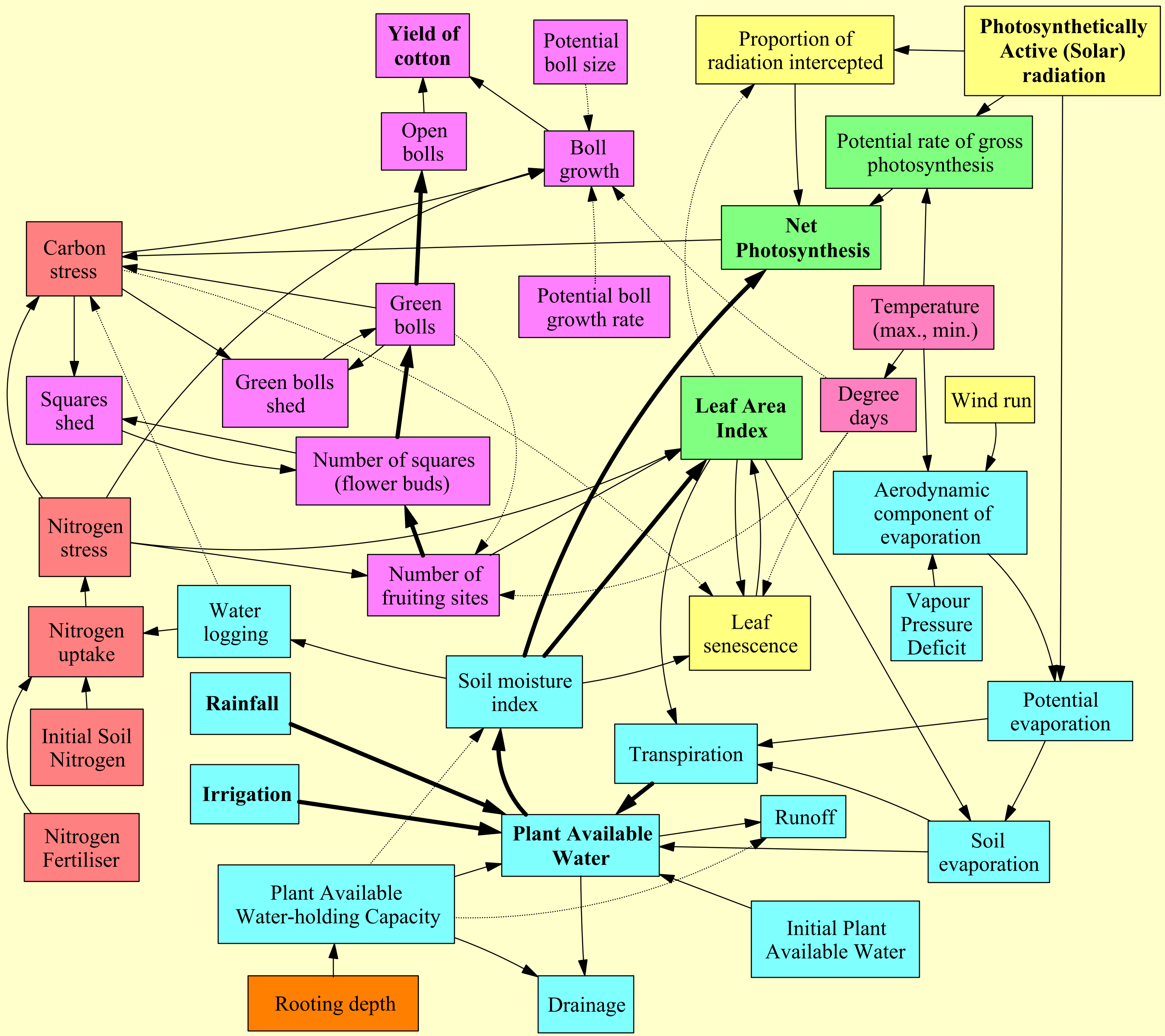
Sirius wheat crop simulations, wide variety of conditions



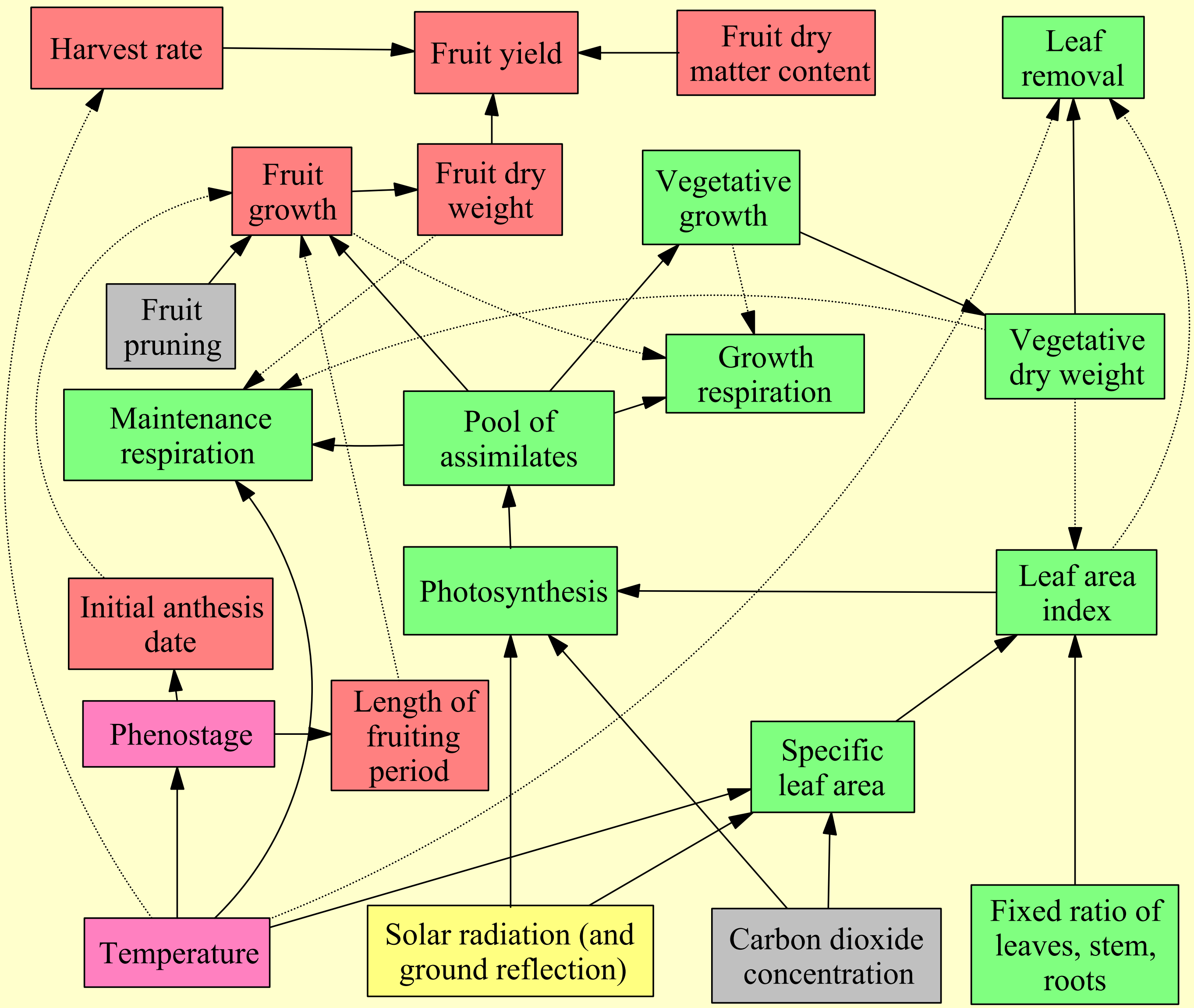
Maricopa in Arizona, USA

QSUN sunflower model

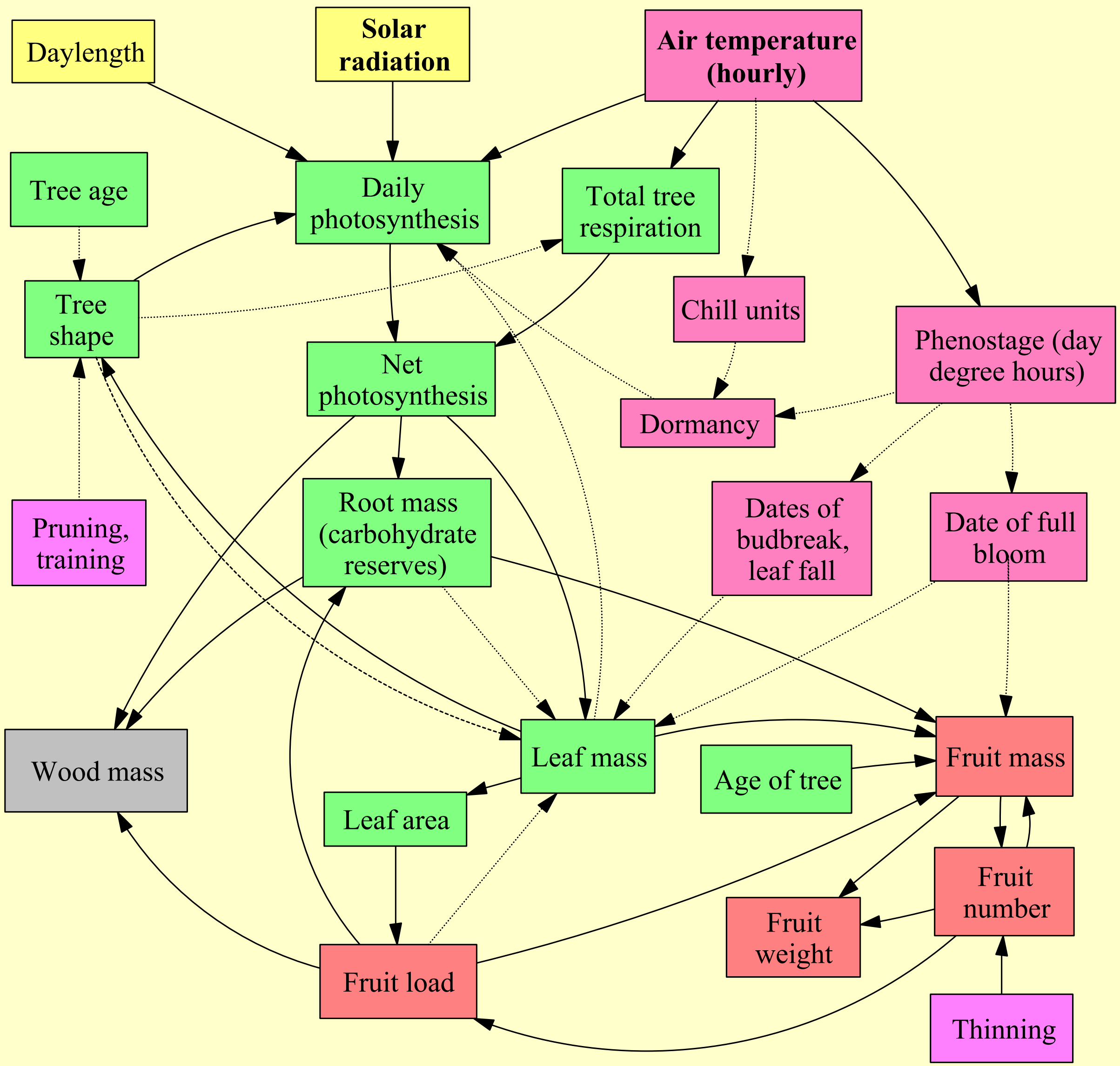
OZCOT Cotton Crop Model

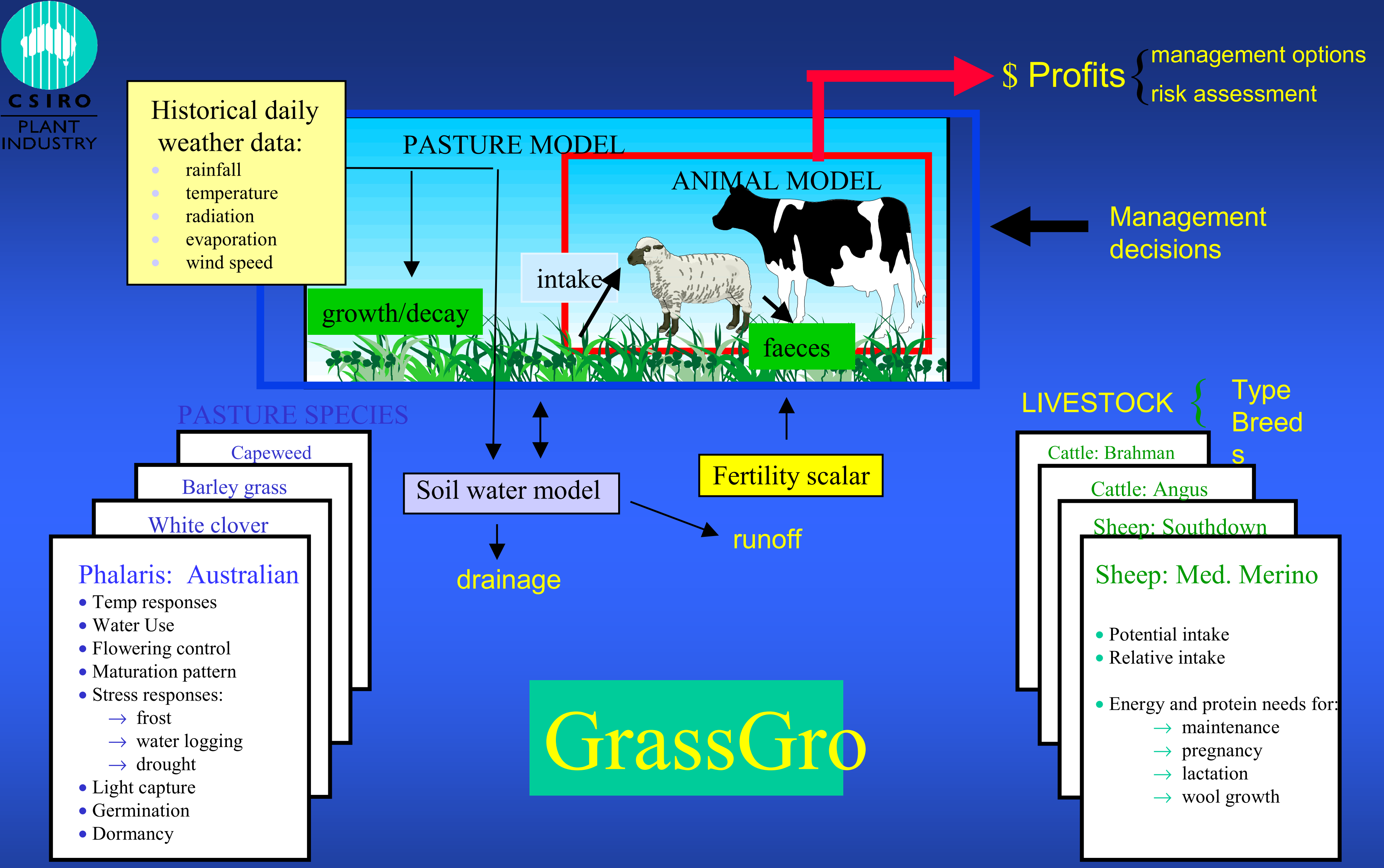


TOMSIM: Tomato crop simulation model

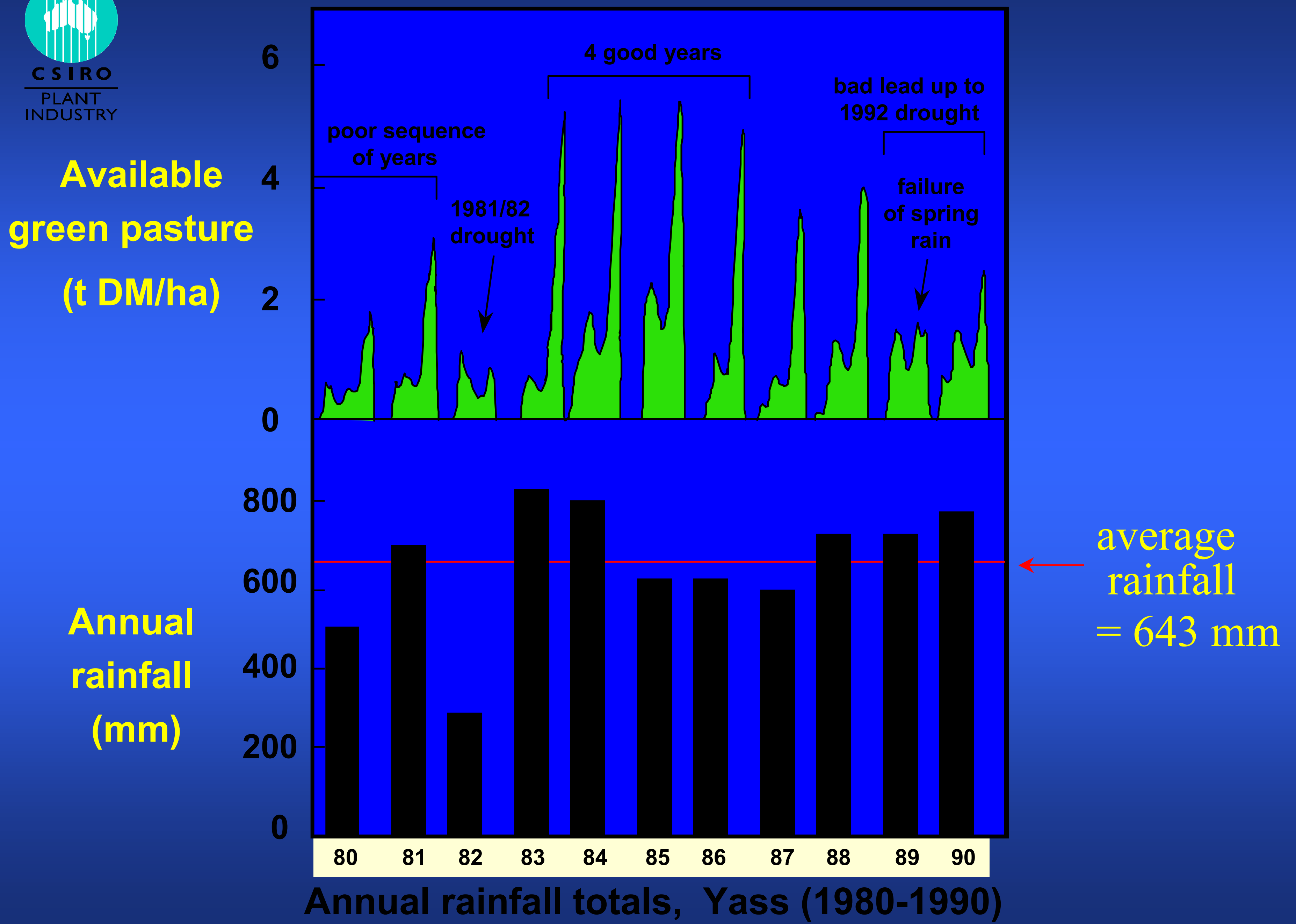


Apple production model (Hester and Cacho)




CSIRO
PLANT INDUSTRY
Historical daily weather data:
rainfall
temperature
radiation
evaporation
wind speed
PASTURE MODEL
ANIMAL MODEL
$ Profits
management options
risk assessment
Management decisions
intake
growth/decay
faeces
PASTURE SPECIES
Capeweed
Barley grass
White clover
Phalaris: Australian
Temp responses
Water Use
Flowering control
Maturation pattern
Stress responses:
→ frost
→ water logging
→ drought
Light capture
Germination
Dormancy
Soil water model
Fertility scalar
runoff
drainage
LIVESTOCK
Type
Breed
s
Cattle: Brahman
Cattle: Angus
Sheep: Southdown
Sheep: Med. Merino
Potential intake
Relative intake
Energy and protein needs for:
→ maintenance
→ pregnancy
→ lactation
→ wool growth
GrassGro

Pasture on offer at Yass, NSW (1980-1990)




GRASP (GRASs Production) Model
Tree biomass
Actual soil evaporation
Green leaf
Surface cover
Litter
Frost death
Temperature (max., min.)
Tree growth
Green stem
Dead biomass
Potential soil evaporation
Annual plant growth
Daily pasture growth - radiation, temperature and nitrogen-limited
User-defined green yield that gives 50% radiation interception
Potential tree growth from transpiration
Daily pasture growth
% perennial grass basal area
Transpiration efficiency
Projected cover of the foliage
Transpiration from trees
Pan evaporation
Radiation Use Efficiency
Daily solar radiation
Potential grass growth from transpiration
Potential evapotranspiration
Total daily grass transpiration
User-defined transpiration efficiency at 20 hPa
Potential tree transpiration
Potential daily transpiration from grass
Multiplier to adjust screen VPD to current grass height
Tree basal area
Tree soil water index
Grass soil water index
Runoff
Vapour Pressure Deficit at screen height
Soil moisture in layer 1
Infiltration
Nitrogen concentration in grass
Soil moisture in layer 2
Multiplier effect for increased VPD above bare and dry soil surfaces
Root depth of trees
Soil nitrogen uptake
Rainfall intensity
Soil moisture in layer 3
Rain
Soil nitrogen availability
Proportion of potential evaporation from green biomass
Soil moisture in layer 4
Deep percolation

Model	Author/Reference	Environment	Validated	Evaluation
APSIM Wheat	Meinke *et al*. (1998b) Asseng *et al*. (1998b) http://www.apsim-help.tag.csiro.au	Dryland, esp Qld, NSW, WA, Netherlands	Extensively in NSW, southern Qld and WA, also Netherlands	Soil moisture *** Biomass ** Grain yield ** Kernel number *
O&C Wheat	O'Leary and Connor (1996a, 1996b)	Dryland, esp NW Vic.	Wimmera and Mallee, Vic.	Soil moisture *** Biomass ** Grain yield ** Kernel number *
SIMTAG wheat	Stapper (1984, 1998) Fischer *et al*. (1990) Angus *et al*. (2001)	Dryland and irrigated	In southern NSW and Syria	Soil moisture *** Biomass ** Grain yield **
APSIM Sorghum	Birch *et al*. (1990) Hammer and Muchow (1991, 1994)	http://www.apsim-help.tag.csiro.au	NE Australia and India	Soil moisture *** Biomass *** Grain yield ** Kernel number **
APSIM Maize	Keating *et al*. (1992) http://www.apsim-help.tag.csiro.au	Irrigated and dryland	Qld, NT, Kenya, Zimbabwe	Soil moisture *** Biomass *** Grain yield ***
APSIM Canola	http://www.apsim-help.tag.csiro.au	Dryland	Qld, NSW, Vic, WA	Soil moisture *** Biomass *** Grain yield *** Oil content **
APSIM Sunflower	Chapman *et al*. (1993) Meinke *et al*.(1993a, b)	Irrigated and dryland	Southern Queensland	Soil moisture ** Biomass ** Grain yield **
APSIM Sugarcane	Keating *et al*. (1999)	Irrigated and dryland	Queensland, Hawaii and southern Africa	Soil moisture *** Biomass *** Sugar yield **

Assessment of model output: *** appears reliable; realistic but needs improvement **; unreliable *

Table 2 (continued): Assessment of major Australian crop and pasture models

Model	Author/Reference	Environment	Validated	Evaluation
OzCot cotton	Hearn (1994)	Irrigated and dryland cotton crops in NSW and Queensland	Irrigated and dryland cotton crops in NSW, central Qld, Kununurra, WA	Soil moisture *** Biomass ** Boll yield **
APSIM Grain legumes (Chickpea, soybean, mungbean, lupins, field pea, pigeon pea)	http://www.apsim-help.tag.csiro.au	Dryland	Qld, NSW, SA, WA	Soil moisture *** Biomass ** Grain yield **
APSIM Lucerne	Probert *et al* (2001) http://www.apsim-help.tag.csiro.au	Irrigated and dryland	Southern Qld, NSW, Wa, NZ	Soil moisture *** Biomass **
GRASP pasture	McKeon *et al*. (1990) Carter *et al*. (2000)	Rangelands, esp. Qld and northern Australia	Rangelands of Queensland. Northern Territory, Western Australia and NSW	Soil moisture *** Biomass *** Herbage quality *
GRAZPLAN: GrassGro	Moore *et al*. (1997)	High-rainfall and cereal-sheep zones of southern Australia	NSW, Victoria, SA, SW of WA, Canadian prairies; annual and perennial grass and lucerne pastures	Soil moisture ** Biomass ** Herbage quality ** Animal production **

Assessment of model output: *** appears reliable; realistic but needs improvement **; unreliable *

Periodic waterlogging

- Understand water balance - critical
- Macropores full of water (>85 per cent)
- Very poor O_2 supply to roots
- Lethal number of days (>3)
- Critical drained depth (below root zone)
- Duplex -> less macropore conductivity
- Root depth reduced -> biomass, grain

Modelling impact of waterlogging

- Senthold Asseng – duplex soils in WA – extended model realistic
- Jon Lizano and Joe Ritchie - CERES-Maize version that is sensitive to water logging
- Soils with unstable macropores are currently beyond existing models

Conclusions

- Simple models using rain, irrigation, Et

- Comprehensive models

  .. detailed soil moisture balance

  .. detailed crop physiology

- For systems analysis and improving management of farming systems

More conclusions

Crop models with relevant inputs are able to reliably estimate:

- soil moisture
- crop biomass

Models vary in their ability to estimate yield

Areas for consideration

- Models need data, often necessary adjuncts to field experimentation

- Logical framework for new knowledge

- Areas requiring attention:
  - root density and depth
  - stem extension (sugarcane)
  - kernel number

Thank you