APSIM - Agricultural Production Systems Simulator

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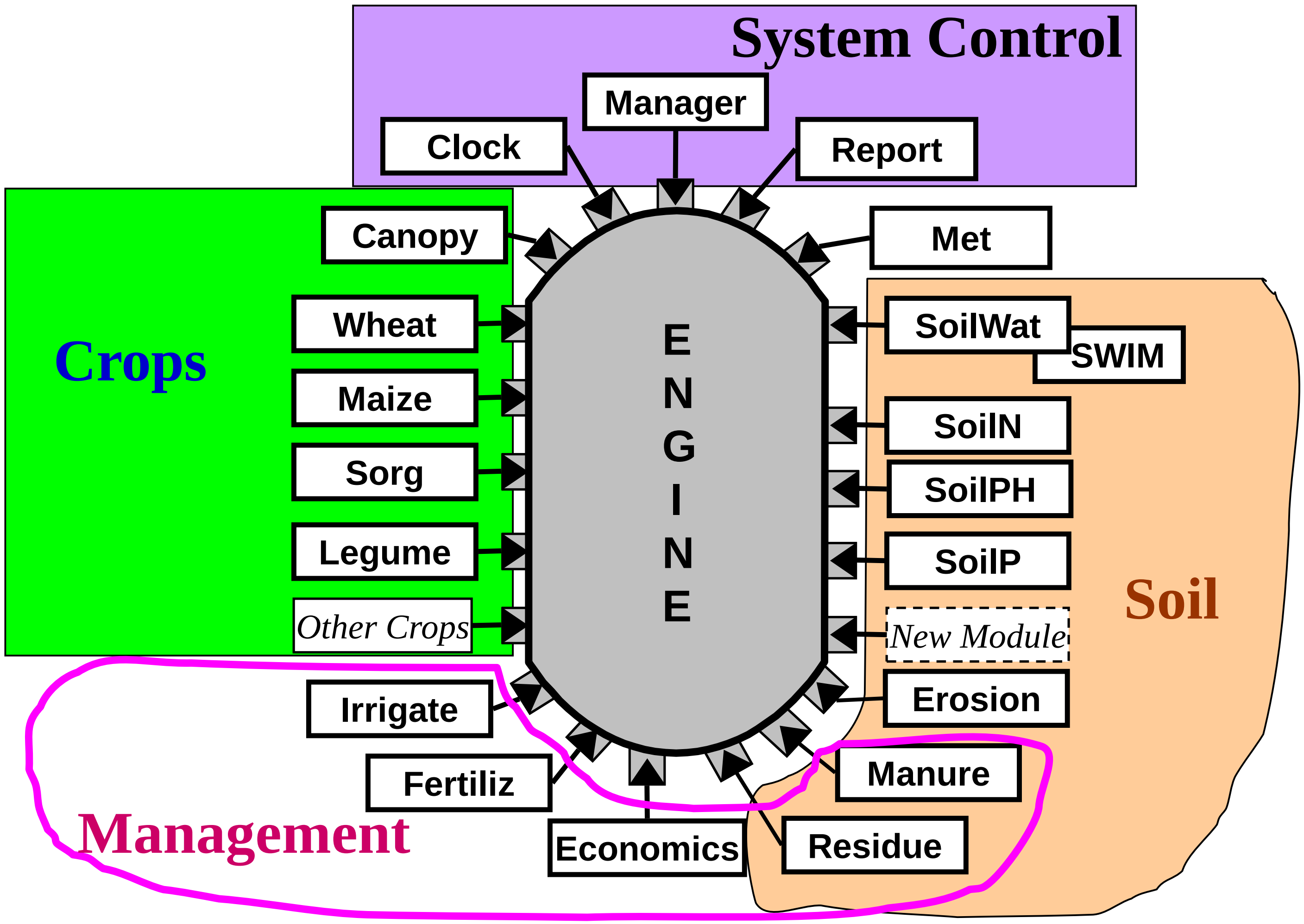
Outline

- APSIM
  - Design
  - Concept
  - Capabilities
- Testing and evaluation
- APSIM demonstration
- APSIM-Derived DSS Tools - WhopperCropper

- **APSIM development initiated in early 1990s**
- **Investment: more than A$ 13 million**

… the soil provides a central focus, crops, seasons and managers come and go, finding the soil in one state and leaving it in another …….

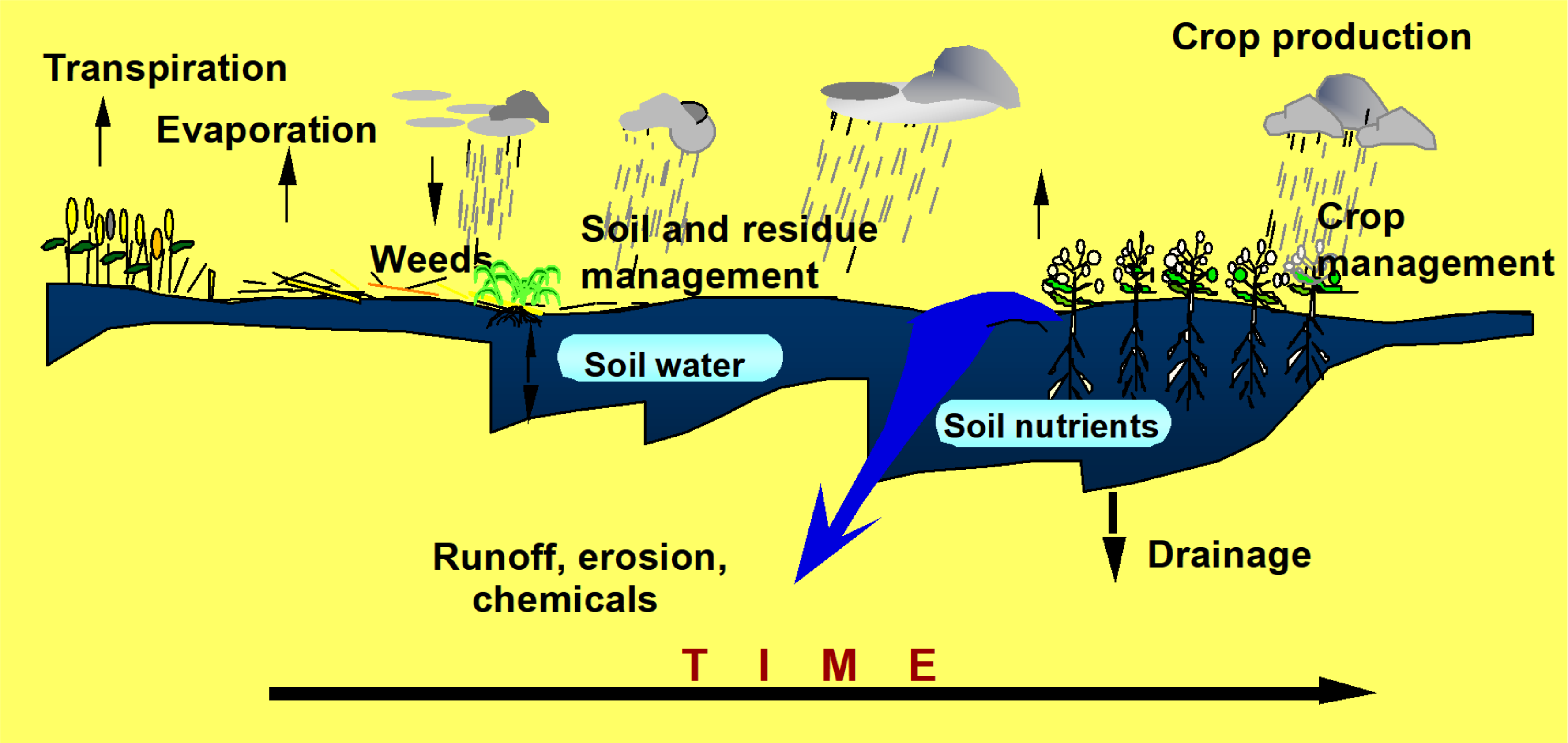
APSIM – A farming systems modelling framework



APSIM simulates

- mechanistic growth of crops, pastures, trees, weeds ...
- key soil processes (water, solutes, N, P, carbon, pH)
- surface residue dynamics & erosion
- dryland or irrigated systems
- range of management options (fertilisation, tillage, irrigation, …)
- crop rotations + fallowing + mixtures
- biotic stresses (parasitic weeds)
- dynamics of populations (eg. weed seedbank)
- short or long term effects
- high software engineering standards

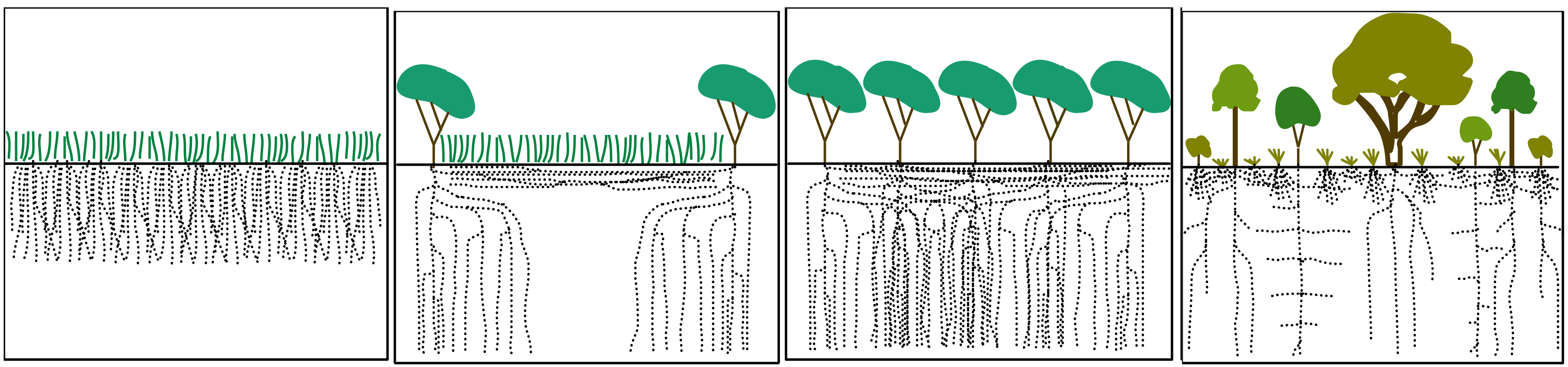
- Systems simulation over time



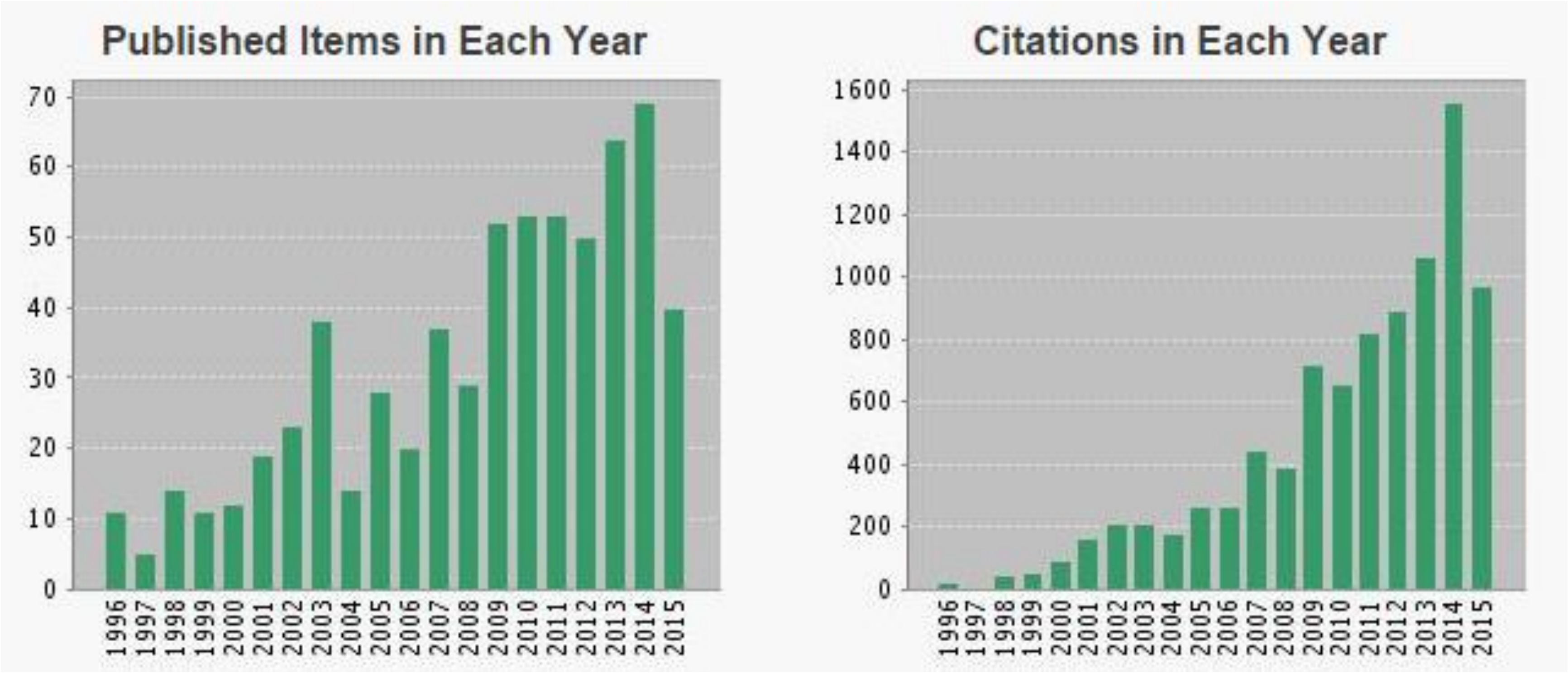
- Systems simulation across different scales

gene – crop – farm – catchment - region

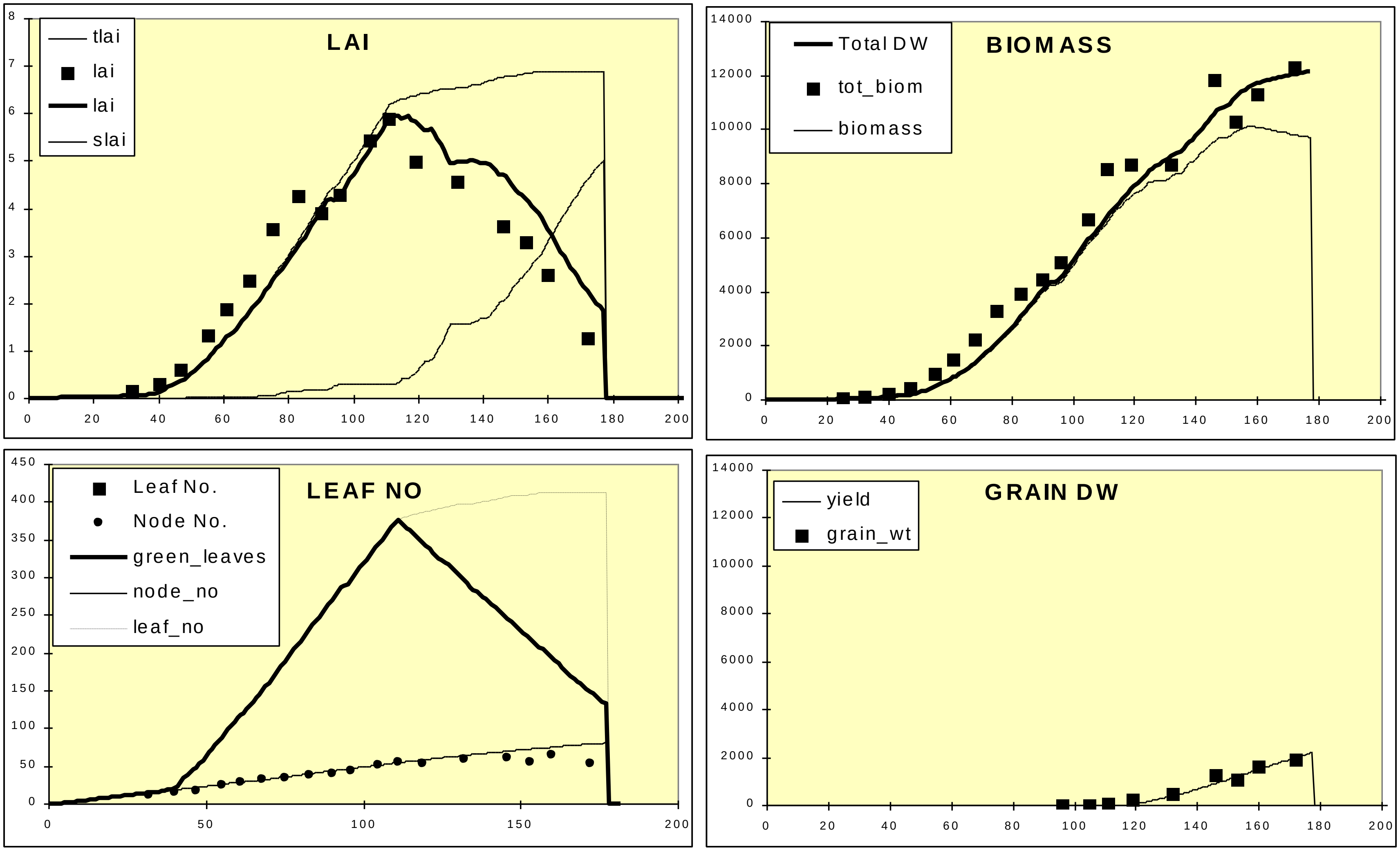
- Systems simulation of the cropping, novel agroforestry systems and native woodland



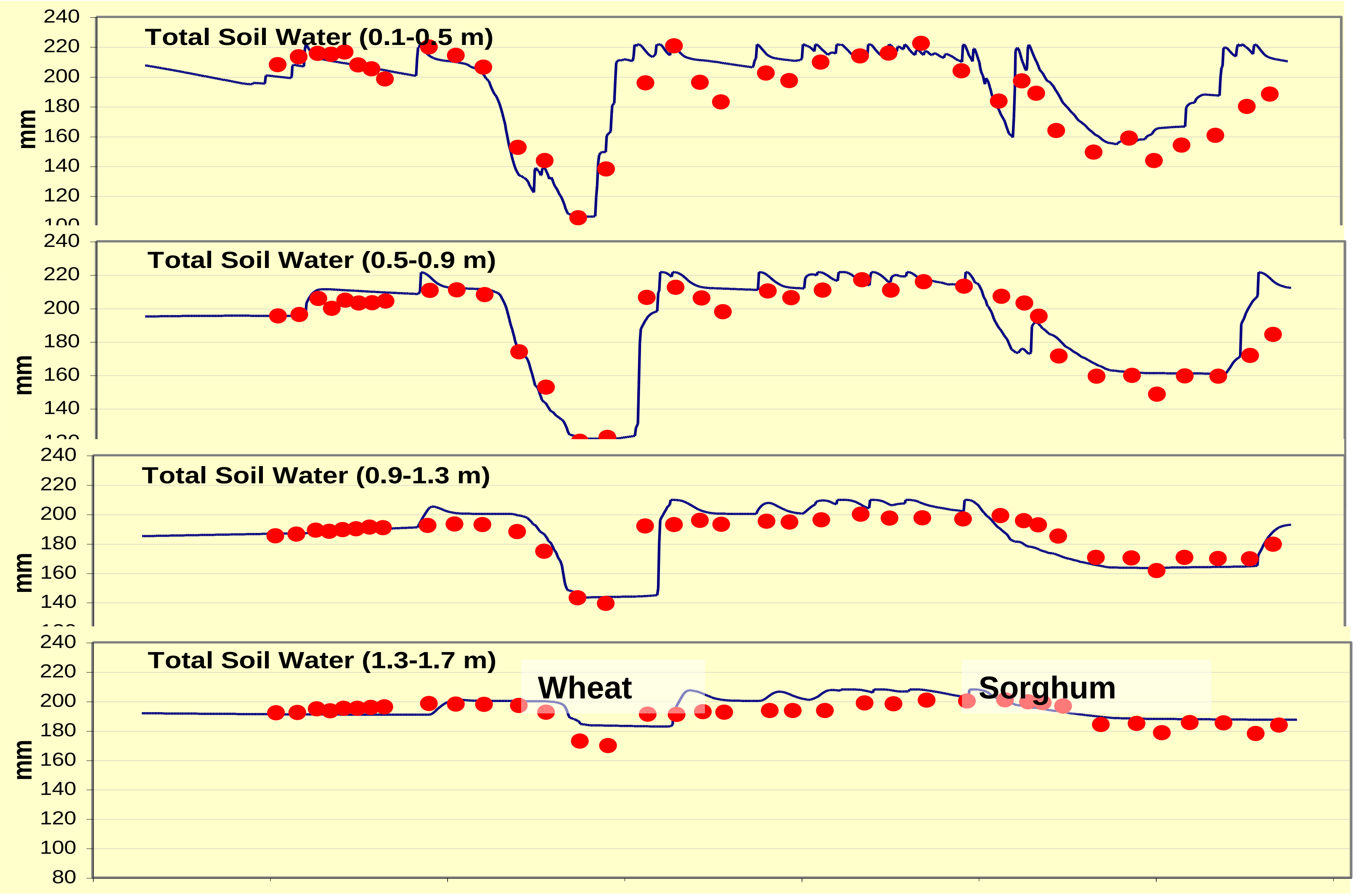
- **Example APSIM applications**



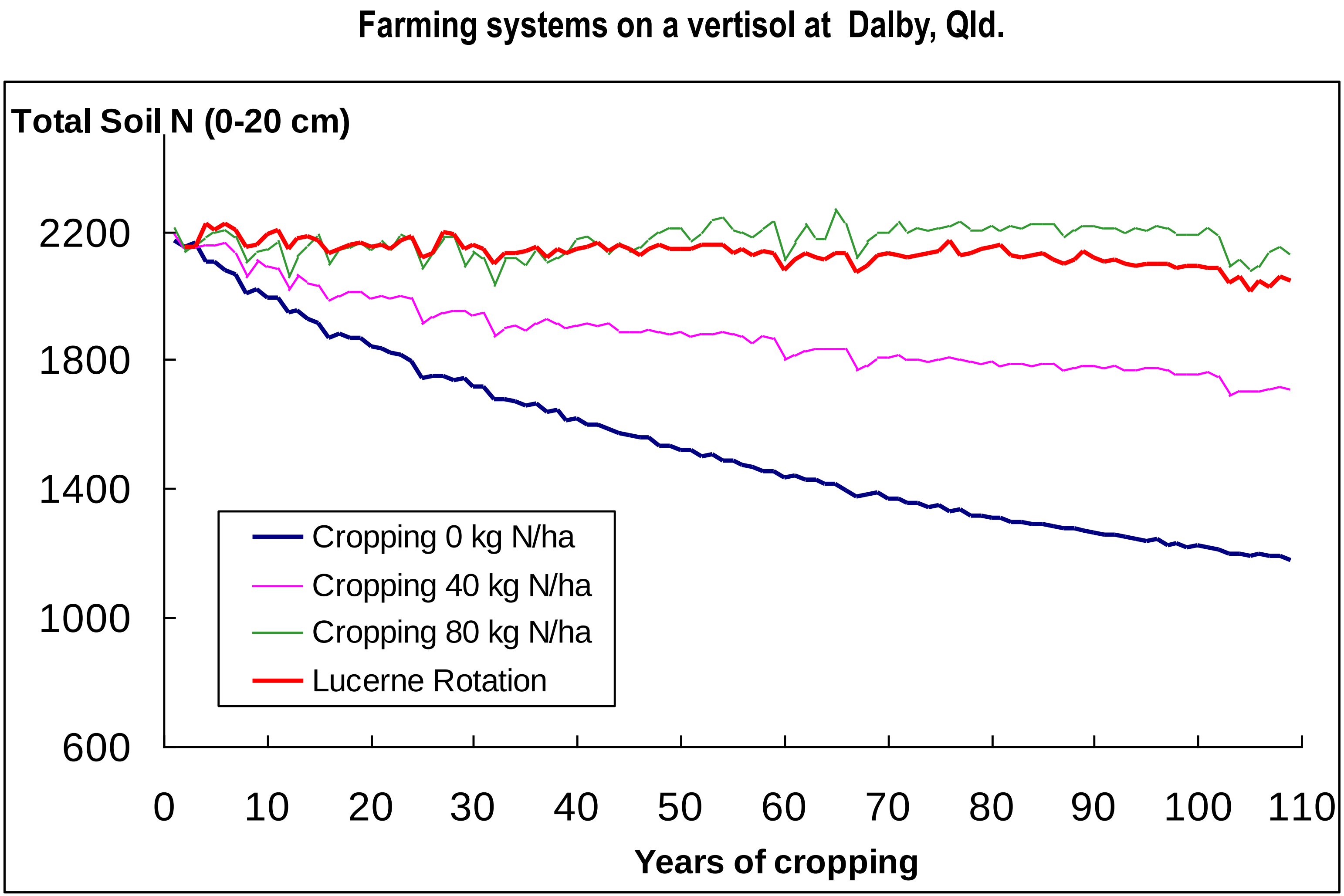
◻ …crop growth & development



- **… soil water of crops in rotation**



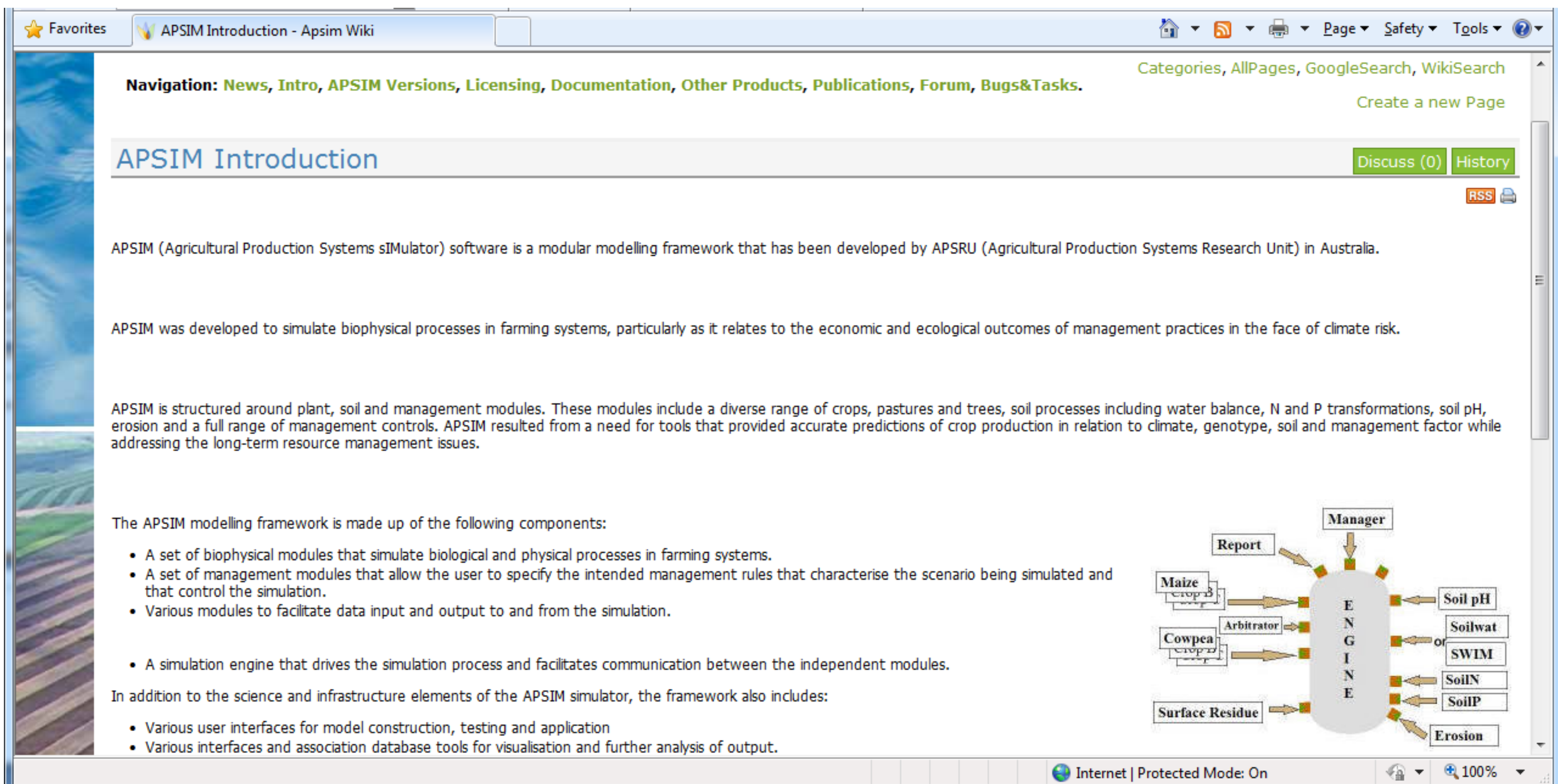
... soil organic matter changes



Further information:

Keating, Carberry, Hammer, Probert et al. (2003). "An overview of APSIM, a model designed for farming systems simulation." European Journal of Agronomy 18(3-4): 267-288.

APSIM Homepage (https://www.apsim.info)



APSIM Plant Modules

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Crop, pasture and tree modules

- Maize, Sorghum, Sunflower, Millet @, Rice$
- **Wheat**, **Barley**, **Canola**
- **Mungbean, Cowpea, Soybean, Peanut, Pigeonpea@, Navybean, Mucuna**
- **Chickpea, Fieldpea, Faba bean**, **Lentil, Lupin**
- Sugarcane
- **Stylo**, Bambatsi pasture
- **Lucerne**
- Cotton (OzCot)*
- Native pasture (GRASP)
- **Generic weed**
- *Eucalyptus grandis, E. globulus, E. camadulensis*
- Potato, ...

*** by arrangement with CSIRO PI**
@ in association with ICRISAT
 # in association with CSIRO L&W
$ by arrangement with WAU

Processes captured

- Phenology and height
- Tillering and leaf area production
- Biomass accumulation and partitioning
- Root growth (depth, density and biomass)
- Crop water relations
- Crop nitrogen relations
- Crop phosphorus relations (not all modules)
- Senescence and plant death

Phenology/Development

Development 'stage'	Determinants
Sowing	User defined
Germination	Thermal time (TT), soil water
Emergence	TT, sowing depth
End of juvenile	TT
Floral initiation	TT, Photoperiod
Flowering	TT
Start of grain fill	TT
End of grain fill	TT
Maturity	TT
Harvest ripe	TT

Leaf area development

- **Net daily change** in leaf area/m^2 (LAI)

  balance between growth and senescence

- **Daily growth** in new leaf area is a function of

  plant density X branching X new leaves produced X

  area per new leaf

- **Daily loss** of leaf area due to senescence a function of

  age, shading, frost, water stress, N stress

Biomass accumulation

- Radiation intercepted by leaf area and extinction coefficient
- Radiation use efficiency converts intercepted radiation to biomass
- Biomass accumulated limited by extremes of
  - temperature
  - N deficit
  - water deficit
  - P deficit
  - oxygen deficit (waterlogging)

Biomass partitioning

Partitioning based on stage-specific ratios/fractions:

- **Root, leaf, stem, reproductive, grain**
- **Roots** grown daily in stage-specific proportion to shoot
- **Emergence to flowering:** biomass partitioned leaf & stem
- **Flowering to start of grainfill:** leaf, stem, pod/flower
- **Start grainfill to maturity:** grain +/- pod/flower
- If demand < supply, residual to leaf, then stem
- If demand > supply, retranslocation from stem & leaf (defined)

Soil water uptake

Minimum of soil water supply and demand

- **Soil water demand (daily):**

  - based on biomass production and transpiration efficiency

- **Soil water supply (daily):**

  - sum of total available water (>lower limit) in all layers with roots

  - ***'kl'*** factor to limit available water for uptake per day

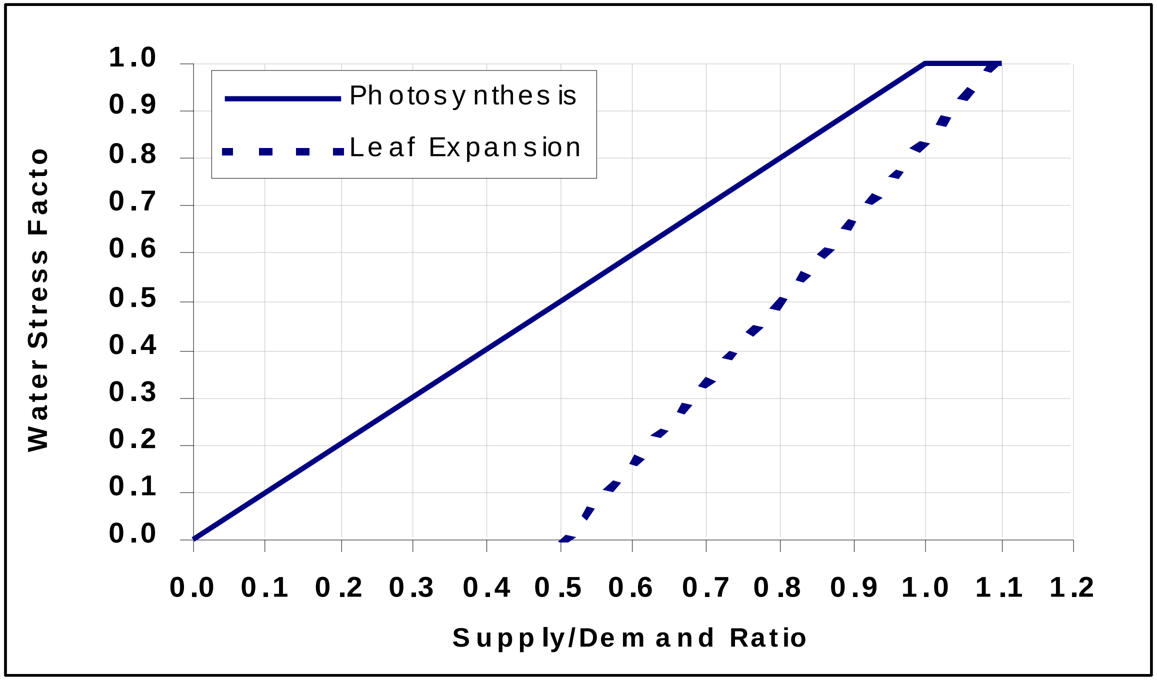
  (varies with layer, empirical based on soil and plant factors

  limiting uptake)

Water relations - stress factors

Four water deficit factors:

photosynthesis, phenology, leaf-expansion, nitrogen fixation



Nitrogen dynamics

- **Supply** is the sum of N available through active (diffusion), passive (mass flow) uptake and N fixation
- **Demand** is a function of biomass of individual plant parts and their critical N%
- **Uptake** is the minimum of supply and demand
- **Partitioning** to vegetative parts is proportional to the demand of these parts
- **Retranslocation** during grain filling depends on availability in veg organs and grain demand
- **N Stress factors** calculated from N-concentration ratio’s

Nitrogen uptake

Minimum of soil N supply and demand

- **Nitrogen demand (daily):**

  - each plant part has **min, max and critical N concentrations**

  - demand attempts to maintain N at critical (non-stressed) level in each plant part

- **Nitrogen supply (daily):**

  - three forms of NO3 and NH4 uptake (mass flow, active, fixation)

  - N distributed to plant parts in proportion to demands

  - grain N is retranslocated from other plant parts (not from soil)

  - N fixation capacity= f(genotype, growth stage, biomass, SW stress)

Depth of the root zone

- Daily potential root depth increase determined by temperature and phenological stage
- Dry soil in a layer (< 25% PAW) limits elongation
- Hospitality factor (***xf***, 0-1) limits elongation through a layer
- Maximum depth limited by depth of profile or season length
- Severe water stress can stop roots

Death and detachment

Plants die/killed:

- No germination within 40 days planting (lack of moisture)
- No emergence within 150 ^{o}C d of sowing (sown too deep)
- Crop past FI and LAI = 0, plants killed due to total senescence
- Fraction of plants killed by high temp. after emergence

Detachment:

- Detachment of dead or senesced plant parts

What can you “do” with a crop in APSIM?

- **Sow it**

  cultivar, sowing depth, plant density,

  row spacing, row configuration

- **Harvest it**

  Height above ground, proportion of crop residues removed

- **Kill it**

  Proportion of plants killed

- **Change class** eg from plant to regrowth

- **Remove** it from the simulation

Some things to keep in mind

- Cultivars basically only differ in phenology
- Some effects not accounted for eg waterlogging, other nutrient deficiencies, frost damage at flowering, lodging
- Some variables have different units eg biomass (kg/ha) vs biomass_wt (g/m^2)
- Grain yield is at zero moisture content
- Some modules have received more testing than others in some environments

Things to watch out for…

- Key variables – *phenology, LAI, root depth, biomass, yield, water and N stress factors (root biomass, residues)*
- Was the crop actually sown, fertilised, irrigated etc on the days you intended?
- Were soil water and N starting conditions what you intended?
- Is the crop making it to maturity?
- Is the downward progress of the root system behaving as it should?
- Does the harvest index seem sensible?

Where can I find out more about the science in a crop module?

- Module documentation
- Key publications
- History of development
- Output variables
- Name of module convener

Modelling Soil Water and Solute Dynamics

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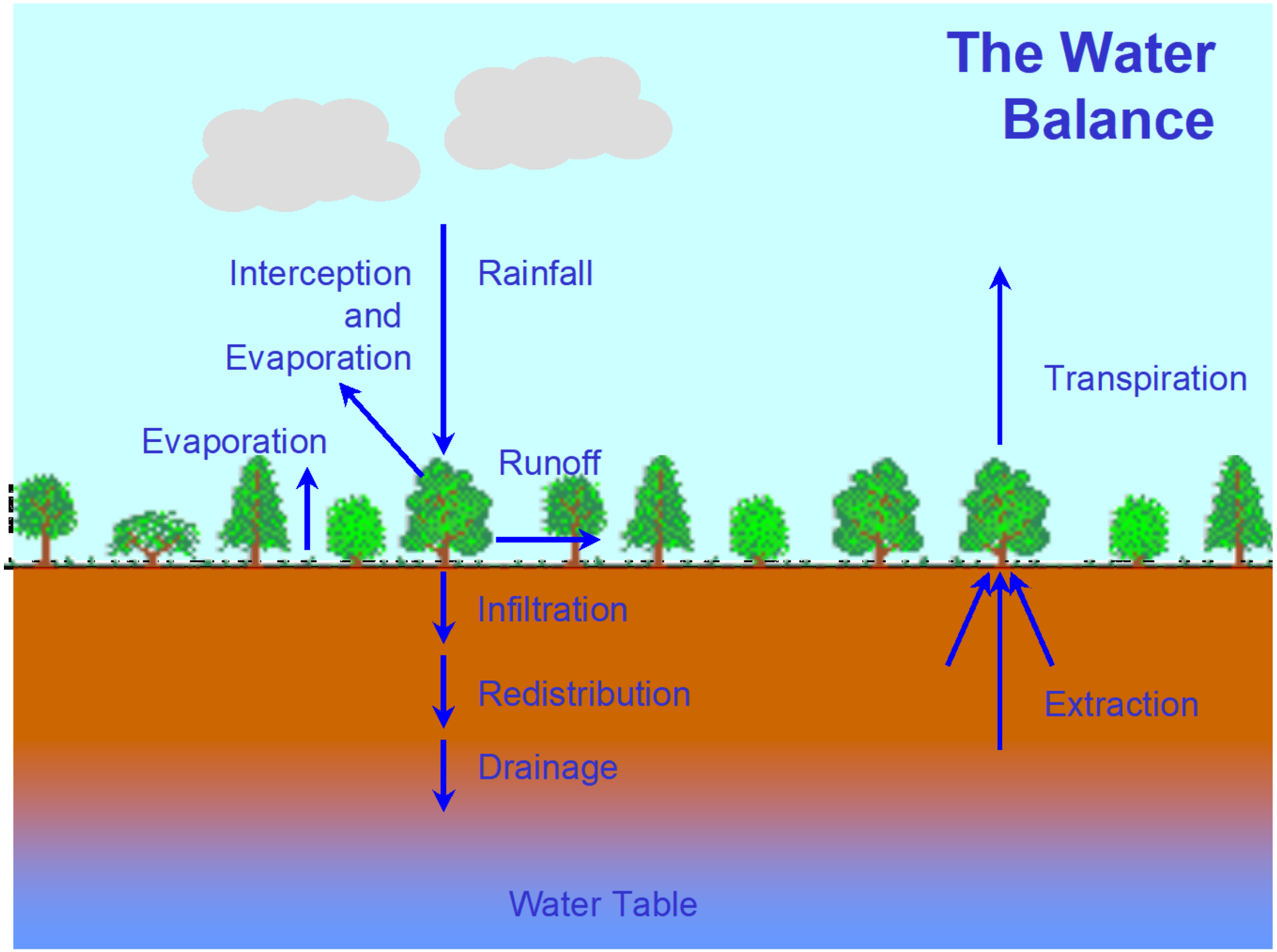
Water & Nitrogen

- The two most limiting factors for crop growth



Soil Water Balance

- change in soil water content

= water in – water out

= precipitation + irrigation + runon

- runoff – drainage – transpiration – evaporation

- Can be applied over any time scale

Soil Water Balance

- Components of the water balance in APSIM

The subroutine structure in SoilWat

Note that transpiration is estimated by the crop modules

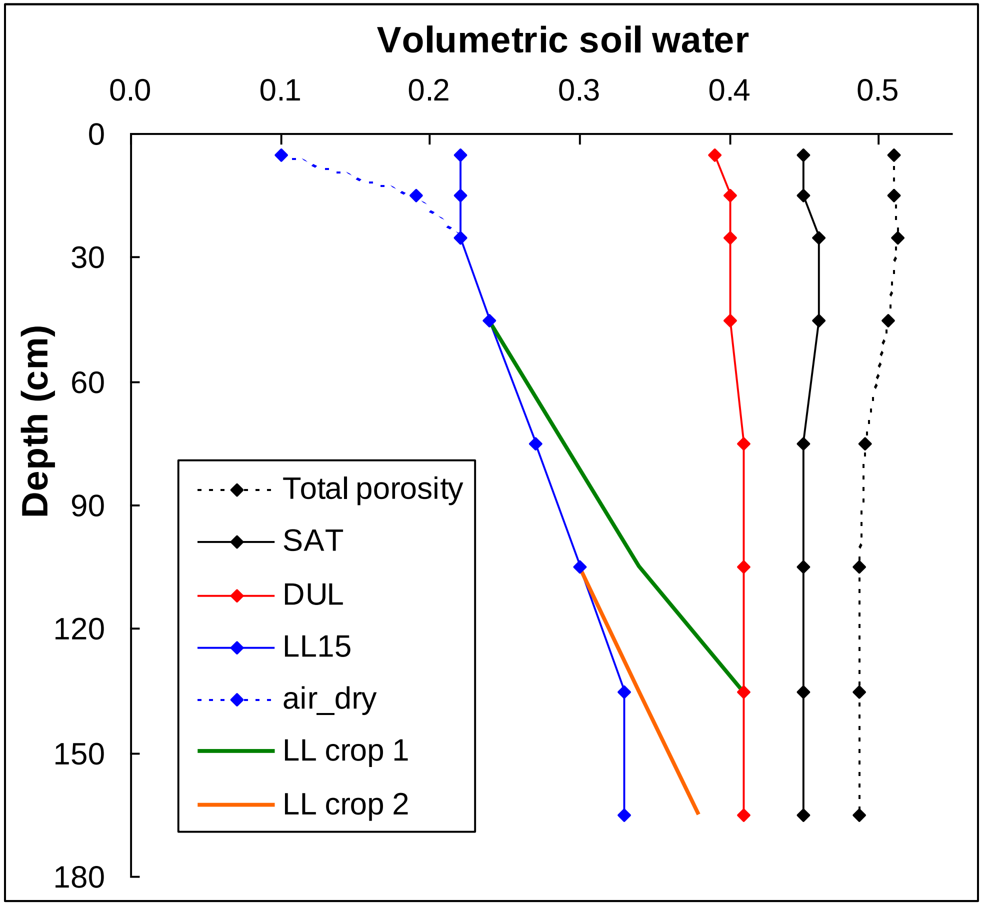
SoilWat

- Runoff
- Drainage
- Solute Flux
- Potential Evapotranspiration
- Soil Evaporation
- Unsaturated Flow
- Solute Flow

Soil Water Balance

- Characterising soil water properties

  - **SAT (saturation)**
  - **DUL (drained upper limit)**
  - **LL15 (lower limit)**
  - **LLcrop (not a true soil property)**
  - **Air Dry**



Soil Water - Runoff

- Precipitation partitioned into infiltration runoff

- Runoff: USDA Soil Conservation Service (SCS) procedure known as **curve number technique**
  - Based on total precipitation for the day
  - Curve numbers derived from experimental data:

    - soil type

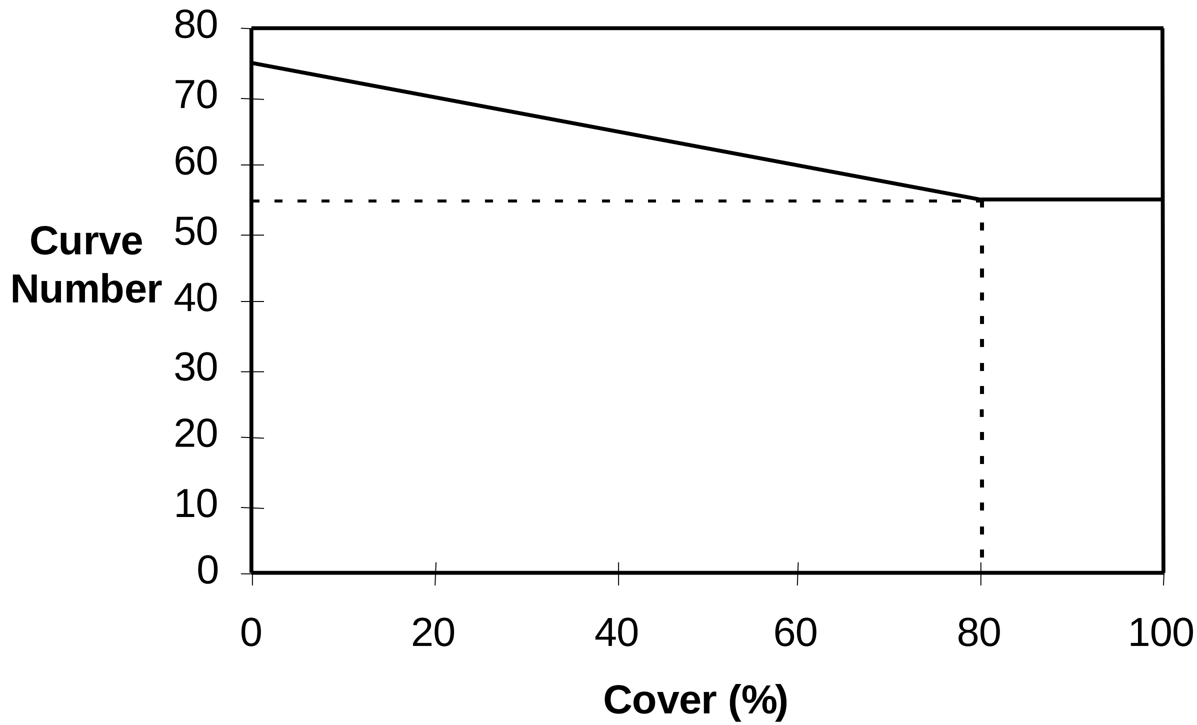
    - land use (row crops, contoured, terraced)

    - antecedent rainfall condition

- **Surface residues** affect runoff

  Curve number is adjusted according to amount of crop and residue cover

Effect of cover on runoff curve number where bare soil curve number is 75 and total reduction in curve number is 20 at 80% cover.



Soil Water - Evaporation

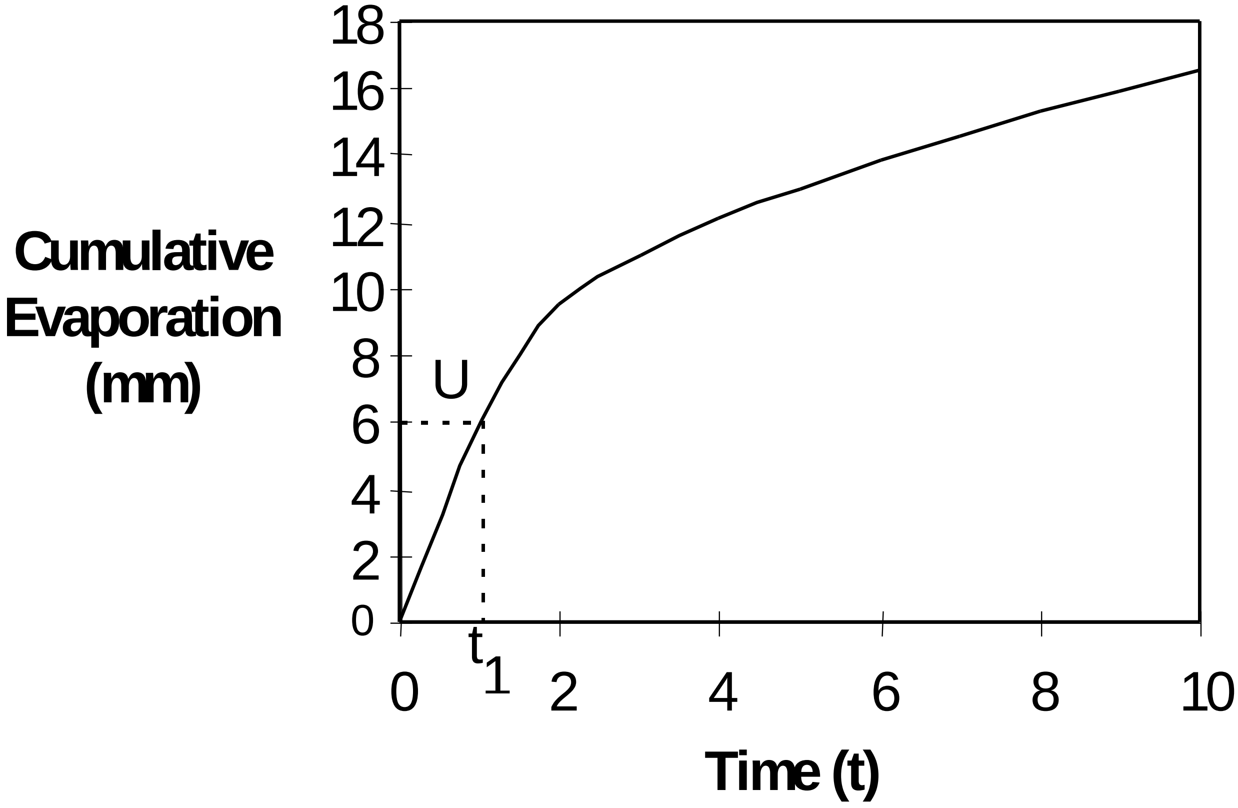
- Soil evaporation occurs in **two stages** –
- **1st stage**: soil is sufficiently wet for water to be transported to the surface to keep up with potential atmospheric evapotranspiration (Priestly and Taylor approach)
- **2nd stage**, transport of water to the surface can't meet potential
- In SoilWat this behaviour is described by two parameters:

  U – the cumulative evaporation (mm) before actual evaporation falls below potential

  CONA – 2nd stage evaporation is described as square root of time (days) since 2nd stage commenced and CONA is the coefficient

- Surface layer can be dried out to the Air Dry moisture content

- Cumulative soil evaporation through time for **U = 6 mm** and **CONA = 3.5**



- Evaporation loss is linear until cumulative loss exceeds U
- Thereafter calculated as $\mathbf{CONA * (t - t_1)^{1/2}}$.

Soil Water - Saturated Water Flow

- **Cascading water balance model**
  - When soil water content in any layer exceeds DUL, a fraction (SWCON) of the excess drains to the next layer

    FLUX = SWCON x (SW_dep – DUL_dep)

  - **SWCON** is the fraction of the water that drains
  - SWCON values: Clay soils = 0.2; free draining sandy soils = 0.7
  - Any water in excess of SAT cascades to the next layer

Soil Water - Unsaturated Water Flow

- When water content is below DUL, movement of water depends on

FLOW = DIFFUSIVITY x SOIL WATER GRADIENT

- **Unsaturated flow** can move water either up or down in the profile (saturated flux is only downwards)
- Drainage from the deepest layer can only occur when this layer wets up above DUL

Soil Water – Solute Movement

- **Solutes are moved together with water** for both saturated and unsaturated flow.
- **Nitrate-N** (mobile) whereas **ammonium-N** (immobile)
- Other mobile solutes (eg **chloride**, **TDS**)
- SoilWat uses a **simple "mixing" algorithm** to calculate the redistribution of solutes between layers.
- All water and solute entering a layer is completely mixed with water and solute already present → new average concentration
- The water that leaves the layer is at a concentration that is proportional to new average concentration