# AgPasture

## 1. Introduction

AgPasture is a pasture growth model developed and integrated in APSIM. It is largely based on the physiological model of Thornley & Johnston (2000) as implemented in SGS/DairyMod/EcoMod (Johnson et al. 2008), but some changes have been incorporated in describing plant growth in relation with environmental factors, and in model structures for plug-in the APSIM system. Also, a set of management tools has been developed for modelling pasture management such as grazing, cutting and renewal.

AgPasture is primarily designed for the simulation of mixed pastures of C3 and C4 grasses and legumes. The default module has been parameterised for any combination of perennial ryegrass, white clover and paspalum.

## 2. Setting up a simulation

The easiest way to set up a pasture simulation is to open the example simulation (agpasture.apsim), and save it as new simulation and modify it according to the pasture to be simulated.

Same as with other crop models in APSIM, simulation of a pasture paddock needs to include a minimum set of other modules in APSIM system in addition to AgPasture. These include Micromet, Soil (SoilN and SoilWat or SWIM), Surface Organic Matter (SurfaceOM) and Fertiliser, and optionally Irrigation and pasture Managers (e.g., "Regular harvest or grazing with return" in Fig 1). AgPasture relies on Micromet to calculate solar radiation interception and water demand of pasture plants, and uses Fertiliser to return animal urine to soil profile.

## 3. Pasture Parameters

The AgPasture component is listed under the 'Crop' folder in the 'Standard' tool box. The default AgPasture is an established pasture of perennial ryegrass and white clover, with initial pasture status (See AgPasture GUI in Fig 2). The parameters include pasture species, and their initial shoot mass and litter mass (kg DM/ha). The parameter values are specified by species in different columns and can be adjusted by users. Also, plant root depth and the assumed distribution profile of relative root mass in soil profiles (with maximum = 1) can be specified. The root distribution profile should have the same number of layers as that described in the soil module, but a minimum number of layers will be used in calculation when they are not the same. The last parameter specifies if the plant water uptake is calculated by the AgPasture module itself (default as 'calc') or by another module in APSIM.

| Description | Value |
|---|---|
| Number of species | 2 |
| Crop name shown as on the simulation tree | AgPasture |
| Species names | ryegrass whiteclover |
| Initial shoot dry matter (kg/ha) | 1500 350 |
| Initial litter dry matter (kg/ha) | 250 50 |
| Minimum green dry matter (kg/ha) | 500 50 |
| Root depth (mm) | 900 400 |
| Root distribution of swards (relative to each soil layer) | 1 0.2 0.1 0.05 0 0 0 |
| Water uptake done by AgPasture (calc) or by apsim? | calc |

Fig 2 Graphical User Interface for setting up the initial state of AgPasture

After dragging an AgPasture component into a paddock, users may specify the initial state. Users may also cultivate the soil and sow pasture using the 'Sow pasture' Manager described below.

# 4. Pasture managers

The Manager module of APSIM provides a flexible approach to allow the user to set up pasture management practices or rules. A set of Managers have been setup to go with the AgPasture module with GUI for convenience, which is in the Standard toolbox, under 'Management\AgPasture management' folder. These include:

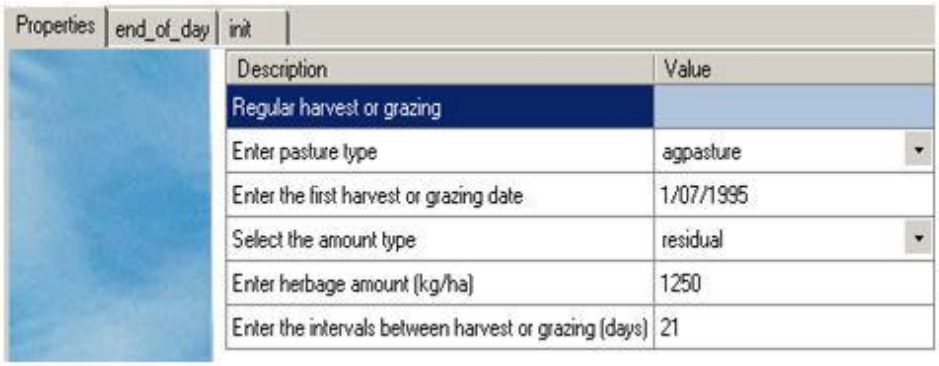


Fig 3 Specification of pasture management – Regular cut and remove (with no return)

## 4.1 Regular cut and remove (with no return) (Fig 3)

It shows that the pasture is not harvested before 1/07/1995, the harvest frequency is once every 21 days and the harvest residual is 1250 kg/ha. In this case, the harvested herbage is assumed as removed from the pasture.

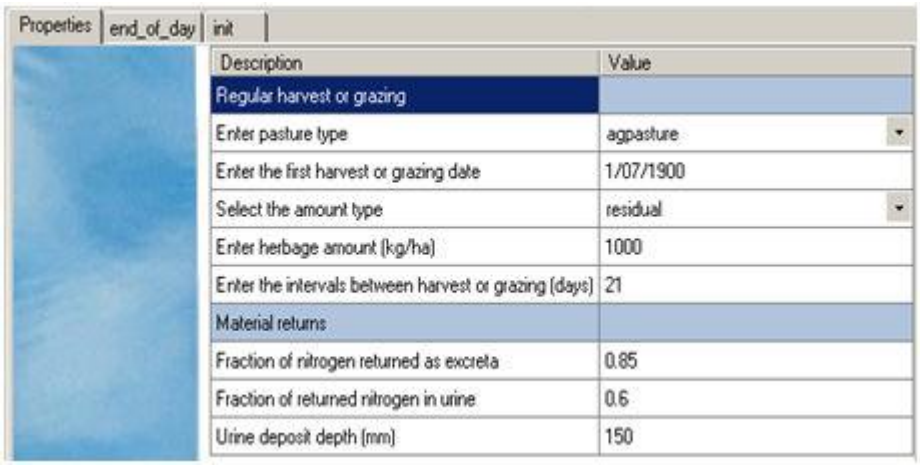


*Fig 4 Specification of pasture management – regular harvest or grazing (with return)*

## 4.2 Regular harvest or grazing (with return) (Fig 4)

It shows that the pasture is not harvested before 1/07/1995, the harvest frequency is once every 21 days and the harvest residual is 1000 kg DM/ha. 85% of grazed/harvested nitrogen is returned to soil, of which 60% is in urine and

returned to the soil profile to a depth of 150 mm. The return of animal ingested nitrogen depends on animal type, age and health conditions, as well as management. Default nitrogen removal is 15% for sheep & beef, and 25% for dairy grazed pastures but it remains the user's choice to set a sensible value for their system.

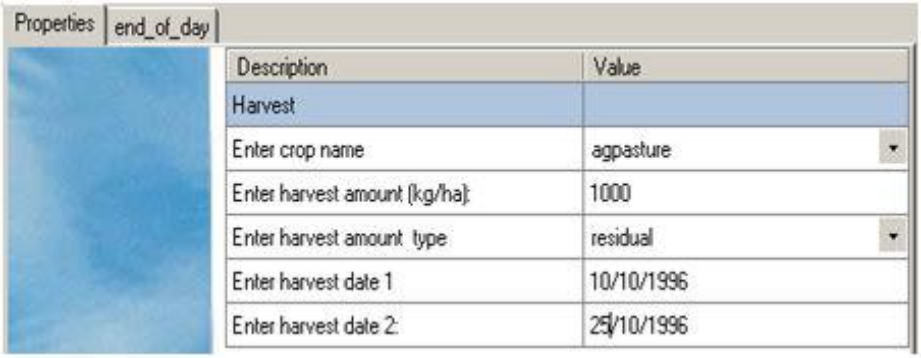


*Fig 5 Specification of pasture management – cut and remove on fixed dates (with no return)*

## 4.3 Cut and remove on fixed dates (no return) (Fig 5)

It shows the two harvests at specified dates, with a residual of 1000 kg DM/ha left after each harvest. The user may right-click on the panel to change it into ' Mode', and add more dates on the 'Properties' tab, and open the 'end_of_day' to copy and paste the script for the added dates, for setting up the harvests on multiple dates.

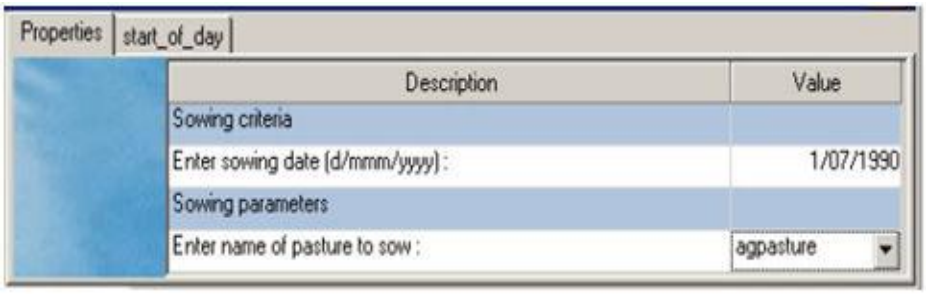


*Fig 6 Specification of pasture management – rotational grazing with herbage mass between two limits*

## 4.4 Rotational grazing with herbage mass between two limits (Fig 6)

It specifies:

- to start grazing when herbage mass reaches 1800 kg DM/ha;
- the daily herbage harvest (grazed) is 400 kg DM/ha;
- to stop grazing when the herbage mass is reduced to a residual of 1000 kg DM/ha;
- 85% of grazed/harvested nitrogen returns to soil, of which 60% is in urine and returned to soil profile to a depth of 300 mm.

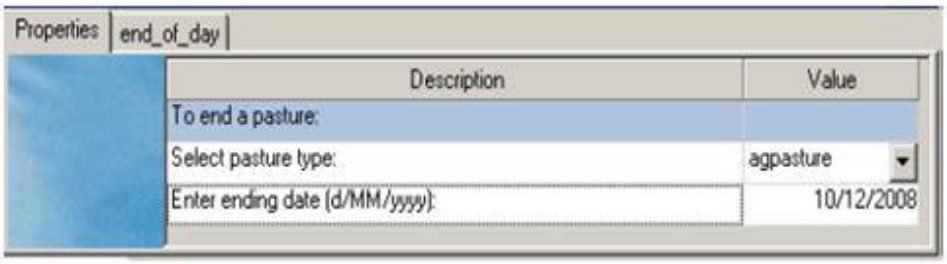


*Fig 7 Specification for sowing a pasture*

## 4.5 Sow pasture on a fixed date (Fig 7)

The default initial state of AgPasture is established perennial pasture as described above. If an user wants to establish a pasture from sowing, the manager described above (Fig 7) could be used.

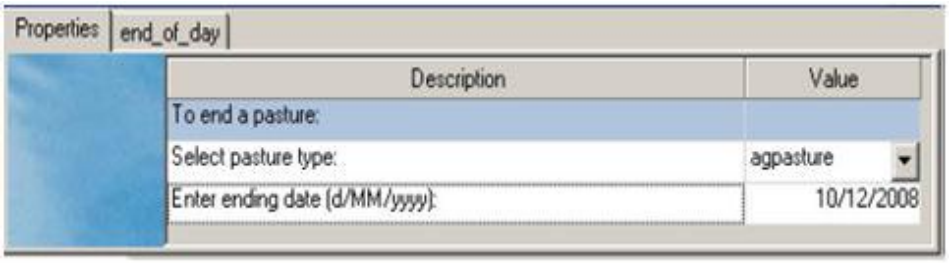


*Fig 8 Specification for ending a pasture*

## 4.6 End pasture on a fixed date (Fig 8)

This manager simply terminates he pasture, making the paddock available for other uses.

# 5. Model output variables

AgPasture model output variables are described in table 1. Note that some variables are arrays, which are either an array of plant properties for different species, or an array of soil properties for different soil layers.

Table 1 Output variables of AgPasture module

| **Variables names** | **Descriptions** |
|---|---|
| AboveGroundDeadN | Nitrogen in plant standing dead (kg N/ha) |
| AboveGroundDeadWt | Plant aboveground dead mass (kg DM/ha) |
| AboveGroundLiveN | Nitrogen in plant live shoots (kg N/ha) |
| AboveGroundLiveWt | Plant aboveground live mass (kg DM/ha) |
| AboveGroundN | Nitrogen in plant aboveground mass (shoots) (kg N/ha) |
| AboveGroundNConcentration | Plant shoot N concentration (%) |

| | |
|---|---|
| AboveGroundWt | Plant aboveground mass (kg DM/ha) |
| BelowGroundN | Nitrogen in plant roots (kg N/ha) |
| BelowGroundWt | Plant below ground mass (kg DM/ha) |
| Biomass | ( = AboveGroundWt) (kg DM/ha) |
| Cover_dead | Cover of dead leaf area (%) |
| Cover_green | Cover of green leaf area (%) |
| Cover_tot | Cover of total leaf area (%) |
| Crop_Type | Crop type |
| DefoliatedDigestibilty | Digestibility of defoliated plant material (0-1) |
| GLFn | Plant growth limiting factor due to nitrogen stress (0-1) |
| GLFnConcentration | Plant growth reduction factor due to low N concentration (0-1) |
| GLFrgr | Plant growth limiting factor due to other factors (0-1) |
| GLFtemp | Plant growth limiting factor due to temperature (0-1) |
| GLFwater | Plant growth limiting factor due to water deficit (0-1) |
| HarvestN | Daily plant nitrogen harvest (kg N/ha) |
| HarvestWt | Daily herbage harvest (kg DM/ha) |
| Height | Pasture height (mm) |
| HerbageDigestibility | Digestibility of standing herbage (0-1) |
| HerbageME | Metabolic energy of standing herbage (MJ/ha) |
| IntRadn | Intercepted solar radiation (MJ) |
| LAI_dead | Dead leaf area index (m2/m2) |
| LAI_green | Green leaf area index (m2/m2) |
| LAI_total | Total leaf area index (m2/m2) |
| LeafDeadWt | Plant dead leaf mass (kg DM/ha) |
| LeafLiveWt | Plant green leaf mass (kg DM/ha) |
| LeafN | Nitrogen in plant leaves (kg N/ha) |
| LeafWt | Plant aboveground leaf mass (kg DM/ha) |

LitterDepositionN Daily plant shoot nitrogen deposition in litter (kg N/ha)

LitterDepositionWt Daily litter deposition (kg DM/ha)

NetHerbageGrowthWt Daily net herbage accumulation (kg DM/ha)

NitrogenDemand Plant nitrogen demand (kg N/ha)

NitrogenSupply Plant available nitrogen in soil (kg N/ha)

NitrogenSupplyLayers Plant available nitrogen in soil layers (array, kg N/ha)

NitrogenUptake Plant nitrogen uptake (kg N/ha)

NitrogenUptakeLayers Plant nitrogen uptake from soil layers (array, kg N/ha)

PlantFixedN Daily plant nitrogen fixation (kg N/ha)

PlantRemobilisedN Plant N remobilisation (kg N/ha)

PlantStatus Plant status – 'live' or 'dead'

PotentialGrowthWt Daily plant potential growth (kg DM/ha)

RootSenescenceN Daily plant root nitrogen deposition in senescent roots (kg N/ha)

RootSenescenceWt Daily root senescence (kg DM/ha)

SpeciesGreenLAI Species - total leaf area index (array, m2/m2)

SpeciesHarvestPct Species - percentage in harvested plant material (array, %)

SpeciesLiveWt Species - total aboveground live mass (array, kg DM/ha)

SpeciesTotalWt Species - total aboveground mass (array, kg DM/ha)

StemDeadWt Plant dead stem mass (kg DM/ha)

StemLiveWt Plant live stem mass (kg DM/ha)

StemN Nitrogen in plant stems (kg N/ha)

StemWt Plant aboveground stem mass (kg DM/ha)

StolonN Nitrogen in plant stolons (kg N/ha)

StolonWt Plant stolon mass (kg DM/ha)

TotalPlantN Plant total nitrogen (kg N/ha)

TotalPlantWt Plant total mass (kg DM/ha)

WaterDemand Plant water demand (mm)

WaterSupply Plant extractable soil water (mm)

WaterSupplyLayers Plant extractable water in soil layers (array, mm)

WaterUptake Plant water uptake (mm)

WaterUptakeLayers Plant water uptake from soil layers (array, mm)

## 6. Model structure and scientific base

AgPasture is largely based on the physiological model of Thornley and Johnson (2000) as implemented in SGS/DairyMod/EcoMod (Johnson et al. 2008). Most of the processes and functions in plant growth have been described in these publications and in documents of Johnson (2008). Here we briefly describe the module structure and the daily pasture growth process in relation with other modules in the APSIM system. Emphasis is on the structures, processes and functions that are different from the previous model descriptions.

AgPasture is majorly a temperate pasture model of ryegrass-clover type, but C4 species can be added. Plant growth processes include photosynthesis and respiration followed by tissue turnover and senescence. Effects of water and nitrogen stress are incorporated. All the plant functions and processes, such as carbon assimilation, tissue turnover, water and nitrogen uptake, are modeled at a species level. The species compete for resources (e.g., solar radiation, soil moisture and nitrogen) and simulated species properties are aggregated into that of the pasture module (Fig 9)

http://www.apsim.info/Wiki/http://www.apsim.info/Wiki/http://www.apsim.info/Wiki/http://www.apsim.info/Wiki/http://www.apsim.info/Wiki/http://www.apsim.info/Wiki/

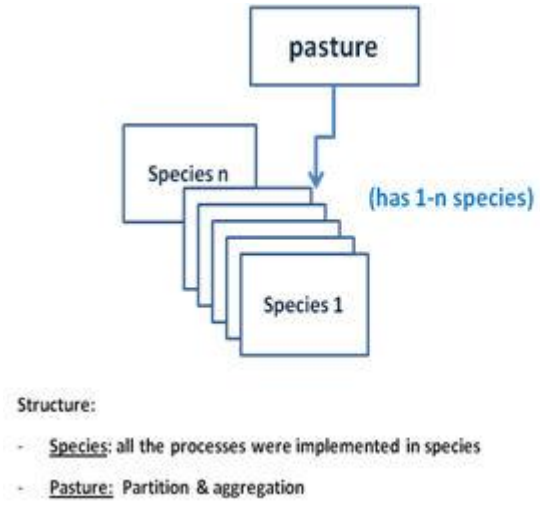


*Fig.9 Pasture module of multiple species*

Fig 9 Pasture module consisting of one to many species. Plant processes are implemented at species level, while pasture (community) is responsible for resources partitioning among species and aggregating of species proporties into that of pasture swards.

APSIM is a daily time-step simulation system. The program flow of AgPasture in APSIM during a one day time-step are as follows. The underlined words or terms are other APSIM modules related or used in the process. Those modules are documented separately (www.apsim.info).

(1) Update weather data (Met):

(2) Calculate site-specific pasture potential growth (Gpot) : This includes gross photosysnthesis, growth and maintenaince respiration and their realtions with environmental conditions (solar radiation and temperature).

(3) Calculate soil moisture deficit: Daily pasture water demand (potential transpiration) is calculated using Penman-Menteith equations (Micromet). Plant uptakable water in soil profile (SW) may be calculated using the soil water capacity module (SoilWat) or alternatively the soil water infiltration and movement module (SWIM). The SW is partitioned to different species relative to their demands. Actual plant water uptake equals to water demand if the demand is bigger than supply (PT< SW); otherwise plant water uptake equals thewater supply (SW), and in this case, the soil moisture limiting factor (GLFw) is defined using the ratio of plant water uptake to demand. Soil moisture uptake from the soil profile is removed.

(4) Pasture N demand and soil N supply: Plant N demand is calculated according to maximum and optimum N concentration of potential new growth tissues, plant N status and N remobilisation. Soil N supply is the mineral N in the root zone of soil profile (SoilN). Nitrogen limitation occurs when plant available N is less than demand, and a N limiting factor (GLFn) for pasture growth is defined as the ratio of plant available N to plant N demand. However, before partitioning plant available N among species, the N-fixation of legume species is calculated. The fraction of actual N fixation of legume species against its total N demand under N stress (GLFn) is calculated as:

$$F = Fmax + (1 - Fmin) \times GLFn$$

where Fmax and Fmin are the fractions of N-fixation in total N-demand when soil N is unavailable and sufficient. Plant available N in soil layers is partitioned among species relative to their demands, and GLFn of each species are updated separately as the ratio of actual plant N uptake to demand.

$$GFLn = N\ uptake/\ N\ demand.$$

Plant N uptake is removed from soil profile.

(5) Effects of water and N limitation on pasture growth: Nitrogen limitation affects plant growth by both reducing new plant tissue growth (reducing green leaf area expansion ) and diluting N concentration in existing plant tissues, which in turn reduce plant raditation efficiency (Lemaire and Salette 1984). The effect is calculated by constructing a N concentration factor (FNc) as follows:

$$FNc = (N - Nmin)/(Nopt - Nmin) \quad if\ N<nopt< i="" style="padding: 0px; margin: 0px;">$$

$$FNc = 1 \quad if\ N \geq Nopt$$

*where N, Nopt and Nmin are actual, optimum and minimum N concentration of plant leaf tissue. So plant new growth incoporating N concentration and water-deficit effects, but not N shortage for the daily uptake, is calculated as:*

$$Gw = Gpot \times minimum\ (GLFw\ ,\ FNc)$$

*Then the effects of soil mineral N shortage against plant daily demand is added by multiplying the square root of GLFn.*

$$G = Gw \times \sqrt{GLFn}$$

*The square root is used to partition the effects of N limitation on plant growth (i.e. the effect on plant tissue increase including green leaf area expansion and the dilution of N concentration in plant tissue). The N concentration in different plant tissue pools are updated daily.*

*(6) Partitioning of plant new growth Plant new growth is partitioned to plant shoots and roots using a dynamic partitioning coefficient towards a target root/shoot ratio as described in Johnson (2008). A variable target root/shoot ratio is used for partitioning more assimilates to shoots in spring (roughly coresponsding to reproductive stages) and less in autumn, as experimentally evidenced by (Parsons and Robson 1981). The assimilates partitioned to shoots are partitioned again among stem (+sheat), stolon and leaf.*

*(7) Plant tissue turnover Plant shoot tissue is traced as four pools (growing, mature, scenesing, and dead). Plant new growth are transferred among these pools and finally scenesced and transferred to litter, surface organic matter pool (SurfaceOM). Senecent root returns to soil fresh organic matter pool (FOM).*

## 7. Acknowledgement

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## 8. References

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Parsons AJ, Robson MJ (1981) Seasonal changes in the physiology of S24 perennial ryegrass (Lolium perenne L.) 3 Partition of assimilates between root and shoot during the transition from vegetative to reprodcutive growth. Annals of Botany 48, 733-744.

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# Barley

The APSIM-Barley module simulates the growth and development of a barley crop in a daily time-step on an area basis (per square meter, not single plant). Barley growth and development in this module respond to weather (radiation, temperature), soil water and soil nitrogen. The barley module returns information on its soil water and nitrogen uptake to the soil water and nitrogen modules on a daily basis for reset of these systems. Information on crop cover is also provided to the water balance module for calculation of evaporation rates and runoff. Barley stover and root residues are 'passed' from barley to the surface residue and soil nitrogen modules respectively at harvest of the barley crop.

Approaches used in modelling crop processes balance the need for comprehensive description of the observed variation in crop performance over diverse production environments and the need to avoid reductionist approaches of ever-greater complexity with large numbers of parameters that are difficult to measure.

A list of the module outputs is provided in the 'Barley module outputs' section below. Basically the module simulates phenological development, leaf area growth, biomass and N concentration of leaves, stems, roots and grains on a daily basis. It also predicts grain size and grain number.

Goto generic Plant model documentation

## Barley Module History

APSIM-Barley was developed from a combination of the approaches used in previous APSIM barley modules: Asseng et al. 1998a,b, Meinke et al. 1997a,b and Wang et al. 2003. The current version of the model is implemented within the APSIM Plant model framework which is currently used for other crops such as grain legumes and canola. Most of the model constants (species-specific) and parameters (cultivar specific) are externalised from the code.

## Barley Module Structure

### Phenology

APSIM-Barley uses 11 crop stages and ten phases (time between stages). It can output stage code and names as well as equivalent Zadok's stage. Table 2 lists the stage code, name and the key processes starting at the commencement of each stage.

*Table 2: Stages of phenological development simulated in APSIM_Barley.*

| Stage Code | Stage Name | Starting processes | Equivalent Zadok's |
|---|---|---|---|
| 1 | Sowing | Seed germination | 0 |
| 2 | Germination | Emergence, leaf initiation | 5 |
| 3 | Emergence | Vegetative growth (LAI, DM), water/N | 10 |

| | | | |
|---|---|---|---|
| | | uptake | |
| 4 | End of Juvenile Stage | Photoperiodism | 10 |
| 5 | Floral Initiation / terminal spikelet* | Spikelet initiation / | 15 / |
| | | Rapid stem growth | 30 |
| 6 | Anthesis | Setting grain numbers | 60 |
| 7 | Start of Grain Filling | Active grain growth | 71 |
| 8 | End of Grain Filling | Maturity | 87 |
| 9 | Physiological Maturity | Grain moisture loss | 90 |
| 10 | Harvest Ripe | | 93 |
| 11 | End Crop | | 100 |

**Because the CERES-Wheat phenology approach is used (see text below), terminal spikelet, instead of floral initiation, is simulated in the current barley model.*

The commencement of each stage (except for sowing to germination, which is driven by soil water content) is determined by accumulation of thermal time. Each day the phenology routines calculate today's thermal time (in degree-days) from 3-hourly air temperatures interpolated from the daily maximum and minimum crown temperatures. Crown temperatures are simulated according to the original routines in CERES-Wheat. Thermal time is calculated using the relationship in Figure 2 with the eight 3-hour estimates averaged to obtain the daily value of thermal time (in degree-days) for the day. These daily thermal time values are cumulated into a thermal time sum, which is used to determine the duration of each phase.

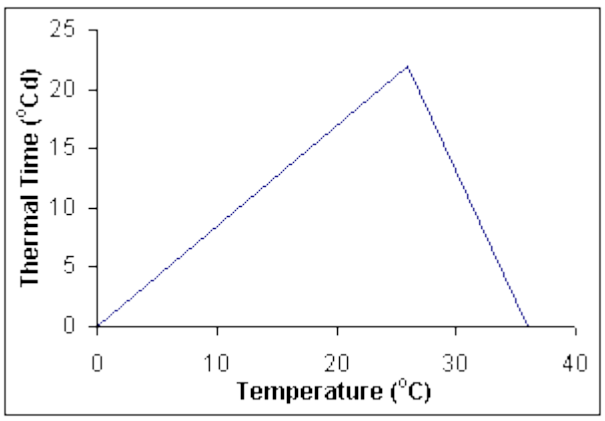



*Figure 2. Relationship between crown temperature and thermal time used in APSIM-Barley.*

Between the stage of emergence and flowering the calculated daily_thermal_time can be reduced by water or nitrogen stresses, resulting in delayed phenology when the plant is under stress. These stress factors can be specified in barley.ini by changing the values of*x_sw_avail_ratio/y_swdef_pheno* and *N_fact_pheno* . Currently these values are set so that there are no water and nitrogen stress effects on phenological development. Research showed that moderate water stress may accelerate development, while severe water stress may delay phenology (Angus, 1977).

Germination is considered as a quick process. Germination is assumed to occur as long as the extractable soil water in the seed layer is above a given value *pesw_germ* specified in Barley.ini. *pesw_germ* is the soil water content above the crop lower limit (mm/mm) in the seed layer inadequate for germination. The default setting is zero, meaning that germination will occur one day after sowing regardless of soil water content.

The phase between germination and emergence includes an effect of the depth of sowing on the thermal time target. The phase is comprised of an initial period of fixed thermal time during which shoot elongation is slow (the “lag” phase) and a linear period, where the rate of shoot elongation towards the soil surface is linearly related to air temperature (measured in o Cd mm -1 ). Most studies on seedling emergence have simply recorded the accumulated thermal time between germination and 50% emergence from a given sowing depth. For the purposes of model parameterisation the value of *shoot_lag* has been assumed to be around 40 o Cd, while *shoot_rate* has been derived from studies where thermal time to emergence was measured and where sowing depth was known and it is set to 1.5 o Cd per mm. This means that at a sowing depth of 4 cm emergence occurs 100 o Cd after germination (40+1.5*40).

There is the capability of increasing the time taken to reach emergence due to a dry soil layer in which the seed is germinating, through the relationship between *fasw_emerg* and *rel_emerg_rate* . Currently this effect is “turned off” in the Barley.ini file.

The phase between emergence and end of juvenile stage is composed of a cultivar-specific period of fixed thermal time, commonly called the basic vegetative or juvenile phase, which is a period when development rate is not affected by photoperiod. The end of the juvenile phase in barley is currently timed as occurring on the day after emergence, because it is known that the development rate of barley is sensitive to photoperiod from emergence. The end of the juvenile phase is included in the model to make the stages compatible with other cereal crops in APSIM that do have a definable juvenile phase.

After the end of the juvenile phase the crop takes 400 o Cdays to reach terminal spikelet stage. The rate at which the crop attains this target depends upon photoperiod and vernalisation. The daily rate of accumulation of thermal development rate is sensitive to photoperiod and accumulation of vernalising days. The sensitivities to photoperiod ( *photop_sens* ) and vernalisation ( *vern_sens* ) are cultivar-specific. The model assumes that barley, as a long day plant, will have a longer phase (dependent upon cultivar) between the end of the juvenile phase and terminal spikelet under short days.

Photoperiod is calculated from day of year and latitude using standard astronomical equations accounting for civil twlight using the parameter*twilight,* which is assumed to be –6 o . Twilight is defined as the interval between sunrise or sunset and the time when the true centre of the sun is 2.2 degrees below the horizon.

Vernalisation is simulated from daily average crown temperature and daily maximum and minimum temperatures using the original CERES approach.

Devernalisation can occur if daily maximum temperature is above 30 o C.

There are fixed thermal time durations for the subsequent phases between terminal spikelet and flag leaf (3 phyllochrons), from flag leaf to flowering (2 phyllochrons + 80 o C days). In the original CERES phenology routines, 2 phyllochrons from flag leaf marked the end of ear growth and then 80 o C days was required to reach anthesis. From flowering to the start of grain fill the thermal duration is assumed to be 120 o C days (= 200-80 o C days, in CERES 200 o C days was assumed to elapse between the end of ear growth and the start of grain filling). The duration of grain filling ( *tt_startgf_to_mat* ) is cultivar specific and usually lies between 500 and 800 o C days.

## Biomass accumulation (Photosynthesis)

### Radiation interception

Radiation interception is calculated from leaf area index and a radiation extinction coefficient ( *extinct_coeff* ) that varies with row spacing.

### Radiation Use Efficiency

The intercepted radiation is converted to above ground biomass via a RUE (radiation-use efficiency), which is 1.24 g MJ -1 from emergence to the end of grain-filling, and does not vary as a function of daily incident radiation as in NBARLEY. RUE is reduced by extremes of daily mean temperature as sown in the following figure. It is also reduced by a nitrogen stress factor *n_fact_photo* specified in Barley.ini.

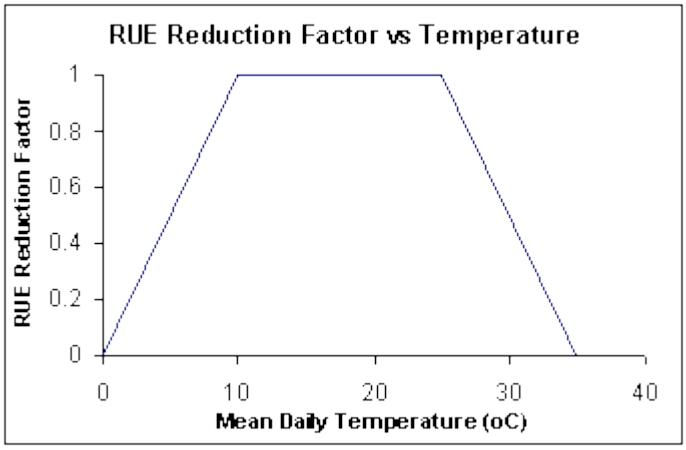



*Figure 3: Response of barley radiation-use efficiency to temperature*

### Water-nonlimiting

Under water non-limiting condition, the biomass growth rate is given by:

dlt_dm_rue = RUE *radiation_interception eqn 1.

### Water-limiting

Each day two estimates of the daily biomass production are calculated, one limited by available water for transpiration (eqn 2), and the other limited by radiant energy (eqn 1). The minimum of these two estimates is the actual biomass production for the day.

dlt_dm_water = soil_ water_ supply * transpiration_efficiency eqn 2.

dlt_dm = min(dlt_dm_water, dlt_dm_rue)

transpiration_efficiency is derived from the transpiration_efficiency_coefficient (=0.006 kPa) and the vapour pressure deficit (vpd) estimated from daily temperatures.

## Biomass partitioning and retranslocation

### *Partitioning*

On the day of emergence, biomass in plant parts (leaf, root, and stem) is initialised to user-specified values. Daily biomass production is then partitioned to different plant parts in different ratios depending on crop stage. In the barley module, leaf includes only leaf blade. Stem is defined in a functional rather than a morphological manner and includes stem proper, leaf sheaths and stem-like petioles.

The biomass increase calculated each day only accounts for the above ground organs. The minimum fraction of biomass going to roots is calculated from the stage dependent root_shoot_ratio specified in Barley.ini.

Between emergence and grain filling, the above ground biomass is partitioned to leaf, stem and head based on stage dependant partitioning rules. If, on any day, the estimated specific leaf area (based on leaf biomass and LAI deltas) goes below the minimum specific leaf area, the extra biomass is diverted to stems.

At anthesis, the number of grains set per plant is determined by the stem weight. From start to end of grain filling biomass increase is used to meet grain demand first, the rest is put into stems. **Grain demand for carbohydrate** (biomass) is calculated by multiplying the grain number by the potential grain growth rate ( potential_grain_filling_rate, g/grain/degree day ) specified in Barley.ini .

### *Re-translocation*

If the supply of assimilate (daily biomass increase) is insufficient to meet grain demand then re-translocation may be used to meet the shortfall. The barley module allows a total retranslocation of no more than 20% of stem biomass present at the start of grainfilling

Grain yield on a commercial moisture basis is calculated using the parameter grn_water_cont = 0.125.

## Leaf initiation/appearance and tillering

Leaves appear at a fixed phyllochron of thermal time, currently set to 95 o Cd in the barley.ini. No effect from water and N stress on leaf appearance is accounted for.

## Leaf area growth

On the day of emergence leaf area per plant is initialised to a value of 200 mm 2 per plant.

## Potential LAI growth rate

Potential increase in plant leaf area is calculated from main stem node appearance rate multiplied by the leaf size (as a function of node number) multiplied by the number of leaves per main stem node (i.e. tiller number)

## Leaf area growth rate under stress

Water and nitrogen limitations affect leaf area development directly rather than via dry matter production. Water and nitrogen limitations result in either a reduction of leaf expansion or in number of tillers produced.

Two stress factors are introduced to account for the effect of water and nitrogen stress respectively on leaf area growth. It is assumed that leaf expansion growth is reduced when the supply/demand ratio for water is below 1.1 and stops when supply/demand ratio reaches 0.1. This relationship is specified in Barley.ini in the look-up table *x_sw_demand_ratio/y_swdef_leaf* . The nitrogen stress factor is defined as:

g_nfact_expansion = N_fact_expansion * n_conc_ratio_leaf

where n_conc_ratio_leaf is the relative N concentration in leaves (N_conc_leaf - N_conc_leaf_min)/(N_conc_leaf_crit - N_conc_leaf_min). N_fact_expansion is a modifying constant specified in Barley.ini. It is currently set to 1.0, ie. leaf expansion is reduced once leaf N concentration is below the critical N concentration, and stops when leaf minimum concentration is reached.

The leaf area growth rate under stress is given by:

g_dlt_lai_stressed = g_dlt_LAI_pot * min (g_swdef_expansion, g_nfact_expansion)

### Actual leaf area growth rate

Actual leaf area growth rate differs from stressed leaf area expansion rate (g_dlt_lai_stressed) only if carbon supply is insufficient to meet a maximum specific leaf area for the daily increase in leaf area ( *sla_max* ). Carbon supply may become limiting, for example, at high plant population densities. The current model specifies *sla_max* as varying from 27 000 to 22000 mm 2 g -1 t o constrain daily leaf area increase where carbon is limiting. However, as the value of the maximum specific leaf area operates on the daily increase in leaf area it is not readily derived from experimental data and must be calibrated by trial-and error.

### Root growth and distribution

#### *Root depth growth*

Between germination and start of grain filling, the increase in root depth is a daily rate multiplied by a number of factors. Root depth is constrained by the soil profile depth.

The optimum rate of elongation is 30mm d -1 . This can be limited by supra- or sub-optimal temperatures. Dry soil can slow roots through a layer if the soil water content is less than 25% of the way between the lower limit and drained upper limit. The increase of root depth through a layer can be constrained by known soil constraints through the use of the 0-1 parameter **xf,** which is input for each soil layer.

#### *Root length density*

Growth of root biomass is partitioned with depth using a branching function and converted to root length density using a fixed specific root length of 105,000 mm g -1 .

Root biomass is grown daily in proportion to the tops production. This proportion ( ratio_root_shoot ) is specified for each growth stage, and varies from 1.0 at emergence, to 0.09 at flowering.

### Senescence

### *Root senescence*

A rate of 0.5% of root biomass and root length is senesced each day and detaches immediately being sent to the soil nitrogen module and distributed as fresh organic matter in the profile.

### *Leaf senescence*

There are four causes of leaf senescence: age, water stress, nitrogen stress and high temperature stress. The barley senescence routines calculate stress factors for water, N and high temperature. The maximum of these is multiplied by the senesced LAI due to age each day to obtain the day's total senescence.

The stress factor for water is calculated from swdef_photo , for N from nfact_photo. Senescence due to frost commences when temperatures decrease below -5 º C.

### *Nitrogen in seneseced leaves*

When leaf is senesced, only a small amount of nitrogen is retained in the senesced leaf, the rest is made available for re-translocation by putting it into stem N pool. The concentration of nitrogen in senesced material is specified in the barley ini file.

## Crop Water Relations

### *Potential water extraction rate*

When the Barley module is coupled to APSIM-SOILWAT2, potential soil water uptake is calculated using the approach first advocated by Monteith (1986). It is the sum of root water uptake from each profile layer occupied by roots. If roots are only partially through a layer available soil water is scaled to that portion that contains roots. The potential rate of extraction in a layer is calculated using a rate constant ( kl ), which defines the fraction of available water able to be extracted per day. The kl factor is empirically derived, incorporating both plant and soil factors which limit rate of water uptake. Root water extraction constants ( kl ) must be defined for each combination of crop species and soil type.

### *Crop water demand*

Following Sinclair (1986) and Monteith (1986), transpiration demand is modelled as a function of the current day's crop growth rate (dlt_dm_rue, see Biomass Accumulation Section), divided by the transpiration efficiency. Transpiration efficiency is related to the daylight averaged vapour pressure deficit ( vpd ). Transpiration demand is calculated from the daily crop growth rate limited by RUE (dlt_dm_rue), vpd , and the transpiration efficiency coefficient. In the model vpd is estimated using the method proposed by Tanner and Sinclair (1983), which requires only daily maximum and minimum temperatures. In this method, it is assumed that the air is saturated at the minimum temperature. The saturated vapour pressure is calculated at both the maximum and minimum temperatures, and the default vapour pressure deficit for the day is taken as 75% of the difference between these two vapour pressures. Crop water demand is capped to below a given multiple of potential ET (taken as Priestly-Taylor Eo from the water balance module) as specified in the barley ini file. This limits water use to reasonable values on days with high VPD or in more arid environments.

### *Water uptake*

The actual rate of water extraction is the lesser of the potential extraction rate and the transpiration demand. If the computed potential extraction rate from the profile exceeds demand, then the extracted water is removed from the occupied layers in proportion to the values of potential root water uptake in each layer. If the computed potential extraction from the profile is less than the demand then, and the actual root water uptake from a layer is equal to the computed potential uptake.

### *Water stresses affecting plant growth*

Soil water deficit factors are calculated to simulate the effects of water stress on different plant growth processes. Three water deficit factors are calculated which correspond to four plant processes each having different sensitivity to water stress i.e. photosynthesis (photo), leaf-expansion (expansion), phenology (pheno), and tillering (tiller). A factor of 0 is complete stress and 1 no stress. Leaf expansion is considered more sensitive to stress than photosynthesis.

## Nitrogen uptake and re-translocation

### *Potential nitrogen supply*

The model uses a simplified formulation for NO3 uptake somewhat similar in structure to that employed in water uptake.

Potential NO3 uptake in a layer is given as

Uptake = NO3 kg/ha x (Kln x NO3 ppm x SWFAC)

Where Kln is a parameter constant and SWFAC is a soil water content factor based on relative soil water content between lower limit and drained upper limit.

### *Nitrogen demand by vegetative organs*

The crop has a defined minimum, critical and maximum N concentration for each plant part. These concentration limits change with phenological stages. The maximum and minimum N concentrations can be found in Barley.ini. Demand for N in each part attempts to maintain N at the critical (non-stressed) level. N demand on any day is the sum of the demands from the pre-existing biomass of each part required to reach critical N content, plus the N required to maintain critical N concentrations in that day's produced biomass. For each plant part (leaf, stem, root) the N demand is given by:

N_demand = dm_green * (n_conc_critic - n_conc) + dlt_dm_green * n_conc_critic.

Where dm_green and dlt_dm_green are the existing live biomass and biomass growth rate today. N_conc and n_conc_critic are the actual and critical N concentration respectively of this plant part.

Total crop N demand is the sum of the n demand in all vegetative parts.

### *Nitrogen partition in the plant*

Daily total nitrogen uptake is distributed to the plant parts in proportion to their individual demands.

### *Grain N demand*

Grain nitrogen demand starts at anthesis and is calculated from grain number, thermal time and a potential grain nitrogen filling rate (g/grain/degree day).

### *Nitrogen re-translocation*

If there is insufficient nitrogen supplied from senescing material or soil nitrogen uptake, grain nitrogen demand is met by re-translocating nitrogen from other plant parts. Nitrogen is available for re-translocation from leaves and stems until they reach their defined minimum N concentration.

### *Nitrogen deficits affecting plant growth*

There are four N availability factors (0-1), one each for the photosynthesis, expansion, phenology and tillering. A N concentration ratio is calculated for the stover (stem + leaf) which is used as a measure of N stress, then different

constants are used to convert that ratio to a deficit factor for each of the processes. A factor of 1.5 is used to restrict photosynthesis (reduces rue), 1.0 for expansion (reduces leaf area expansion) and 100 to slow phenological development (effectively disabled). For tillering a squared n_conc_ratio is used as the stress factor. As a value of 1 is no stress and 0 complete stress, phenology is least sensitive to nitrogen deficiency and grain N the most.

N_conc_ratio=(N_conc_stover-N_conc_stover_min)/(N_conc_stover_crit-N_conc_stover_min)

### Plant death

All or some of the plants can be killed due to a variety of stresses.

If the crop hasn't germinated within 40 days of sowing, due to lack of germinating moisture, all plants are killed.

If the crop does not emerge with 300 o Cdays of sowing, because it was sown too deep, then all plants are killed.

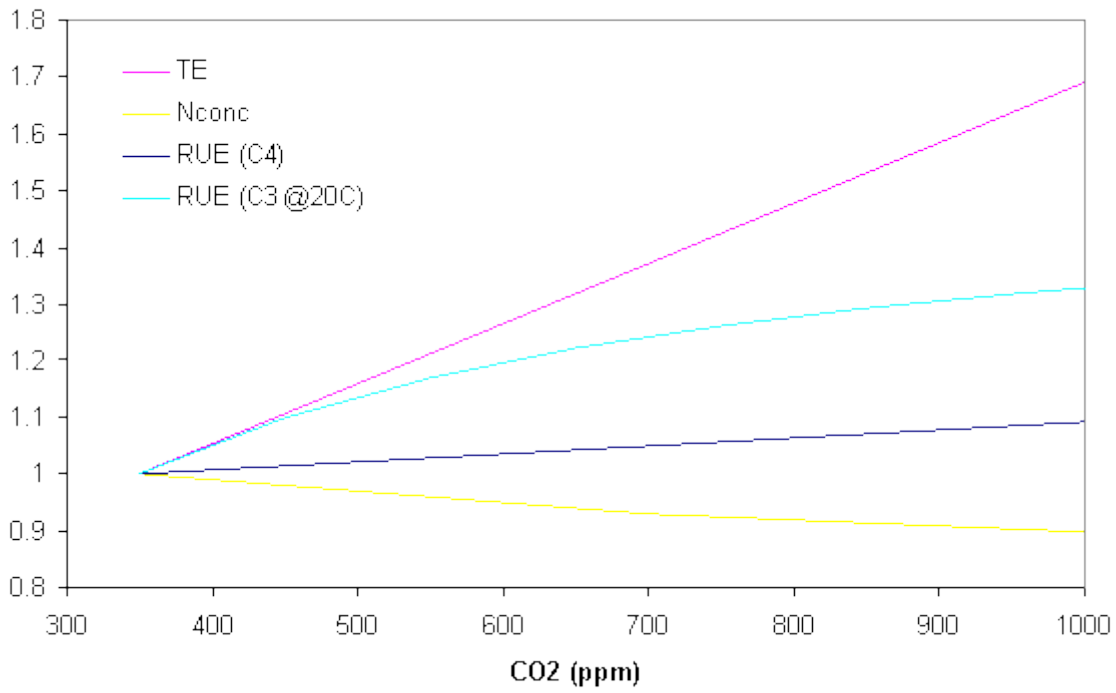
If crop is past floral initiation and LAI = 0, then all plants are killed due to total senescence.

### Detachment

The detachment routines in **barley** are disabled in the barley.ini file, except the detachment of senesced roots.

### Effects of elevated atmospheric $CO_2$

Elevated levels of atmospheric $CO_2$ affect plant growth in this module via three mechanisms. Carbon dioxide concentration can affect radiation use efficiency, transpiration efficiency and critical leaf nitrogen concentration. The following graph shows the relative change in RUE for C4 and C3 plants (at 20 o C), TE and critical nitrogen concentration. More information can be found in Reyenga et al (1999).



# Canola

## Introduction

The canola module was developed by Michael Robertson in conjunction with Chris Smith (CSIRO Land and Water), John Holland (NSW Agriculture) and John Kirkegaard (CSIRO Plant Industry). Further testing has been conducted by Imma Farre (CSIRO Plant Industry). The module is described in the paper by Robertson et al. (1999). The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-Canola. This document outlines some canola-specific issues that are not covered by the plant science document. The canola module simulates canola (Brassica napus) and the related species Indian mustard (Brassica juncea).

Goto generic Plant model documentation

## Notable features of APSIM-Canola

The phenology of canola cultivars respond to vernalisation and photoperiod (daylength).

In the module, all green leaf area senesces soon after flowering and photosynthesis is then conducted by the pods.

APSIM-Canola is not phosphorus-responsive, this is currently under development.

Crop growth is not sensitive to row spacing

Crop growth is not sensitive to waterlogging.

## Cultivars and crop classes

There are three crop classes:

Conventional canola

Triazine tolerant canola – this crop class has a radiation use efficiency 20% less than the conventional type

Winter canola – this is designed to simulate European types, but has received limited testing. It differs from the conventional crop class in that it has a different sensitivity of leaf senescence to frost and a different rate of leaf senescence due to ageing.

There are 14 conventional cultivars: PacN145, Monty, Hyola42, Surpass400, Rainbow, Mystic, Narendra, Surpass600, Geordie, Oscar, Marnoo, Eureka, Charlton, Clancy, Dunkeld There are three triazine-tolerant cultivars: Karoo, Drum, Pinnacle There are two mustards: JL1, 397 There are four generic cultivars: early, mid and late maturing, and a mustard **NOTE**: there is no explicit linking of crop classes with cultivars in APSIM-Canola, so the user must be aware to specify the triazine-tolerant class, for instance, if they are using a triazine-tolerant cultivar.

## Validation

APSIM-Canola has received testing across the Australian wheat belt, with factors such as cultivars, sowing date, N supply, irrigation, soil type varying. Papers describing validation of APSIM-Canola are by Robertson et al. (1999),

Robertson et al. (2001), and Farre et al (2001). The following two figures demonstrate the performance of the module against Australian datasets.

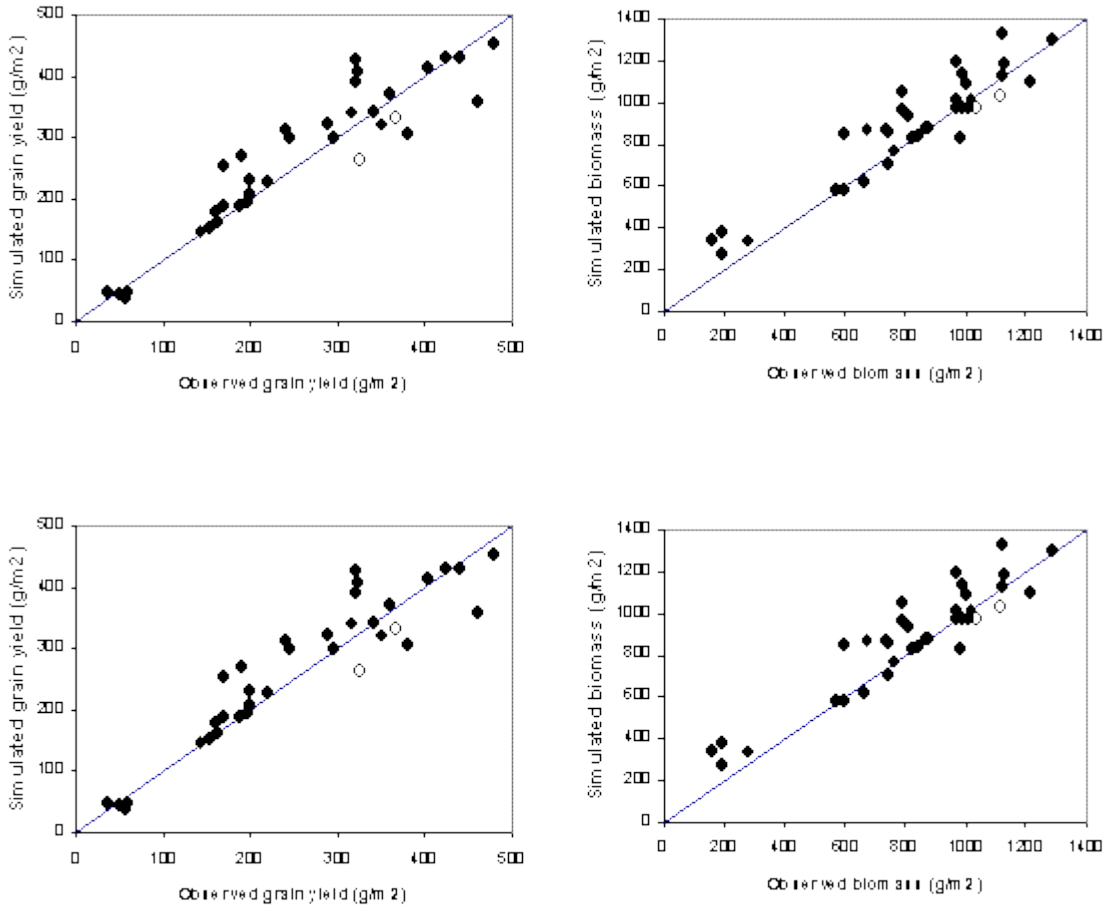



*Figure 1*: Observed and predicted (a) grain yield (oven-dry) at maturity and, (b) total biomass at maturity for datasets presented by Robertson et al (1999). The line is the 1:1 relationship. The model was tested against independent datasets from Australia (26 to 36o latitude), which varied in terms of nitrogen supply, water supply, sowing date, and variety. Grain yields, ranging from 30 to 500 gm-2, were simulated with a root mean squared deviation of 45 gm-2 (15% of the observed mean).

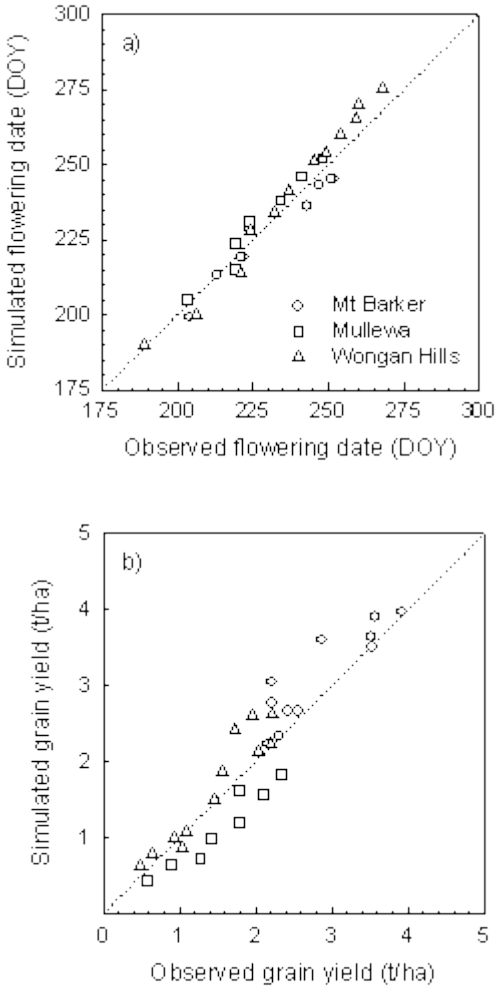



*Figure 2:* Simulated and observed flowering date and grain yield for different canola cultivars at three sites in Western Australia (Mt Barker, Mullewa and Wongan Hills) in 1998 . The dotted line is the 1:1 line. DOY-day of the year.

## References

Farré, M. J. Robertson, G. H. Walton, S. Asseng 2000. Simulating response of canola to sowing date in Western Australia. 10th Australian Agronomy Conference, Hobart, Tasmania. Robertson MJ, Holland JF, Kirkegaard JA, and Smith C J 1999. Simulating growth and development of canola in Australia. Proceedings 10th International Rapeseed Congress. (CD-Rom Proceedings).

Robertson MJ, Holland J, Cawley S, Bambach R, Cocks B and Watkinson AR 2001. Phenology of canola cultivars in the northern region and implications for frost risk. 10th Australian Agronomy Conference, Hobart, Tasmania.

# Canopy (Intercropping)

## Operation

When a simulation is conducted in APSIM involving light and water competition between crops, the user must plug in the CANOPY module.

The CANOPY module arbitrates the competition for intercepted radiation.

On a daily basis, the module finds the number of crops in the simulation and their canopy heights.

Canopy layers are then defined, with the layer boundaries being defined by the top of each canopy. Thus there are as many layers as canopies.

Then each layer in turn is taken from the top, in the combined canopy, to get the,

combined **(extinct_coeff * lai)** value (green + dead) of the canopies present in that layer.

The fraction of light transmitted out of the bottom of that layer can be calculated, which is in turn the fraction entering the next layer below.

The total radiation intercepted in a layer is divided amongst the canopies occupying the layer, being done on the basis of **(extinct_coeff * LAI)** of each canopy.

This approach ignores the possibility of different LAI distributions within a layer.

LAI is distributed with height in the canopy using normalized height and integration of a function to the power of 5.

This results in 47% of the leaf area in the top 10% of height, 27% in the next 10%, 15% in the next 10%, and so on.

Arbitration for water and nitrogen uptake is done on the basis of APSIM changing the order each day (on a rotational basis) in which the competing species are given the opportunity to capture soil resources.

**A maximum of ten crops can be specified for inter cropping.**

# Chickpea

## Introduction

The chickpea module was developed by Peter Carberry, Jill Turpin and Michael Robertson, with contributions of data from Bob Brinsmead and Harry Marcellos. The module is described in the paper by Robertson et al. (2002). This module is being updated by work conducted by Jeremy Whish at APSRU. The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-Chickpea. This document outlines some chickpea-specific issues that are not covered by the plant science document.

Goto generic Plant model documentation

## Notable features of APSIM-CHICKPEA

The Module simulates dsi types of cultivars The phenology of chickpea cultivars is responsive to temperature and photoperiod, but not vernalisation. Model performance on days to flowering was reported by Carberry (1996) and is repeated in the graph below (Figure 1). The module does not simulate production from second and further flushes of flowers and pods. Under well-watered conditions, chickpea may have a low harvest index due to continued vegetative growth at the expense of reproductive yield. The model does not currently simulate this phenomenon. When chickpea flowers and attempts to set pods under cold conditions, pod set can be delayed until temperatures rise above a critical threshold. This phenomenon is not simulated in this module. APSIM-Chickpea is not phosphorus-responsive, this is currently under development. Crop growth is not sensitive to waterlogging.

## Cultivars and crop classes

There is one crop class. There are 6 cultivars able to be simulated: Amethyst, CPI56288, Dooen, Tyson, CV244-1, CPI56566. Cultivars differ in terms of biomass partitioning to grain and phenology. If users wish to use more modern cultivars they should contact Jeremy Whish at APSRU for advice.

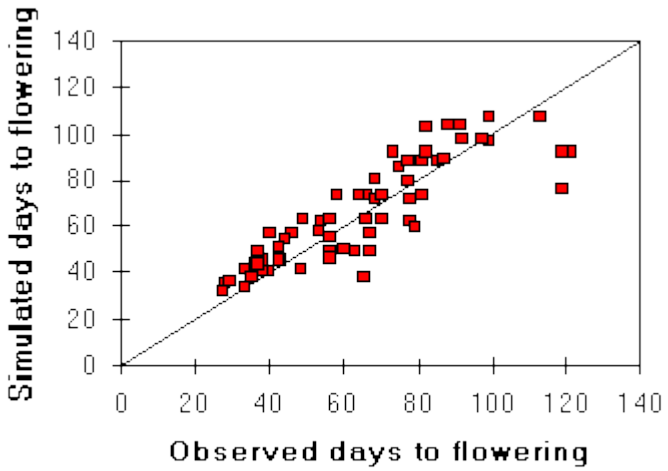


*Figure 1: Observed and simulated days to flowering for chickpea.*

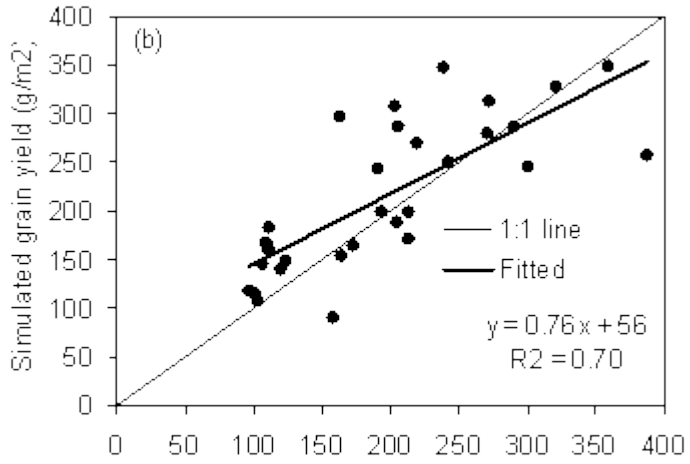



*Figure 2: Performance of the chickpea module (observed versus simulated grain yield in g/m2) against test datasets reported by Robertson et al. (2002).*

## Validation

APSIM-Chickpea has received testing across the northern Australian wheat belt, with factors such as cultivars, sowing date, irrigation, soil type, row spacing varying. Some testing has occurred in Wa as well. Limited testing has been conducted under dryland conditions in Syria (Moeller 2004). Papers describing validation of APSIM-chickpea are by Carberry (1996) and Robertson et al. (2002). The accompanying figure 2 demonstrates the performance of the module against Australian datasets.

## In which environments should this module be used with confidence?

APSIM-Chickpea can be used with most confidence in the semi-arid sub-tropics of northern Australia, the Western Australian wheat belt, and with less confidence in dryland environments of the Merranean.

## References

Carberry PS 1996 Assessing the opportunity for increased production of grain legumes in the farming system. Final Report to the Grains Research and Development Corporation, Project CSC9, 33pp.

Moeller, C 2004. Simulation of chickpea and wheat growth in response to a semi-arid Merranean-type environment using APSIM' (Agricultural Production Systems Simulator. PhD Thesis Hohenheim University.

Robertson, M.J., Carberry, P.S., Huth, N.I., Turpin, J.E., Probert, M.E., Poulton, P.L., Bell, M., Wright, G.C., Yeates, S.J., and Brinsmead, R.B. 2002. Simulation of growth and development of diverse legume species in APSIM, Australian Journal of Agricultural Research 53:429-446.

# Cowpea

## Introduction

The cowpea module was developed by Peter Carberry and Michael Robertson . The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-Cowpea. This document outlines some cowpea-specific issues that are not covered by the plant science document.

Goto generic Plant model documentation

## Notable features of APSIM-COWPEA

The module does not simulate production from second and further flushes of flowers and pods.

APSIM-Cowpea is not phosphorus-responsive, this is currently under development.

Crop growth is not sensitive to waterlogging.

## Cultivars and crop classes

There is one crop class. There are 4 cultivars able to be simulated: Banjo, Red Caloon, CPI28215, spreading. Cultivars differ in terms of biomass partitioning to grain and phenology. The spreading type is typical of that found growing under smallholder conditions in southern Africa.

## Validation

APSIM-Cowpea has received testing across the northern Australia , with factors such as cultivars, sowing date, irrigation, soil type, row spacing varying. There are no papers describing validation of APSIM-Cowpea, however the accompanying figures demonstrate the performance of the module against Australian datasets. Table 1 summarises module performance.

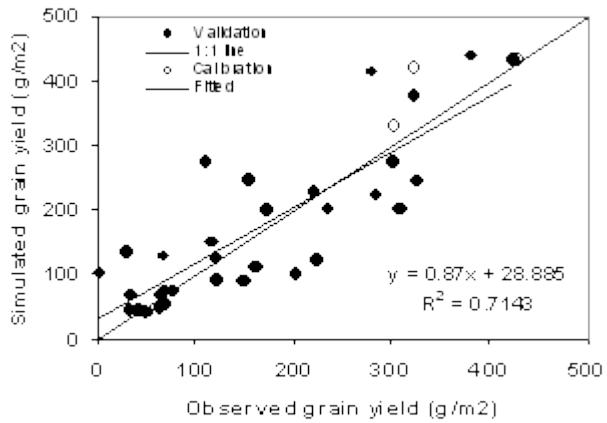



*Figure 1: Performance of the cowpea module (observed versus simulated grain yield in g/m2) against test datasets from northern Australia .*

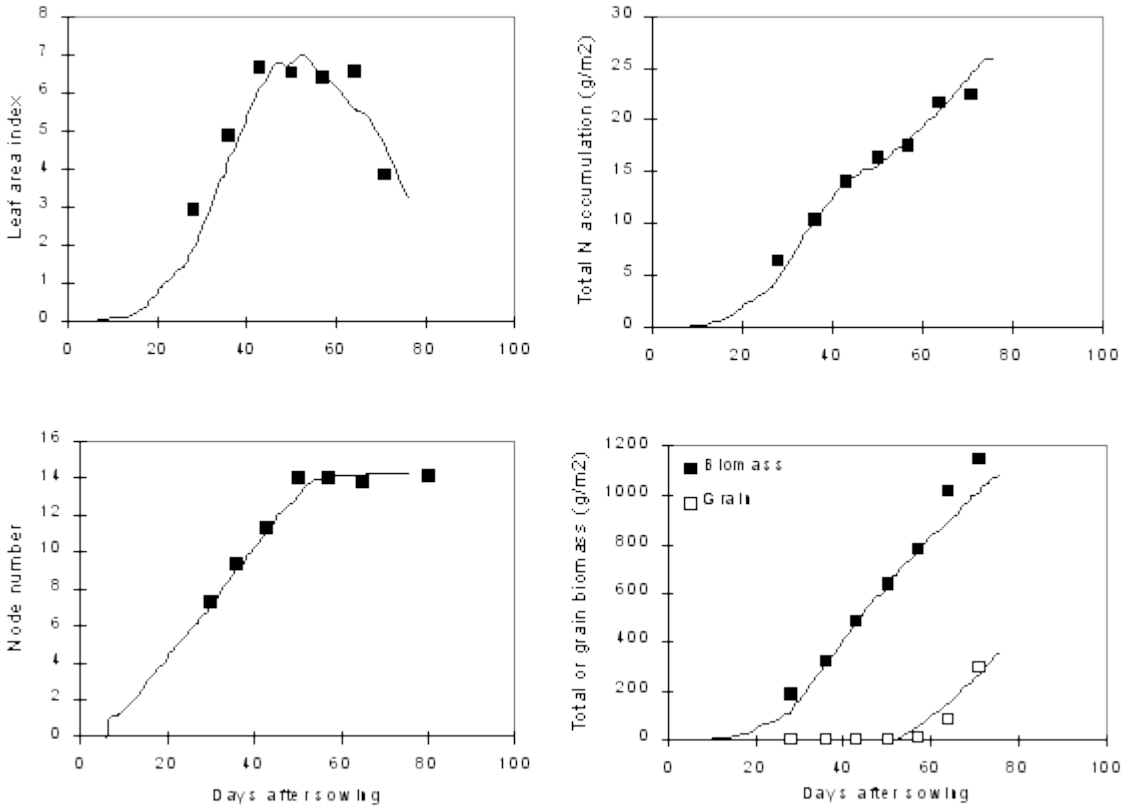



*Figure 2: Time course of crop gowth for cowpea cv. Banjo sown at Gatton , Queensland under full irrigation. Symbols are observed data and lines are simulated.*

| | N | Observed Mean (range) | RMSD | Linear regression between simulated and observed | | |
|---|---|---|---|---|---|---|
| | | | | **Slope** | **Intercept** | **R 2** |
| Grain yield (g m -2 ) | 18 | 155 (44-294) | 107 | 0.66 ± 0.142 | 49.2 ± 25.0 | 0.58 |
| Biomass at maturity (g m -2 ) | 15 | 387 (130 - 670) | 314 | 0.68 ± 0.158 | 236 ± 68.9 | 0.59 |

*Table 1:* Statistics for goodness-of-fit for grain yield and biomass at maturity for cowpea module testing.

## In which environments should this model be used?

APSIM-Cowpea can be used with most confidence in the sub-tropics and tropics of northern Australia. Limited tested has been conducted in southern Africa.

## References

Adiku S.K., Carberry P.S. Rose, C. W., McCown, R.L. & Braddock, R. (1993). Assessing the performance of maize (Zea mays - cowpea (Vigna unguiculata) intercrop under variable soil and climate conditions in the tropics. Proceedings of the 7th Australian Society of Agronomy Conference, September 1993, Adelaide , South Australia , p. 382. Carberry, P.S.; Adiku, S.G.K.;

McCown, R.L. and Keating, B.A. 1996b. Application of the APSIM cropping systems model to intercropping systems. In: O Ito, C Johansen, JJ Adu-Gyamfi, K Katayama, JVDK Kumar Rao, and TJ Rego (Eds.) Dynamics of Roots and Nitrogen in Cropping Systems of the Semi-Arid Tropics, pp. 637-648. Japan International Research Centre for Agricultural Sciences.

# Fababean

## Introduction

The fababean module was developed by Michael Robertson and Jill Turpin, with contributions from Bill Bellotti, Ian Rose, Andrew Moore, and KM Siddique. The module is described in the paper by Turpin et al. (2003). The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-Fababean.

This document outlines some fababean-specific issues that are not covered by the plant science document.

Goto generic Plant model documentation

## Notable features of APSIM-FABABEAN

The Module simulates small-seeded types of cultivars

The phenology of fababean cultivars is responsive to temperature and photoperiod, but not vernalisation. There is an effect of photoperiod on post-flowering development.

Model performance on days to flowering was reported by Turpin et al. (2003) and is repeated in the graph below (Figure 1).

The module does not simulate production from second and further flushes of flowers and pods.

Under well-watered conditions, fababean may have a low harvest index due to continued vegetative growth at the expense of reproductive yield. The model does not currently simulate this phenomenon.

APSIM-Fababean is not phosphorus-responsive, this is currently under development.

Crop growth is not sensitive to waterlogging.

## Cultivars and crop classes

There is one crop class. There are 6 cultivars able to be simulated: Amethyst, CPI56288, Dooen, Tyson, CV244-1, CPI56566. Cultivars differ in terms of biomass partitioning to grain and phenology. If usrs wish to use more modern cultivars they should contact Jeremy Whish at APSRU for advice.

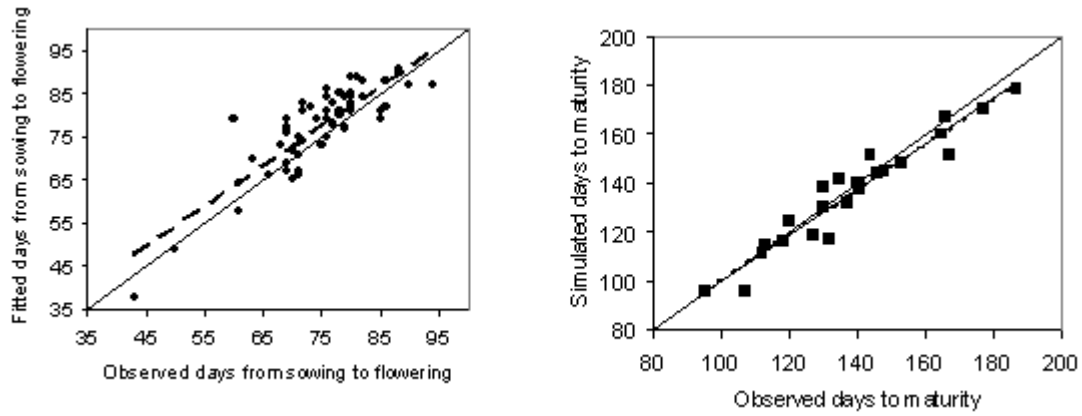



*Figure 1: Observed and simulated days from sowing to flowering and days to maturity for fababean.*

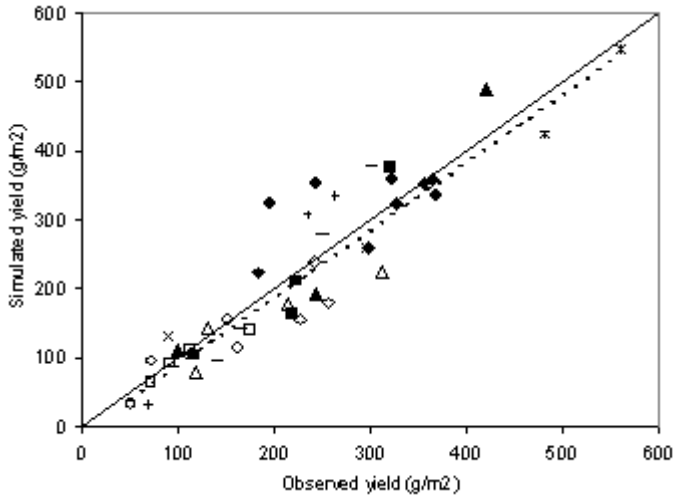



*Figure 2: Performance of the fababean module (observed versus simulated grain yield in g/m2) against test datasets reported by Turpin et al. (2003).*

## Validation

APSIM-Fababean has received testing across the Australian wheat belt, with factors such as cultivars, sowing date, irrigation, soil type, row spacing varying. Some testing has occurred in WA as well as Victoria, Queensland and northern NSW. The accompanying figure 2 demonstrates the performance of the module against Australian datasets.

## In which environments should this model be used?

APSIM-Fababean can be used with most confidence in the semi-arid sub-tropics of northern Australia, the Western Australian wheat belt, and the dryland environments of the Merranean-type regions. The module has received limited testing under irrigation on black cracking clay soils of northern NSW.

## References

Turpin JE, Robertson MJ, Haire C, Bellotti WD, Moore AD, Rose I (2003) Simulating fababean development, growth, and yield in Australia. Australian Journal of Agricultural Research 54, 39-52.

Robertson, M.J., Carberry, P.S., Huth, N.I., Turpin, J.E., Probert, M.E., Poulton, P.L., Bell, M., Wright, G.C., Yeates, S.J., and Brinsmead, R.B. 2002. Simulation of growth and development of diverse legume species in APSIM, Australian Journal of Agricultural Research 53:429-446.

# FieldPea

## Introductory notes

The fieldpea module is currently under development and has only received testing in South Australia over a range of sowing dates in two seasons under dryland conditions

Cultivars currently simulated in order of earliest to latest flowering are: Parvie, Excel, Parafield, Kaspa, Mutka

Green area of stems and tendrils is not explicitly simulated but included as part of the leaf area index

There is no explicit differentiation between semi-leafless and conventional types

Users are invited to provide feedback on module performance to the convenor, Michael Robertson (Michael.Robertson@csiro.au).

Goto generic Plant model documentation

## Science notes

The parameters are for the fieldpea module are those for chickpea, unless specified below. Refer to the PLANT module science document for detail on the definition of parameters:

Shoot_rate – 4 o Cdays per mm

Cardinal temperatures for thermal time. 3, 28, 40 o C from Olivier and Annandate (1998)

Leaf appearance rates 40 o Cd per leaf: from Olivier and Annandate (1998)

Branching parameters – complete guess – 2.5 leaves per node at 4 nodes onwards

Rue of 1.1 g/MJ. From Jamieson, Wilson and Hanson (1984)

Node number correction = 1.2

Leaf size vs node number – use fababean numbers

SLA_max = 30000 mm 2 /g

SLA_min = 20000 mm 2 /g

Temperature and root advance cardinal temps of 0, 20, 32 o C

Initial tpla =1000 mm 2 per plant

Transpiration efficiency – 0.004 Pa

Rate of HI increase (all cultivars) – 0.025 per day (Lecoeur and Sinclair 2001)

## Relevant references

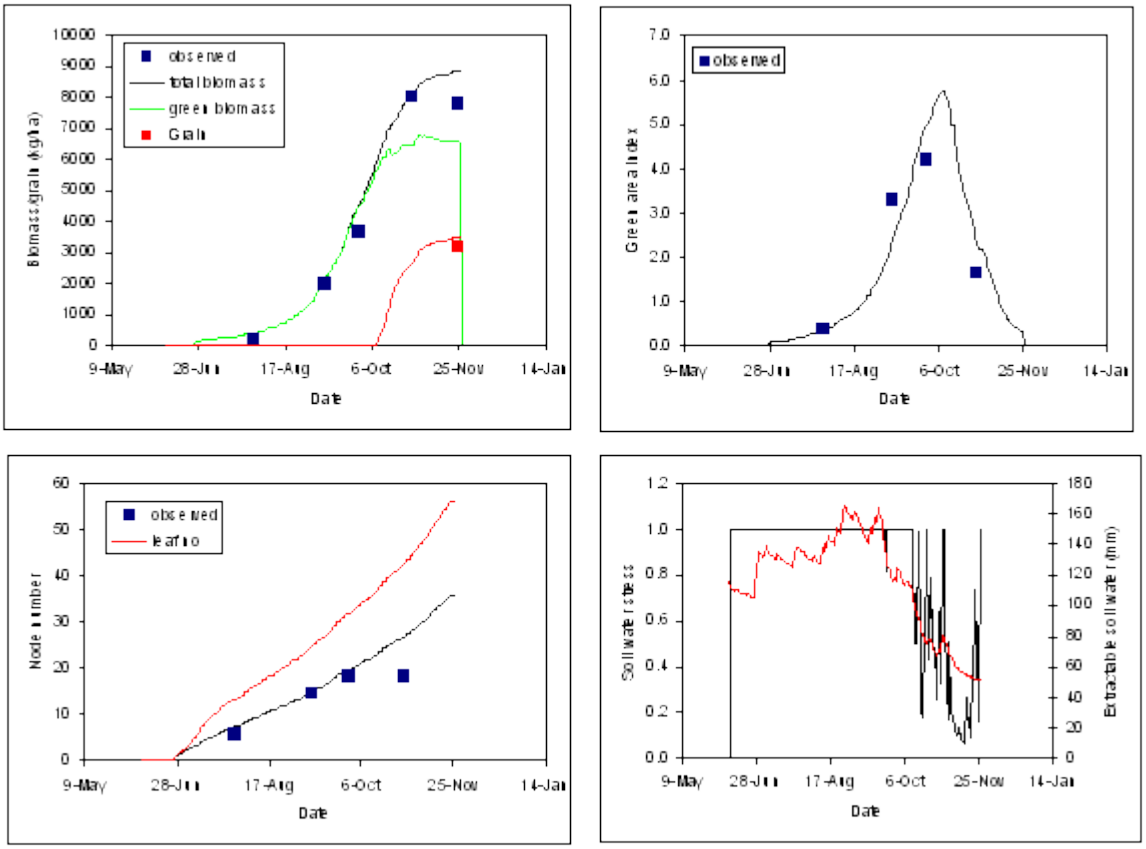
Jamieson PD, Wilson DR and Hanson R 1984. Analysis of response of field peas to irrigation and sowing date. 2. Models of growth and water use. Proceedings of the NZ Society of Agronomy 1984 75-81. Lecoeur J and Sinclair TR 2001. Harvest index increase during seed growth of field pea. European Journal of Agronomy 14: 173-180.

Olivier FC and Annandale JG 1998. Thermal time requirements for the development of green pea (Pisum sativum L.). Field Crops Research 56: 301-307.

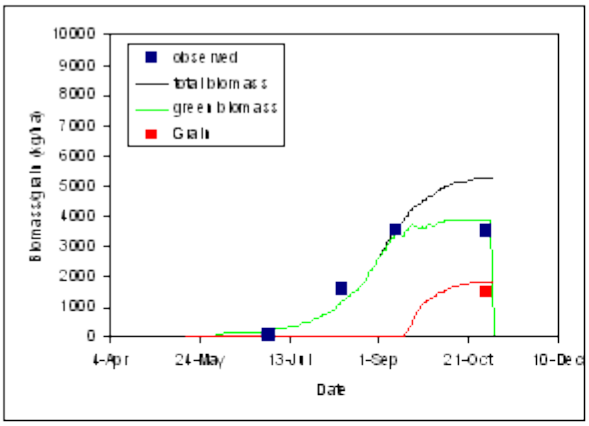
## Module performance

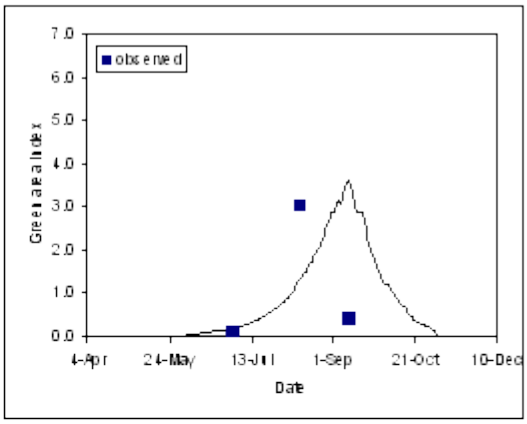
Figures below show module performance for one cultivar (Parafield) at Roseworthy in South Australia over two seasons. Prediction of flowering is for 5 cultivars (Parv, Excel, Parafield, Kaspa, Mutka) over those same two seasons.

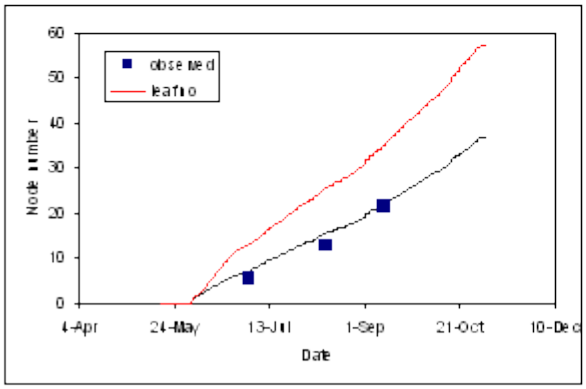
*Roseworthy 2003 sown 10th June .*

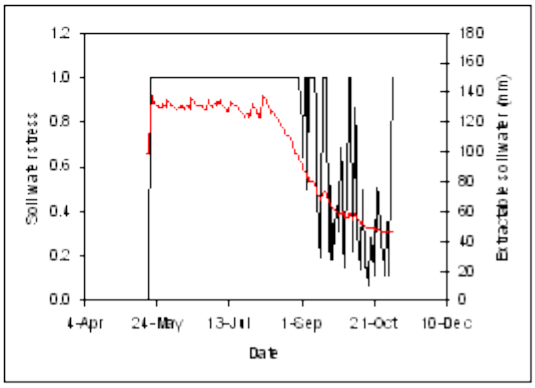



*Roseworthy 2002 sown 17th May*

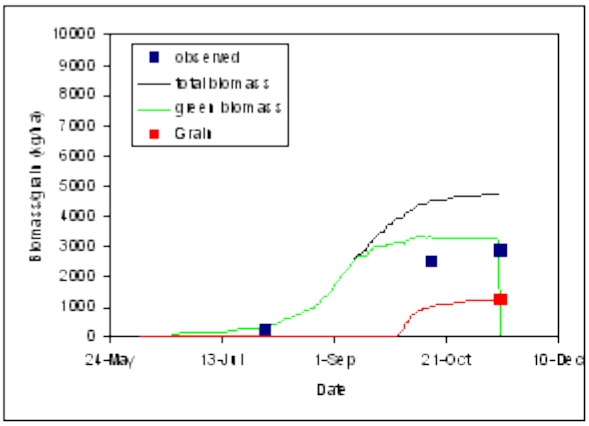


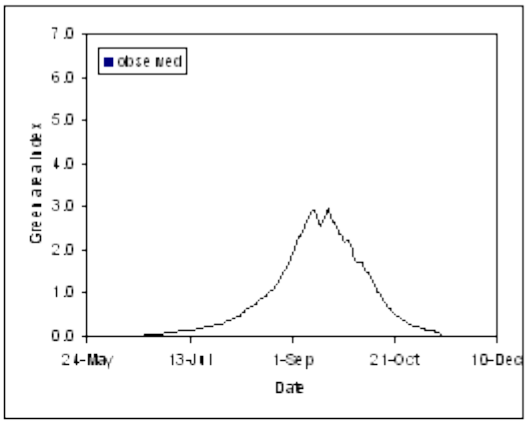



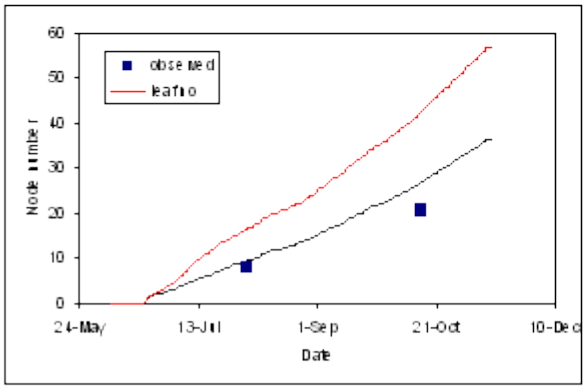



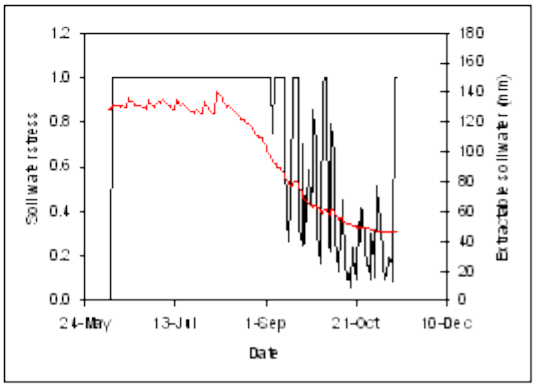




*Roseworthy 2002 sown 6th June*




## Phenology

Agreement for 5 cultivars over 4 sowing dates in South Australia Squares are observed and crosses are simulated

# Growth

## Introduction

The growth module is a simplified plant growth module developed for simulating pasture and forestry systems module. Whilst simplified in many respects, the major processes relating to growth, resource (water and nitrogen) use and responses to climate and resource supply, partitioning of photosynthate and links to the wider carbon and nitrogen balance are captured within the module. This document summarises the functional components of the module.

## Notable features of APSIM-Growth

A flexible method of assimilate partitioning is that is able to maintain structural (stem, branch, large roots, etc) and growth (foliage and fine root) pools.

A whole plant light use efficiency is used.

Soil water demand is provided by the micromet module using a Penman-Monteith formulation.

Germination processes are not modelled, swards or plantations are established.

Responses to nitrogen supply can be modelled in a simplistic fashion by a single 'site index' parameter or via a full nitrogen balance and cycle.

No 'phenology' is modelled, although, changes in partitioning rules for photosynthate can change with plant development (i.e. size).

## Example Manager Syntax

Module_name establish plants = ppp (/ha), init_section = ssssss

This statement will establish the sward/plantation where Module_name is the name of the instance of the growth module within the simulation (e.g. Bambatsi or Egrandis), ppp is the plant population and ssssss is the name of the data section used to initialise the new population of plants.

Module_name cut foliage_remove_fr = 0.7, adm_remove_fr = 0.5

This statement will remove 70% of leaves and 50% of stem (adm = above-ground dry matter, refers to structural pools). Biomass is removed from the system. Module_name thin plants_fraction = 0.1, biomass_fraction = 0.05

This statement will remove 10% of population and but only 5% of all above-ground biomass pools (i.e. thinning out of smaller than average sized individuals). Biomass is removed from the system.

## Module_name kill

This statement will kill the model, sending any remaining biomass to the residue module.

## Model Components

The APSIM Growth module is based on the lessons learned from other APSIM crop (Keating et al, 2003, Robertson et al, 2002, Wang et al, 2002) and forest (Huth et al, 2001, 2002) productivity models as well as other pasture models such as GRASP (McKeon et al). A range of APSIM modules provide daily data for meteorological conditions and uptake of water and nitrogen and so that time step is used for all growth calculations.

The APSIM Growth module contains two major classes of biomass pools: growth and structural pools. Growth pools are responsible for most growth processes (i.e. leaves intercepting radiation) and water uptake (fine roots). Structural pools are provide sinks for assimilate and nutrients and are used to describe plant properties such as plant height. Structural pools are either above or below ground. The number of structural pools for a given plant model can be user-defined but a standard configuration may only contain stem above ground and a tap root below ground.

Growth is calculated as, $\Delta G = R_{int} \times \varepsilon \times \min(F_T, F_N, F_{VPD}) \times F_W$

Where ?G is daily growth, R int is daily intercepted solar radiation (MJ/m 2 ), e is the light use efficiency (g/MJ) and F t , F n , F vpd and F w are growth modifiers for temperature, nitrogen, vapour pressure deficit and soil water supply respectively. R int is calculated using crown cover, leaf area, and an assumption of exponential light extinction. F t and F vpd are based on average daily temperature and vapour pressure deficit. Fn is based on leaf nitrogen concentration. Fw is calculated as the ratio of soil water demand and supply.

## Partitioning of daily Growth

Unlike other APSIM modules, e is a whole plant (above and below ground) light use efficiency. As a result, the daily growh has to be partitioned into foliage, roots, above-ground structure and below-ground structure. The rules for partitioning are described via two main mechanisms: variation in root:shoot ratio and structural fraction of above-ground growth.

Stresses due to deficiency in below ground resources such as water and nutrients is often found to increase the root:shoot ratio. In this module the user can define how increasing severity of stress can increase the proportion of daily growth going into below-ground growth. This extra rooting growth can then assist the plant in accessing scarce resources, depending on the way in which APSIM is configured (e.g. use of the APSIM-SWIM water balance where root length density impacts on root water uptake). Currently, soil water supply, soil water content and plant nitrogen status can all be used to alter the root:shoot ratio of the plants.

The partitioning of above-ground growth changes throughout the growth cycle of plants. The result is the often consistent allometry observed in plants. The Growth module will allow the user to specify how the fraction of above-ground growth going into structure changes with mean plant size. For example, small plants may put proportionally more photosynthate into foliage than larger plants relfecting their need to establish a canopy as against compete with other plants via increased structural/height growth.

On a daily basis, the above two partitioning rules are evaluated. The model will then back-calculate the partitioning into leaf, roots and structure such that root:shoot ratios and growth:structure ratio are conserved..

Leaf Area growth is calculated from leaf growth and a specific leaf area. Similarly, root length calculations utilise a

specific root length, with root length partitioned spatially according to supplies and demands for both water and nitrogen.

## Senescence and Detachment of biomass

Each biomass pool undergoes continual senescence and the resultant senesced material is continually detached from the plant.

Senescence of growth pools (foliage and roots) is calculated using simple first order decay. The user specifies a mean residence time ( in days) which is inverted within the model to provide a decay coefficient. Senescence of foliage is often observed to also show a certain seasonality. This is achieved within the model via use of the daily temperature stress factor and the annual sinusoidal temperature curve such that the annual average mean residence time will equate to that provided by the user but that the daily value will vary around that throughout the year.

Other processes can be responsible for leaf death. Senescence of foliage can also be triggered by low temperatures (i.e. frosting). In this case, low nightly minimum temperatures can specified to fractionally decrease green leaf area. Alternatively, mutual shading of leaves in dense canopies can be specified to decrease leaf area. If total leaf senescence occurs, a small initial leaf area is maintained on the plant in order to initiate further regrowth when conditions are favourable.

Senescence of structural pools is said to follow the patterns in the growth pools. This is achieved by relating the senescence rate of above-ground pools to the senescence rate of foliage and by relating the senescence rate of below-ground pools to the senescence rate of roots. For example, a 1% loss of green leaf may result in a 0.5% loss in live stem mass.

All senesced pools (growth or structural, above or below ground) detach via a first order decay function. Above-ground biomass is added to the surface residues. Below-ground biomass is added to soil organic matter.

## Plant water use

Plant water demand is calculated using the Micromet module which is developed from the work of Snow et al. 1999 and Kelliher et al. 1995, while plant water supply is calculated using one of the two soil water modules available in APSIM. Please refer to these modules for further information.

Plant water uptake is calculated within the Growth module using the assumption that uptake of water from soil follows a simple first order decay with soil drying.

$$\frac{\partial \theta}{\partial t} = -kl \times (\theta - \theta ll)$$

## Plant nitrogen

Plant nitrogen demand is based upon the size of the biomass pools and a target nitrogen concentration for each pool. When nitrogen supply is insufficient to meet all this demand, nitrogen is partitioned according to the sink strength in each pool. If this results in a decrease in leaf nitrogen concentration the plant may experience nitrogen stress.

In extreme nutritional conditions, or in cases where fertility information is unknown, it is possible to constrain the Growth module via use of a site index. In this case, Fn is maintained at a constant value.

## Uptake of nitrogen

Nitrate-nitrogen can be taken up by the plant via the uptake of water from the soil. If this is insufficient to meet daily demand a set fraction of the unmet demand can be taken up via active uptake processes. This active process is further discounted when soil water content is low.

## Output Variables

| Variable Name | Units | Description |
|---|---|---|
| adm_dead(num_above*) | kg DM /ha | Dry matter in each of the above ground part of dead plants |
| adm_green(num_above) | kg DM /ha | Dry matter in each of the above ground part of live plants |
| adm_sen(num_above) | kg DM /ha | Senesced dry matter in each of the above ground part of live plants |
| Age | years | Age of the plants |
| an_green(num_above) | kg DM /ha | N in each of the green above ground parts of live plants |
| bdm_dead(num_below**) | kg DM /ha | Dry matter in each of the below ground parts of dead plants |
| bdm_green(num_below) | kg DM /ha | Green matter in each of the below ground parts of live plants |
| bdm_sen(num_below) | kg DM /ha | Senesced matter in each of the below ground parts of live plants |
| Biomass | kg DM /ha | Total above ground dry matter |
| bn_green(num_below) | kg N /ha | N in each of the green below ground parts of live plants |
| cover or cover_green | 0-1 | Fractional ground cover from green material |
| cover_tot | 0-1 | Fractional ground cover from all material |
| crop_type | Text | Crop type for looking up properties |
| dlt_adm_green(num_above) | kg DM /ha | Change in adm_green today due to photosynthesis |
| dlt_an_green(num_above) | kg N /ha | Change in an_green today due to N uptake from soil |
| dlt_bn_green(num_below) | kg N /ha | Change in bn_green today due to N uptake from soil |
| dlt_dm | kg DM /ha | Change in total dry matter today |
| dlt_foliage_mass | kg DM /ha | Change in foliage_mass today due to photosynthesis |

| Variable Name | Units | Description |
|---|---|---|
| dlt_foliage_mass_detached | kg DM /ha | Change in foliage_mass_detached today from senesced foliage |
| dlt_foliage_mass_sen | kg DM /ha | Change in foliage_mass_sen today due to senescence of live foliage |
| dlt_foliage_n | kg N /ha | Change in foliage_n today due to N uptake from soil |
| dlt_foliage_n_detached | kg N /ha | Change in foliage_n today from senesced foliage. |
| dlt_lai_sen | kg DM /ha | Change in lai_sen today due to senescence of live foliage |
| dlt_lai_sen_age | kg DM /ha | Change in lai_sen today due to age driven senescence of live foliage |
| dlt_lai_sen_frost | kg DM /ha | Change in lai_sen today due to frosting of live foliage |
| dlt_lai_sen_light | kg DM /ha | Change in lai_sen today due to shading of live foliage |
| dlt_no3(num_layers***) | kg N /ha | Change in no3 today (i.e. uptake of NO3 from each layer by the plant) |
| dlt_root_mass | kg DM /ha | Change in root_mass today due to photosynthesis |
| dlt_root_mass_sen | kg DM /ha | Change in root_mass_sen today due to senescence of live fine roots |
| dlt_root_n | kg N /ha | Change in root_n today due to uptake of N from soil. |
| dlt_root_n_sen | kg N /ha | Change in root_n_sen today due to senescence of live fine roots |
| Ep | Mm | Actual water uptake summed across all soil layers |
| Fage | 0-1 | Stress factor for age – generic factor used to capture loss of productivity as plant stands mature. |
| Fasw | 0-1 | Fraction of plant available soil water |
| Fdl | 0-1 | Stress factor for daylength – used to capture increased partitioning to roots prior to winter. |
| Ff | 0-1 | Stress factor for frost |
| Ffasw | 0-1 | Stress factor for fasw – used to capture increased partitioning to roots in dry conditions.???? |
| Fn | 0-1 | Stress factor for nitrogen |
| foliage_mass | kg DM /ha | Mass of foliage |

| Variable Name | Units | Description |
|---|---|---|
| foliage_n | kg N /ha | N in the foliage |
| Frgr | 0-1 | Relative growth rate factor for photosynthesis = min(Ft, Fn, Fvpd, Fage) |
| Ft | 0-1 | Stress factor for temperature |
| Fvpd | 0-1 | Stress factor for vapour pressure deficit |
| Fw | 0-1 | Stress factor for water supply (= supply/demand) |
| Height | Mm | Height of the plants |
| Lai | m/m2 | Leaf area index |
| n_demand | kg N /ha | Nitrogen demand |
| no3_demand | kg N /ha | Nitrate Nitrogen demand |
| plant_status | Text | “in”, “out”, “dead” etc |
| Plants | #/ha | Number of plants per ha |
| rld (num_layers) | mm/mm3 | Root length density |
| rlv(num_layers) | mm/mm3 | Root length density corrected for aeration stress |
| rlv_Growth(num_layers) | cm/cm3 | Same as rlv but with different units |
| root_depth | mm | Depth of the root system |
| root_length(num_layers) | mm/mm2 | Root length for each layer (area basis) |
| root_mass | kg DM /ha | Mass of live fine roots |
| root_n | kg N /ha | N in the live fine root system |
| rue_actual | g/MJ | Radiation use efficiency = RUE * Frgr |
| SLA_senescing | mm/g | Specific leaf area of the senescing leaves |
| Slai | m/m2 | Senesced leaf area index |
| sw_demand | Mm | Soil water demand |
| total_n | kg N /ha | Total in the plants, above and below |

## References

Huth, N.I., Snow, V.O. and Keating, B.A. 2001. Integrating a forest modelling capability into an Agric. production systems modelling environment - current applications and future possibilities. Proceedings of the International Congress on Modelling and Simulation, Aust. National University , Dec. 2001. pp. 1895-1900.

N. I. Huth, P. S. Carberry, P. L. Poulton, L. E. Brennan, and Brian A. Keating. "A framework for simulation of agroforestry options for the low rainfall areas of Australia using APSIM." European Journal of Agronomy 18 (2002): 171-185.

Keating, Brian A., P. S. Carberry, G. L. Hammer, Mervyn E. Probert, M. J. Robertson, D. Holzworth, N. I. Huth, J. N. G. Hargreaves, H. Meinke, Z. Hochman, G. McLean, K. Verburg, V. O. Snow, J. P. Dimes, M. Silburn, E. Wang, Stuart Brown, K. L. Bristow, S. Asseng, S. C. Chapman, R. L. McCown, D. M. Freebairn, and C. J. Smith. "An overview of APSIM, a model designed for farming systems simulation." European Journal of Agronomy 18 (2002): 267-288.

Kelliher, F. M., R. Leuning, M. R. Raupach, and E. D. Schulze. 1995. Maximum conductances for evaporation from global vegetation types. Agricultural and Forest Meteorology 73: 1-16.

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Paydar, Z., Huth N. I., and Snow V. O. 2005. Modelling irrigated Eucalyptus for salinity control on shallow watertables. Australian Journal of Soil Research 43: 587-97.

Snow, V. O., W. J. Bond, B. J. Myers, S. Theiveyanathan , C. J. Smith, and R. G. Benyon. 1999. Modelling the water balance of effluent-irrigated trees. Agricultural Water Management 39: 47-67.

Wang, E., Robertson, M. J., Hammer, G. L., Carberry, P. S., Holzworth, D. P., Meinke, H., Chapman, S. C., Hargreaves, J. N. G., Huth, N. I., and McLean, G. Development of a generic crop module template in the cropping system model APSIM. European Journal of Agronomy. 18 (2002):121-140.

# HorseGram

## Introduction

The horsegram module was developed by Dr R. Selvaraju, building largely on the mungbean module developed by Peter Carberry and Michael Robertson . The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-horsegram. This document outlines some horsegram-specific issues that are not covered by the plant science document. The horsegram module simulates horsegram (black gram or green gram). Notable features of APSIM-horsegram The phenology of horsegram cultivars are photoperiod insensitive. The module does not simulate grain weathering, although some users have simulated the number of rainfall events during pod-fill (using the manager module) and used this as a surrogate of weathering damage. The module does not simulate production from second and further flushes of flowers and pods. APSIM-horsegram is not phosphorus-responsive, this is currently under development. Crop growth is not sensitive to waterlogging.

Goto generic Plant model documentation

## Cultivars

There are 2 cultivars able to be simulated: CO1 and Paiyur. Cultivars differ in terms of biomass partitioning to grain and phenology.

## Validation

APSIM-horsegram has received testing in Tamil Nadu, with factors such as cultivars, sowing date, irrigation, soil type, row spacing varying.

## In Which Environments Should This Module Be Used With Confidence?

APSIM-horsegram can be used with a high degree of confidence in South India.

## References

Robertson, M.J., Carberry, P.S., Huth, N.I., Turpin, J.E., Probert, M.E., Poulton, P.L., Bell, M., Wright, G.C., Yeates, S.J., and Brinsmead, R.B. 2002. Simulation of growth and development of diverse legume species in APSIM, Australian Journal of Agricultural Research 53:429-446.

Robertson, M. J.; Carberry, P. S., and Lucy. M. 2000 Evaluation of cropping options using a participatory approach with on-farm monitoring and simulation: a case study of spring-sown mungbeans. Australian Journal of Agricultural Research. 51:1-12.

# LabLab

Michael Robertson/Jacqui Hill 4th May 2004

## Introductory notes

The lablab module has received testing against four datasets from Queensland and the Northern Territory Cultivars currently simulated are: Highworth (annual) and Endurance (perennial) Users are invited to provide feedback on module performance to the convenors, Michael Robertson ( Michael.Robertson@csiro.au ) and Jacqui Hill ( Jacqueline.Hill@csiro.au ).

Goto generic Plant model documentation

## Science notes

Refer to the PLANT module science document for detail on the definition of parameters:

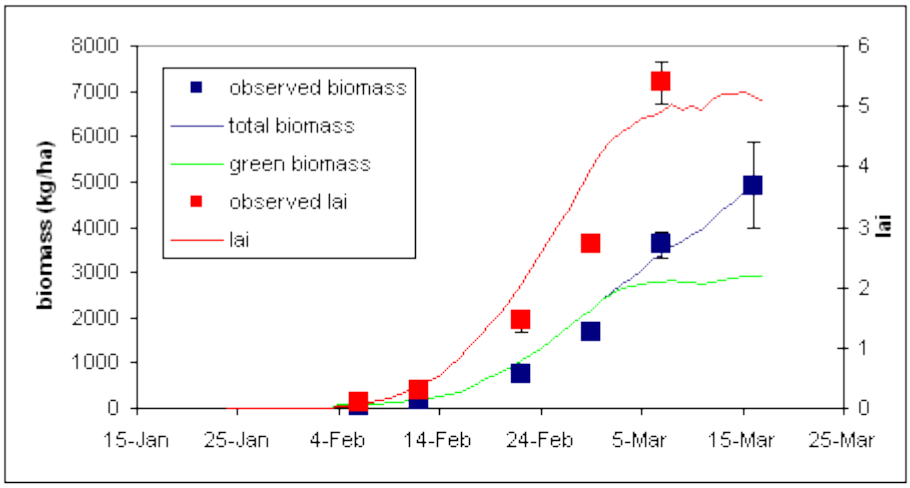
## Syntax examples

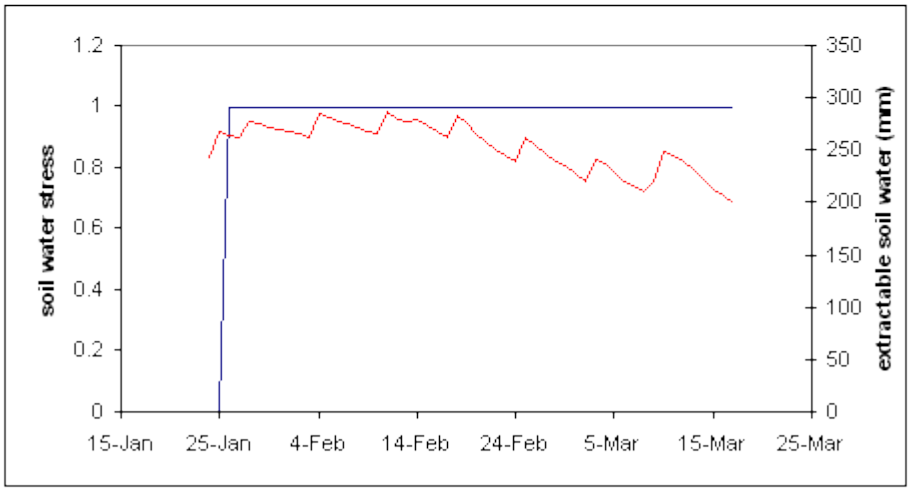
To sow the annual cultivar: if day = 24 and year = 2000 then lablab sow cultivar = highworth, plants = 5 (/m2), sowing_depth = 40 (mm) endif To sow the perennial cultivar: if day = 24 and year = 2000 then lablab sow cultivar = endurance, crop_class = small_leaf, plants = 5 (/m2), sowing_depth = 40 (mm) endif To kill the stems of the perennial cultivar over winter in order to stall progression into higher phenological states: if (mint < 5) and (lai < 0.5) and (day > 120 or day < 240) then lablab kill_stem endif

## Module performance

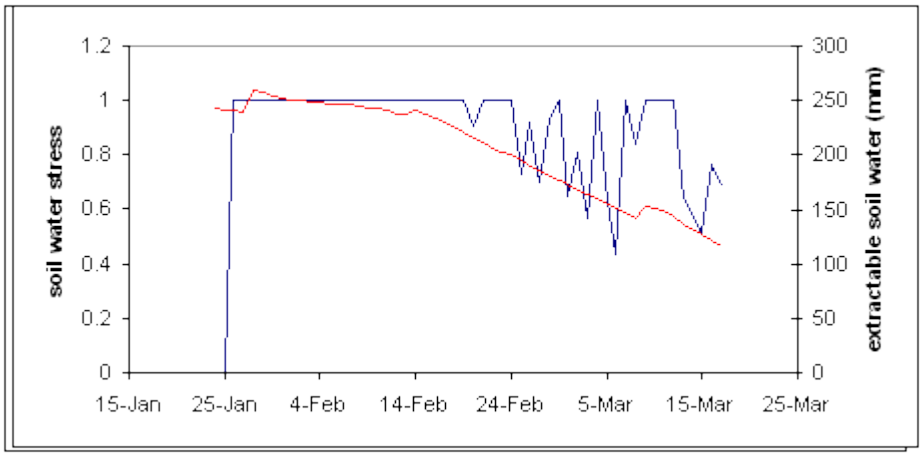
Figures below show module performance for both cultivars at Gatton in Qld over one season (sown 24 th Jan 2000) under irrigated and dryland conditions; cultivar Highworth at Katherine in NT over one season (sown 1 st April 1980) under irrigated and dryland conditions; cultivar Highworth at Brian Pastures Research Station near Gayndah in Qld over two seasons (sown 4 th Jan 2000 and 14 th Dec 2000) under dryland conditions.

*Gatton, Highworth irrigated*

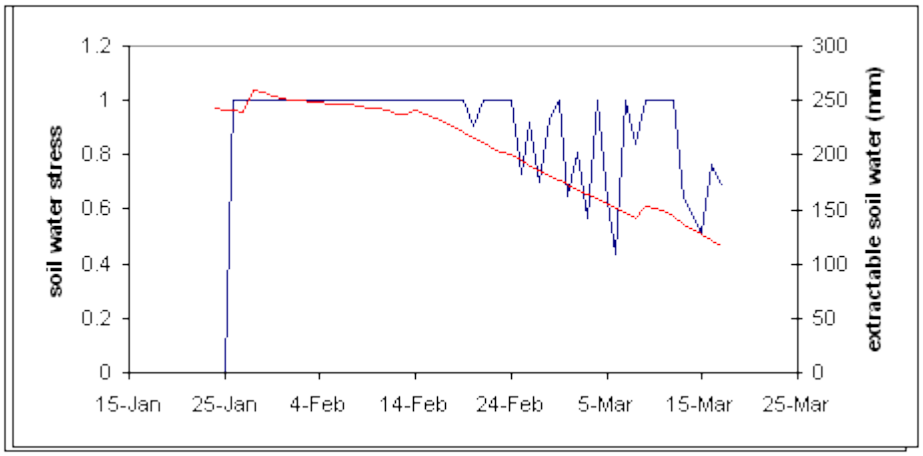


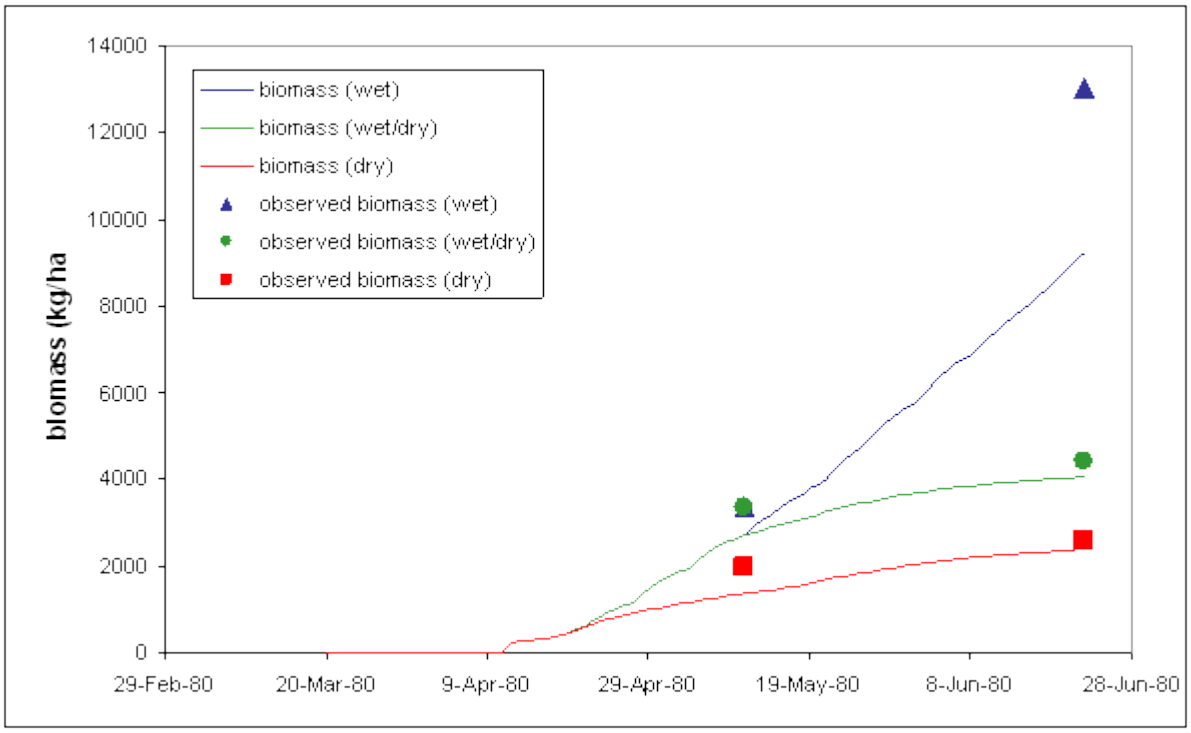




*Gatton, Highworth dryland*

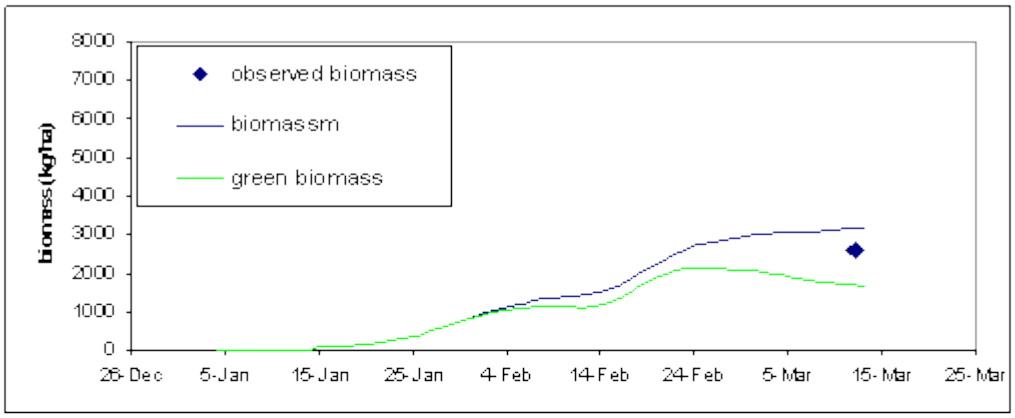


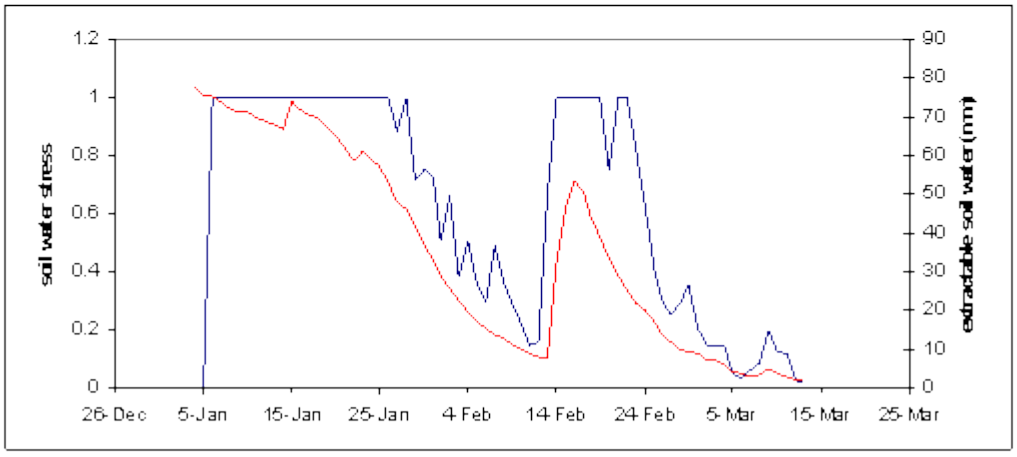
*Gatton, Endurance irrigated  Katherine, High*worth  *Brian Pastures,*



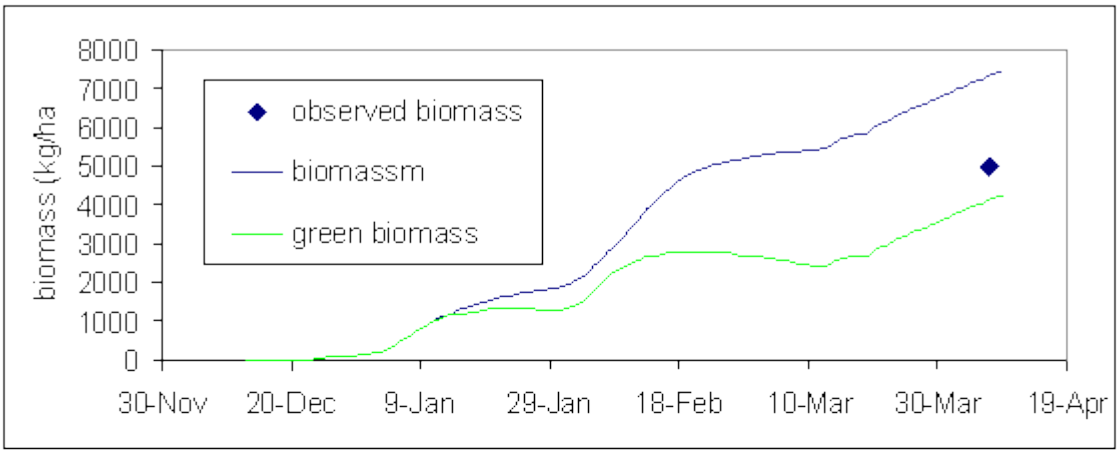



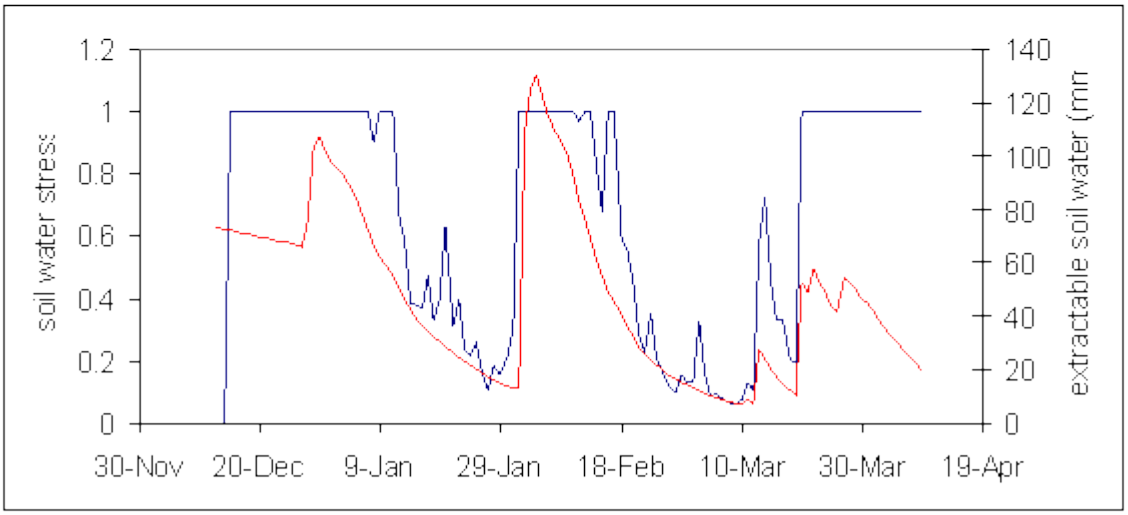

*Highworth, 2000  Brian Pastures,*




*Highworth, 2001*


biomass (kg/ha
8000
7000
6000
5000
4000
3000
2000
1000
0
observed biomass
biomassm
green biomass
30-Nov
20-Dec
9-Jan
29-Jan
18-Feb
10-Mar
30-Mar
19-Apr


soil water stress
1.2
1
0.8
0.6
0.4
0.2
0
140
120
100
80
60
40
20
0
extractable soil water (mm
30-Nov
20-Dec
9-Jan
29-Jan
18-Feb
10-Mar
30-Mar
19-Apr

# Lucerne

For detailed information on module development and science please consult the PLANT module science document.

## Introduction

The lucerne module was developed by Peter Carberry, Perry Poulton, Merv Probert and Michael Robertson . The module is described in the paper by Robertson et al. (2002). The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-Lucerne. This document outlines some lucerne-specific issues that are not covered by the plant science document.

## Notable features of APSIM-LUCERNE

The phenology of only one of the lucerne cultivars is responsive to photoperiod (see Moot et al. 2001), however it is likely that the other cultivars respond to photoperiod as well. Lack of data precludes parameterising this, though.

The module does not simulate the well-known decline in biomass production in the autumn (influence of photoperiod on increase partitioning of assimilate below ground). There is module development going on to overcome this deficiency. In the meantime users are suggested to contact Michael Robertson or John Hargreaves at APSRU for a known work-around.

The module does not simulate different degrees of winter dormancy in cultivars. Please see Michael Robertson at APSRU on advice on how to parameterise an unknown cultivar.

The module operates on the basis of the stem as the unit, rather than the plant. As a rough guide if plant numbers are all that is known then work on 5-10 stems per plant depending upon stand age.

APSIM-Lucerne is not phosphorus-responsive, this is currently under development.

Crop growth is not sensitive to waterlogging.

Goto generic Plant model documentation

## Example Syntax

Sowing: lucerne sow cultivar = trifecta, plants = 200 (/m2), sowing_depth = 40 (mm) Harvest (end crop): Lucerne harvest Lucerne kill_crop Lucerne end_crop Harvest (with regrowth): Lucerne harvest plants = 150 (/m2), height = 50 (mm), remove = 0.95 The above harvest statement will cut the lucerne plant at 50 mm and remove 95% of the biomass. The plant density will also be reduced to 150 plants per sq metre from the previous 200 plants per sq metre.

## Cultivars and crop classes

There are two crop classes, representing crops growing from seed (plant) and crops growing after cutting. Crops change automatically from plant to regrowth classes at the first cut after sowing. There are a number of cultivars able to be simulated: Kaituna, Trifecta, Hunter_River, Sceptre, Aquarius. Northern China cultivars Longdong and Dingxi are also included.

## Validation

APSIM-Lucerne has received testing in northern Australia (Probert et al. 1998) and New Zealand (Moot et al., 2001), Western Australia (Dolling et al 2004, Robertson et al 2004), New South Wales (Robertson et al 2004, Verberg and Bond 2003) and China (Chen et al 2003) with factors such as cultivar, irrigation, and soil type varying.

## IN WHICH ENVIRONMENTS THIS MODULE SHOULD BE USED WITH CONFIDENCE?

APSIM-Lucerne can be used with most confidence throughout the wheat belt of Australia and in cool temperate environments such as New Zealand and northern China. When using the model in these environments, users should consult the module development team on how to simulate their particular cultivar.

## References

Chen W, Yu Ying Shen, Michael Robertson, Merv Probert, Bill Bellotti, Zhi Biao Nan. Simulation of Crop Growth and Soil Water for Different Cropping Systems in the Gansu Loess Plateau, China using APSIM. In: "New directions for a diverse planet". Proc. 4th International Crop Science Congress, Brisbane, CDROM ISBN 1 920842 217. Web site www.cropscience.org.au

Dolling P.J., Robertson M.J., Asseng S., Ward, P.R., Latta, R.A. (2004) Simulating lucerne growth and water on diverse soil types in a Merranean-type environment. Australian Journal of Agricultural Research (submitted).

Moot, D., Robertson, M.J. and Pollock, K. (2001). Validation of the APSIM-Lucerne model for phenological development in a cool-temperate climate. 10th Australian Agronomy Conference, Hobart , Tasmania . Probert, M. E.; Robertson, M. J.; Poulton, P. L.; Carberry, P. S.; Weston, E. J., and Lehane, K. J. (1998). Modelling lucerne growth using APSIM. Proceedings of the 9th Australian Agronomy Conference, Wagga Wagga 1998:247-250.

Robertson, M.J., Carberry, P.S., Huth, N.I., Turpin, J.E., Probert, M.E., Poulton, P.L., Bell, M., Wright, G.C., Yeates, S.J., and Brinsmead, R.B. (2002). Simulation of growth and development of diverse legume species in APSIM, Australian Journal of Agricultural Research 53:429-446.

Robertson M, Gaydon D, Latta R, Peoples M and Swan A (2004) Simulating lucerne/crop companion farming systems in Australia. In: "New directions for a diverse planet". Proc. 4th International Crop Science Congress, Brisbane, CDROM ISBN 1 920842 217. Web site www.cropscience.org.au Verburg K, Bond WJ (2003) Use of APSIM to simulate water balances of dryland farming systems in south eastern Australia. CSIRO Technical Report 50/03, CSIRO, Canberra, Australia.

# Lupin

## Introduction

The lupin module it is being developed by CSIRO Plant Industry in Perth (Drs Imma Farre and Senthold Asseng) together with Dr Michael Robertson at APSRU. The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-Lupin. This document outlines some lupin-specific issues that are not covered by the plant science document. The lupin module simulates narrow leaf lupin (Lupinus angustifolius).

### Notable features of APSIM-LUPIN:

The lupin model has had only a limited testing. The model is still under development and caution should be taken when using outside conditions it has been validated for (sandplain soils in WA)

The phenology parameters have been tested on cultivars Belara, Kalya, Merrit, Myallie, Tallerac, Tanjil, Wodjil and Gungurru in several locations across Western Australia.

Crop growth, final yield, LAI and water uptake has been only tested in cultivars Merrit and Gungurru in Moora (sandy soil) and Beverley (duplex soil) in Western Australia, respectively.

The phenology of the lupin cultivars tested so far respond to photoperiod (daylength) but not to vernalisation. (The modern cultivars used for calibration and testing do not respond to vernalisation, but some old cultivars do respond to vernalisation)

Crop growth is not sensitive to row spacing

Crop growth is not sensitive to waterlogging.

In the module, pods do not photosynthesise.

Goto generic Plant model documentation

## Cultivars

There are 8 conventional cultivars of narrow leaf lupin in the lupin.ini file: Belara, Kalya, Merrit, Myallie, Tallerac, Tanjil, Wodjil and Gungurru.

## Validation

APSIM-Lupin has received limited testing in the wheatbelt of Western Australian, with factors such as cultivars, sowing date, irrigation, soil type varying. Cultivar Merrit has been tested against observed data (Dracup et al., 1998) on a duplex soil in Beverley (average annual rainfall = 400 mm), under rainfed conditions and supplementary irrigation in 1993. Model outputs have been compared to measurements of time course of total above ground biomass, seed weight, pod wall and LAI.

Cultivar Merrit has been tested against observed data (Anderson et al., 1998a, 1998b) on a deep sand soil in Moora (average annual rainfall = 460 mm), under rainfed conditions, in 1995 and 1996. Observed time course of total above ground biomass, final seed yield and daily values of soil water content at different depths were compared to model simulations. Cultivar Gungurru has been tested against observed data (Gregory, 1998; Gregory and Eastham, 1996) on a duplex soil in Beverley, under rainfed conditions, in 2 sowing dates from 1990 to 1993. Because of the limited testing we would caution users taking the model outside WA and sandy soils.

## References

Anderson , G.C., Fillery, I.R.P., Dolling, P.J. & Asseng, S. 1998. Nitrogen and water flows under pasture-wheat and lupin-wheat rotations in deep sands in Western Australia . 1. Nitrogen fixation in legumes, net N mineralisation, and utilisation of soil-derived nitrogen. Australian Journal of Agricultural Research , 49, 329-343.

Anderson , G.C., Fillery, I.R.P., Dunin, F.X., Dolling, P.J. & Asseng, S. 1998. Nitrogen and water flows under pasture-wheat and lupin-wheat rotations in deep sands in Western Australia . 2. Drainage and nitrate leaching. Australian Journal of Agricultural Research , 49, 345-361.

Dracup, M., Reader, M.A. & Palta, J.A. 1998. Variation in yield of narrow-leafed lupin caused by terminal drought. Australian Journal of Agricultural Research , 49, 799-810.

Gregory, P.J. 1998. Alternative crops for duplex soils: Growth and water use of some cereal, legume, and oilseed crops, and pastures. Australian Journal of Agricultural Research , 49, 21-32.

Gregory, P.J.& Eastham, J. 1996. Growth of shoots and roots, and interception of radiation by wheat and lupin crops on a shallow, duplex soil in response to time of sowing. Australian Journal of Agricultural Research , 47, 427-447.

# Maize

## MAIZE Module Scope

The maize module simulates the growth of a maize crop in a daily time-step (on an area basis not single plant). Maize growth in this model responds to climate (temperature, rainfall and radiation from the input module), soil water supply (from the soilwat module) and soil nitrogen (from the soiln module). The maize module returns information on its soil water and nitrogen uptake to the soilwat and soiln modules on a daily basis for reset of these systems. Information on crop cover is also provided to the soilwat module for calculation of evaporation rates and runoff. Maize stover and root residues are 'passed' from maize to the residue and soiln module respectively at harvest of the maize crop. A list of the module outputs is provided in the 'Maize module outputs' section below, but basically the module will predict leaf area development, N% and biomass of stover; depth, N% and biomass of roots; grain N% and biomass; grain yield and N%, grain size and grain number all on a daily basis.

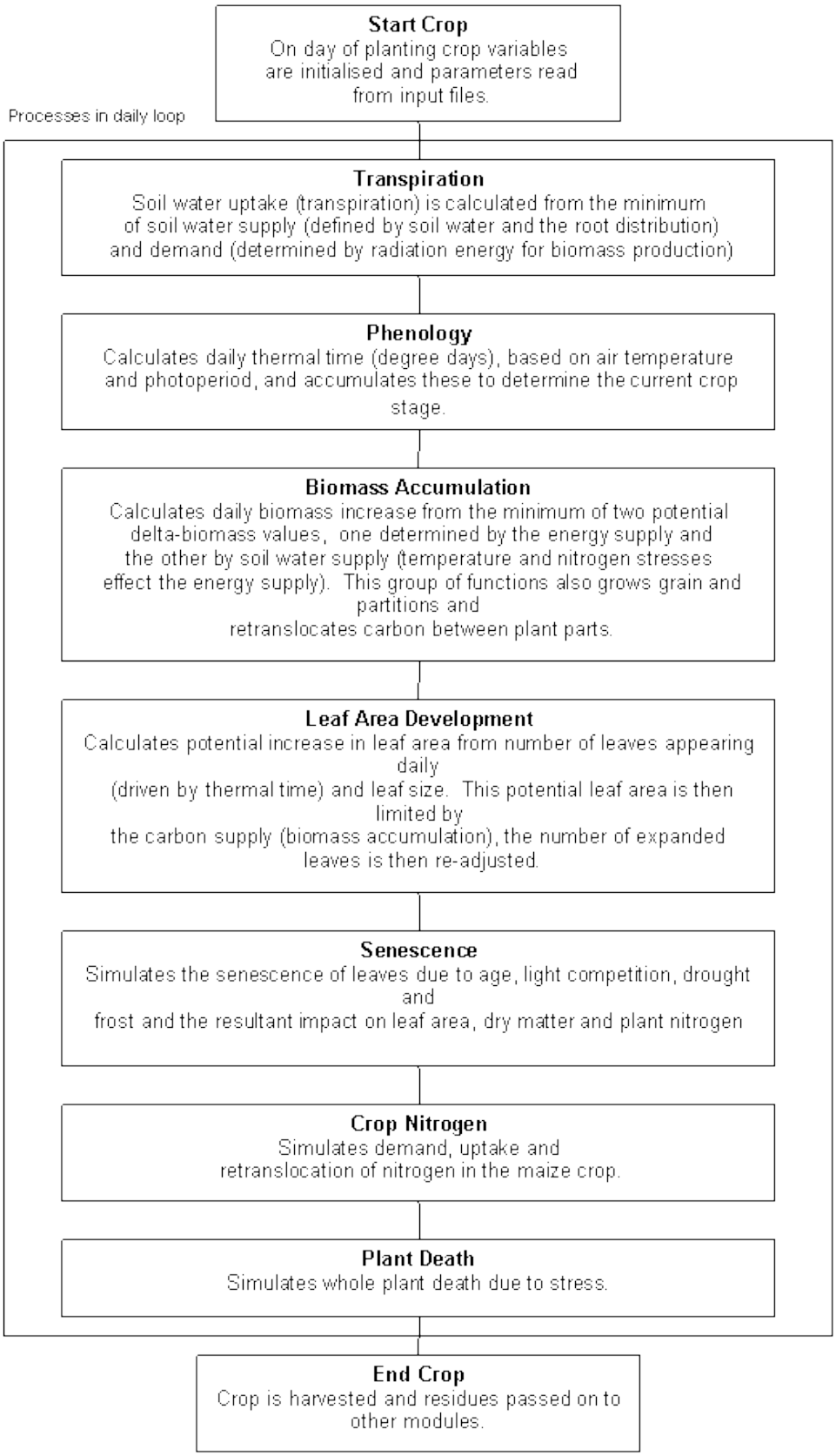
## Maize Module History

The maize module was developed from a combination of the approaches used in the CM-KEN (Keating et al., 1991, 1992) and CM-SAT (Carberry et al., 1989; Carberry and Abrecht, 1991) models of maize (both derivatives of CERES-Maize, Jones and Kiniry, 1986), with some features of the maize model of Wilson et al. (1995). The major differences from CERES-Maize are routines which kill crops in response to severe water deficit during the early- to mid-vegetative stage (Carberry and Abrecht, 1991).

Delay silking by severe water or nitrogen stress simulate leaf area development by accounting for relationships between total leaf number and leaf area (Muchow and Carberry, 1989; Keating and Wafula, 1991) allow thermal time to accumulated between 0 and 10 oC, thus permitting the accurate simulation of phenological development in cool temperate environments (Wilson et al., 1995).

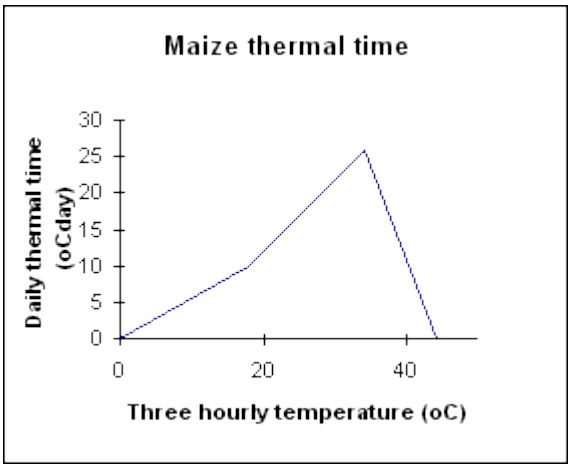
Determine transpiration based on biomass accumulation, a transpiration efficiency coefficient, daily vapour pressure deficit and a 0-1 soil water deficit factor. Uses a radiation-use efficiency based on above-ground biomass accumulation, and grows root biomass based on fixed root:shoot ratios for different phenological phases (Carberry et al. 1989) The model was validated on many of the same datasets that were originally used to develop CM-KEN and CM-SAT, in addition to new datasets (see Table below).

## Maize Module Structure



## Phenology

There are 11 crop stages and nine phases (time between stages) in the maize module, and commencement of each stage (except for sowing to germination which is driven by soil moisture) is determined by accumulation of thermal time. Each day the phenology routines calculate today's thermal time (in degee days) from 3-hourly air tempertures interpolated from the daily maximum and minimum temperatures. Thermal time is calculated using the relationship in Figure 1 with the eight 3-hour estimates averaged to obtain the daily value of thermal time (in growing degree days) for the day. These daily thermal time values are cumulated into a thermal time sum which is used to determine the duration of each phase. Between the stage of emergence and flowering the calculated daily_thermal_time is reduced by water or nitrogen stresses, resulting in delayed phenology when the plant is under stress.




The thermal time between sowing and germination is dependent upon soil water levels. The phase between germination and emergence includes an effect of the depth of sowing on the thermal time target. The duration between emergence and flag leaf appearance is determined by the total number of leaves destined to appear on the plant, and the rate at which they appear, which is determined by temperature (see below). The total number of leaves is equal to the number in the seed at germination (7) plus the number subsequently initiated at a rate of 21 o Cdays per leaf, until floral initiation is reached. Hence the timing of floral initiation will determine the total leaf number and the timing of the appearance of the flag leaf and flowering (i.e. silking). The phase between emergence and floral initiation is composed of a cultivar-specific period of fixed thermal time, commonly called the basic vegetative or juvenile phase. Between the end of the juvenile phase and floral initiation the thermal development rate is sensitive to photoperiod (calculated as a function of day of year and latitude) if the cultivar is photoperiod sensitive. The model assumes that maize, as a short day plant, will have a longer phase (dependent upon cultivar) between the end of the juvenile phase and initiation if photoperiods exceed 12.5 hours. There are cultivar-specific fixed thermal time durations for the subsequent phases between flowering and the start of grain fill, between the start and end of grainfill, between the end of grainfill and maturity, and between maturity and harvest ripe.

## Biomass accumulation (Photosynthesis)

Each day two estimates of the daily biomass production are calculated, one limited by available water for transpiraton (eqn 1), and the other limited by radiant energy (eqn 2). The minimum of these two estimates is the actual biomass production for the day. delta_drymatter_transpiration = soil_ water_ supply * transpiration_efficiency eqn 1. Note: transpiration_efficiency is derived from the transpiration_efficiency_coefficient (=0.009) and the vapour pressure deficit (vpd) estimated from daily temperatures. dlt_drymatter_potential = rue *radiation_interception eqn 2. Note rue

(radiation-use efficiency) is 1.6 g MJ-1 from emergence to the start of grain-filling, and then declines to 1.06 g MJ-1 from the start of grain filling to account for the effects of leaf aging on reduced photosynthetic capacity (Muchow et al. 1990). Radiation interception is calculated from leaf area index and a radiation extinction coefficient of 0.45.

## Biomass partitioning

Daily biomass production is partitioned to different plant parts in different ratios depending on crop stage. Until the end of juvenile phase the root:shoot ratio is maintained at 1.0, and then decreases to a value of 0.087 at flowering. Between emergence and flag leaf appearance the proportion of biomass produced that is partioned to leaf increases exponentially as leaves appear. Between the stage floral initiation and flag leaf appearance, the biomass remaining after allocation to leaf is allocated between stem and developing ear in the ration 1:0.30. After leaf growth has ceased at flag leaf appearance, biomass is partitioned between stem and ear only until the start of grain filling, whereuopon partitioning to grain only occurs. The maize module allows a total retranslocation of no more than 15 and 20% of leaf and stem biomass present at the start of grainfilling, respectively Grain demand for carbohydrate (biomass) is calculated by multiplying the grain number by the maximum potential grain growth rate (e.g. for Dekalb_XL82 10 mg/grain/day). The number of grains set per plant is determined by the average daily growth rate per plant between floral initiation and the start of grain filling, using the function developed by Edmeades and Daynard, (1979).

## Leaf development

Leaf appearance rate is driven by thermal time, the last 14 leaves before the flag leaf appear each 36 o Cdays, before which a leaf appears every 65 o Cdays (Wilson et al., 1995).

## Potential LAI

is a product of leaf number, leaf size, number of plants per m2 and the water stress factor for expansion (see water deficits section below). An adjustment factor is used to account for the area of currently expanding leaves. Leaf size is calculated from final leaf number assuming that it follows a bell-shaped distribution with leaf position along the stalk (Keating and Wafula, 1992). Early in crop development, before floral initiation is reached and hence before final leaf number is known, an estimated date of floral initiation is used to calculate a provisional final leaf number for the purposes of simulating leaf size.

## Actual LAI

is less than the potential LAI if there is not sufficient biomass partitioned to leaf on that day. Maximum specific leaf area (SLA_MAX) defines the maximum leaf area (m 2 ) that can be expanded per gram of biomass. SLA_MAX declines with increasing LAI i.e. smaller, younger crops have larger thinner leaves.

## Leaf senescence

There are four causes of leaf senesence; age, light competition, water stress and frost. The maize senescence routines calculate a senesced LAI for each stress each day and take the maximum of the four values as the day's total senescence. A fraction of the oldest green leaf dies each day after flowering. This senescence due to age occurs a rate of leaves per day (this is calculated from the day's thermal time divided by a constant leaf-death-rate). This number of dead leaves is then converted to a senesced LAI. Above an LAI of 4.0 light competition causes leaf area to be lost. The LAI senesced because of light competition is related to the amount LAI exceeds 4.0 (see eqns 3 and 4). sensLAI_light_fac = 0.008 *(LAI- 4.0) eqn 3. delta_sensLAI_light = LAI * sensLAI_light_fac eqn 4. Water stress during crop growth will cause

leaf senescense (eqns 5 and 6). sensLAI_water_fac = 0.05 * (1 - maize_swdef(photo)) eqn. 5. delta_sensLAI_water = LAI * sensLAI_water_fac eqn 6. Note: the calculation of the water stress factor maize_swdef(photo) is descibed in the 'water deficits' section below. Frost senescence. Temperatures between 6.0 and 0 o C will cause a linearly increaseing loss of leaf area from 0 to 100% respectively. From the values of senesced LAI the maize module calculates the biomass and nitrogen in that leaf area that is senesced, however a proportion of the carbon and nitrogen of these leaves is retranslocated to stem before senescence.

## Tillering

The potential tiller no. in the maize module has been set to 0, effectively disabling the tillering routine.

## Regrowth

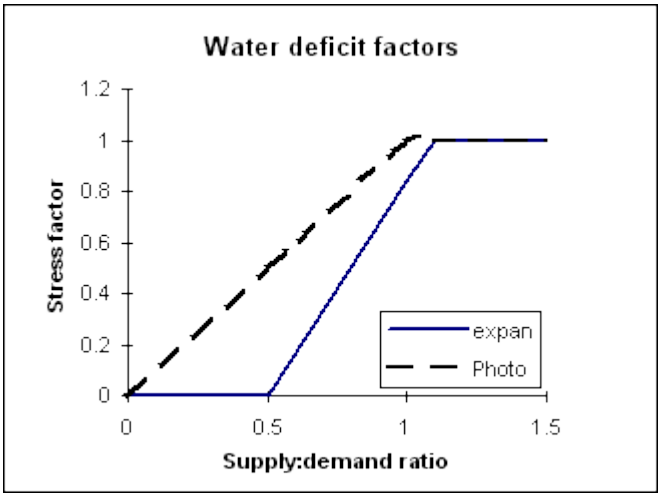
There are no regrowth routines in maize .

## Water uptake

To determine the amount of water supply to the crop on any day, first the total available water above the lower limit for all soil layers with roots is summed (eqn 7). If roots are only partially through a layer available soil water is scaled to that portion that contains roots. The kl constant (value differs for each soil layer) is then used to limit the amount of water available on any day (eqn 8). The kl factor is emphirically derived, incorporating both plant and soil factors which limit rate of water uptake. do layer = 1, deepest_layer (do loop to calculate available water for all layers) sw_avail = sw(layer) - ll (layer) eqn 7. sw_supply(layer) = sw_avail * kl (layer) eqn 8. Soil water demand is calculated as in the 'biomass accumulation' section above where potential biomass production is a function of radiation interception and rue . This potential biomass production is converted to water demand using transpiration efficiency. Transpiration efficiency is calculated from the transpiration effieicny coefficient ( transp_eff_cf ), which can vary with growth stage, and vapour pressure deficit. Soil water demand can be capped in the *.ini file by the atmospheric evaporative demand (eo) adjusted by the proportion of green canopy cover (cover_green) and a crop factor (eo_crop_factor) i.e. eo_crop_factor * eo * cover_green . Users wishing to use the eo_crop_factor should consult with the module owner. Water uptake is the minimum of the supply and demand.

## Water deficits affecting plant growth

Soil water deficit factors are calculated to simulate the effects of water stress on different plant growth processes. Three water deficit factors are calculated which correspond to four plant processes each having different sensitivity to water stress i.e. photosynthesis (photo), phenology (pheno), and leaf-expansion (expansion). A water availability ratio is calculated by dividing actual soil water supply (sw - ll) by the potential soil water supply (dul - ll). This ratio is used in the relationships illustrated to derive the stress factors for photosynthesis and leaf expansion. A factor of 0 is complete stress and 1 no stress.




A fraction of plants (0.044) will be killed each day due to water stress once the cumulative water stress factor for photosynthesis exceeds 4.6. Nitrogen uptake and retranslocation In order to calculate nitrogen demand today, first potential biomass production is re-calculated unlimited by water, nitrogen or temperature i.e. as a function of rue and radiation-interception (eqn 2). This dry matter (biomass) is then partition into plant parts according to their current relative weights. The maize module has a defined minimum, critical and maximum N concentration for each plant part. Demand for nitrogen in each part attempts to maintain nitrogen at the critical (non stressed) level. Nitrogen demand on any day is the sum of the demands from the pre-existing biomass of each part required to reach critical N content, plus the N required to maintain critical N concentrations in today's potentially assimilated biomass. A nitrogen uptake maximum is defined as the nitrogen uptake required to bring all plant part N contents to the maximum allowable concentration. Nitrogen supply is the sum of nitrogen available via mass flow (eqn 9) and by diffusion (eqn 10). no3_massflow (layer) = no3_conc * delta_sw (layer) eqn 9. no3_diffusion (layer) = sw_avail_frac *no3_conc eqn 10. note: these layer values are summed to root depth and sw_avail_frac is ratio of extractable soil-water over total soil-water. If nitrogen demand cannot be satisfied by mass flow then it is supplied by diffusion. Demand can only be exceeded by supply from mass flow (up to the nitrogen uptake maximum). If both mass flow and diffusion supplies can't satisfy demand then nitrogen is sought from N fixation (see next section). Nitrogen available for uptake is distributed to plant parts in proportion to their individual demands. Nitrogen for grain is retranslocated from other plant parts, N is not directly taken up from the soil or atmosphere to meet grain demand. Nitrogen is available for retranlocation from all parts except for grain and roots; other plant parts will translocate nitrogen until they reach their defined minimum N concentration. Grain nitrogen demand is again driven by critical N content but this demand is lowered if the plant is under N stress. Grain N demand is also affected by temperature and water stress using eqns 11 and 12 below. N_grain_temp_fac = 0.69 + 0.125 * aver_temp equ 11. N_grain_sw_fac = 1.125 - 0.125 * swdef (expansion) eqn 12. The greatest of these two factors is multiplied by the previously calculated N demand i.e. if temperature is high or sw deficit is low (water stressed) the N demand will be increased above the level required to reach the critical N concentration.

## N fixation

There is no nitrogen fixation in the maize module.

## Nitrogen deficits affecting plant growth

There are three N availability factors (0-1), one each for the photosynthesis, expansion, phenology and grain filling processes. A N concentration ratio is calculated for the stover (stem + leaf) in eqn 14 which is used as a measure of N

stress, then different constants are used to convert that ratio to a deficit factor for each of the processes. A factor of 1 is used for effecting grain N concentration, 1.25 for photosynthesis (reduces rue), 0.8 for expansion (reduces leaf area expansion) and 5.75 to slow phenological development. As a value of 1 is no stress and 0 complete stress, phenology is least sensitive to nitrogen deficiency and grain N the most.

N_conc_ratio = (N_conc_stover - N_conc_stover_min) / (N_conc_stover_crit - N_conc_stover_min) eqn14.

## Root growth and distribution

Root depth is initialised at the depth of sowing. Between emergence and grain filling, the increase in root depth is a daily rate multiplied a soil water availability factor. The daily rate is 10-15 mm/day during emergence and 33mm/day from end-of-juvenile to the start of grain-filling. Root depth is constrained by the soil profile depth. The increase of root depth through a layer can be constrained by known soil constraints through the use of the 0-1 parameter xf, which is input for each soil layer. Growth of root biomass is partitioned with depth using an exponential decay function from the soil surface and converted to root length density using a fixed specific root length. Roots are not senesced during the life of the crop, but are incorporated in the soiln module at harvest and distributed as fresh organic matter in the profile

## Temperature stress

There are no generic temperature factors, as for water and nitrogen stress, but as discussed in sections above temperature does influence grain N content, rate of senescence and radiation use efficiency (rue).

## Plant death

All or some of the plants can be killed due to a variety of stresses; If the crop hasn't germinated within 40 days of sowing, due to lack of germinating moisture, all plants are killed. If the crop does not emerge with 150 o Cdays of sowing, because it was sown too deep, then all plants are killed. If crop is past floral initiation and LAI = 0, then all plants are killed due to total senescence. If the cumulative phenological water stress factors exceed 25, all plants are killed due to water stress prolonging phenology. A fraction of plants will be killed by high temperatures immediately following emergence.

## Detachment

The detachment routines in maize are disabled in the current code.

## Maize Module Parameterisation

Crop lower limit and kl values are need for each soil layer

ll = 0.200 0.200 0.200 0.220 0.250 () ! crop lower limit

kl = 012 0.08 0.06 0.04 0.02 () ! kl need calibrating for each crop and soil type

Phenology and grainfilling parameters are needed for each cultivar. An example is given below of those for the katumani composite cultivar. Some of the parameters are not used in the current version, as they can be used in alternative options for simulating some processes (e.g. grain filling). (indicated below as option).

**calibration.maize.katumani**

| | |
|---|---|
| hi_incr | 0.018 (1/days) |
| hi_max_pot | 0.55 (g/g) |
| head_grain_no_max | 450 () |
| grain_gth_rate | 10.5 (mg/grain/day) |
| tt_emerg_to_endjuv | 150( o C day) |
| est_days_endjuv_to_init | 20 () |
| pp_endjuv_to_init | 10 |
| tt_endjuv_to_init | 0.0 ( o C day) |
| photoperiod_crit1 | 12.5 (hours) |
| photoperiod_crit2 | 24.0 (hours) |
| photoperiod_slope | 10.0 ( o C/hour) |
| tt_flower_to_maturity | 660 ! ( o C day) |
| tt_flag_to_flower | 10 ( o C day) |
| tt_flower_to_start_grain | 120 ( o C day) |
| tt_maturity_to_ripe | 1 ( o C day) |

## Module Dependencies

The minimum module configuration required to run maize in APSIM is the inclusion of the report, input, manager, soilwat, soiln and residue and maize modules. Soilwat2, soiln2 and residue2 can be used instead of the original modules.

## Crop Sowing and Harvesting Logic

Within the manager file the following syntax is used for harvest and planting the maize crop: if (maize.stage_name = 'harvest_ripe' and maize.plant_status = 'alive') then maize harvest maize kill_crop maize end_crop endif if (maize.plant_status = 'dead') then report do_output maize harvest maize end_crop endif if (day > 120 and day < 240 and maize.plant_status = 'out' ) then maize sow plants = 15 (p/m2), sowing_depth = 50 (mm), row_spacing = 0.35 (m), cultivar = katumani, fertile_tiller_no = 0 endif (note: row_spacing in sowing command is optional)

## Skip Row Planting

maize sow plants = 15 (p/m2), sowing_depth = 50 (mm), row_spacing = 0.35 (m), cultivar = katumani, fertile_tiller_no = 0, skip = single Skip row planting can be specified by using the skip keyword on the sowing command with a value of “single”, “double” or “solid”. A single skip has two crop rows followed by a single unplanted row whereas a double skip has two crop rows followed by two unplanted rows. A solid planting behaves as it no skip row information has been specified. Currently, the change to light interception is the only effect of the skip planting on the crop growth. Maize Module Outputs The following Maize variable can be output through the report module

| ===Variable Name=== | Units | Description |
|---|---|---|
| stage | | current phenological stage |
| stage_code | | |
| stage_name | | |
| crop_type | | |
| leaf_no | | number of fully expanded leaves |
| leaf_no_dead | | no of dead leaves |
| leaf_area (max_leaf = 1000) | mm 2 | leaf area of each leaf |
| height | mm | canopy height |
| root_depth | mm | depth of roots |
| rlv | mm.mm -3 | root length per volume of soil in each soil layer |
| hi | | Harvest index |
| plants | plants/m 2 | plant density |
| grain_no | grains/plant | grain number |
| grain_size | g | individual grain wt |
| cover_green | 0-1 | fraction of radiation reaching the canopy that is intercepted by green leaves |
| cover_tot | 0-1 | total crop cover fraction |
| lai_sum | | leaf area index of all leaf material live + dead |
| tlai | | tot lai |
| slai | | area of leaf that senesces from plant |
| lai | m 2 /m 2 | live plant green lai |

| | | |
|---|---|---|
| tlai_dead | m 2 /m 2 | total lai of dead plants |
| root_wt | g/m 2 | root biomass |
| leaf_wt | g/m 2 | leaf biomass |
| stem_wt | g/m 2 | stem biomass |
| grain_wt | g/m 2 | grain biomass |
| grain_wt | g/m 2 | grain biomass |
| dm_green (max_part = 6) | g/m 2 | live plant dry weight (biomass) |
| dm_senesced (max_part = 6) | g/m 2 | senesced plant dry wt |
| dm_dead (max_part = 6) | g/m 2 | dry wt of dead plants |
| yield | kg/ha | grain yield dry wt |
| biomass | kg/ha | total above-ground biomass |
| stover | kg/ha | above-ground biomass not including grain |
| dlt_dm | g/m 2 | the daily biomass production |
| dlt_dm_green (max_part = 6) | g/m 2 | plant biomass growth |
| n_green (max_part = 6) | g/m 2 | plant nitrogen content |
| n_senesced (max_part = 6) | g/m 2 | plant n content of senesced plant |
| n_dead (max_part = 6) | g/m 2 | plant n content of dead plants |
| dlt_n_green (max_part = 6) | g/m 2 | actual n uptake into plant |
| dlt_n_retrans (max_part = 6) | g/m 2 | nitrogen retranslocated out from parts to grain |
| dlt_n_detached (max_part = 6) | g/m 2 | actual n loss with detached plant |
| dlt_n_dead_detached (max_part = 6) | g/m 2 | actual n loss with detached dead plant |
| swdef_pheno | 0-1 | water deficit factor for phenology |
| swdef_photo | 0-1 | water deficit factor fo photosynthesis |
| swdef_expan | 0-1 | water deficit factor for leaf expansion |
| ep (num_layers) | mm | water uptake in each layer |
| cep | mm | cumulative water uptake |
| sw_demand | mm | total crop demand for water |

| | | |
|---|---|---|
| sw_supply | mm | total supply over profile |
| esw_layer (num_layers) | mm | plant extractable soil water |
| n_conc_stover | % | sum of tops actual n concentration |
| n_conc_crit | % | sum of tops critical n concentration |
| n_grain_pcnt | % | grain n concentration percent |
| n_uptake_grain | g/m 2 | n uptake by grain |
| n_uptake | g/m 2 | cumulative total n uptake by plant |
| n_uptake_stover | g/m 2 | n uptake by stover |
| no3_tot | g/m 2 | total no3 in the root profile |
| n_demand | g/m 2 | sum n demand for plant parts |
| n_supply | g/m 2 | n supply for grain |
| n_supply_soil | g/m 2 | n supply from soil |
| n_fix_pot | g/m 2 | potential N fixation |
| nfact_photo | | N deficit factor for photosynthesis |
| nfact_grain | | N deficit factor for grain N content |
| nfact_photo | 0-1 | Nitrogen stress factor for photosynthesis |
| nfact_expan | 0-1 | Nitrogen stress factor for cell expansion |
| dlt_tt | o Cday | daily thermal time |
| das | | days after sowing |

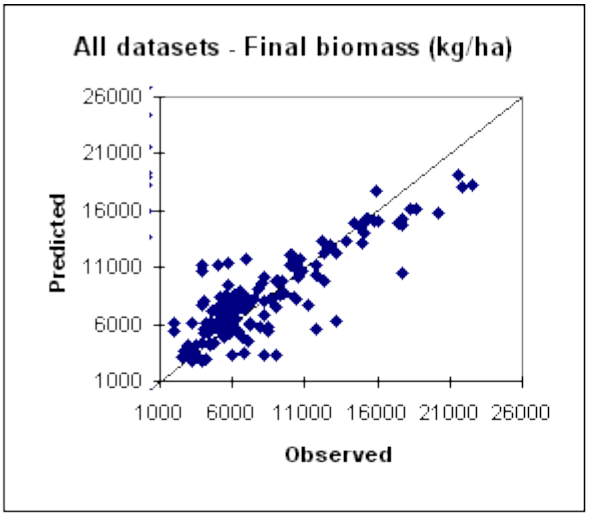
## Maize Module validation

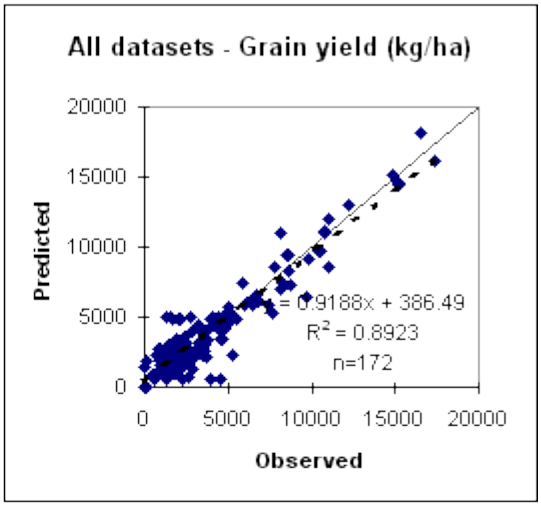
The maize model was validated against a wide range of datasets originating from tropical and sub-tropical Australia , semi-arid Kenya and USA (Table 1). Overall model performance with a combined set of this data is presented in the following figure. Overall, model performance was good, particularly for grain yield, usually the most important variable to be simulated. The range in grain yield covered 0 to 17.3 t ha -1 . The r-squared value for observed versus predicted grain yield was 89%.

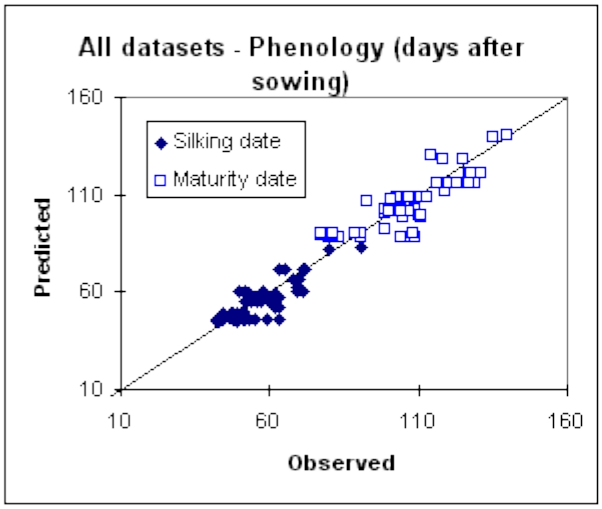
*Table 1: Details of datasets used to validate the maize crop module.*

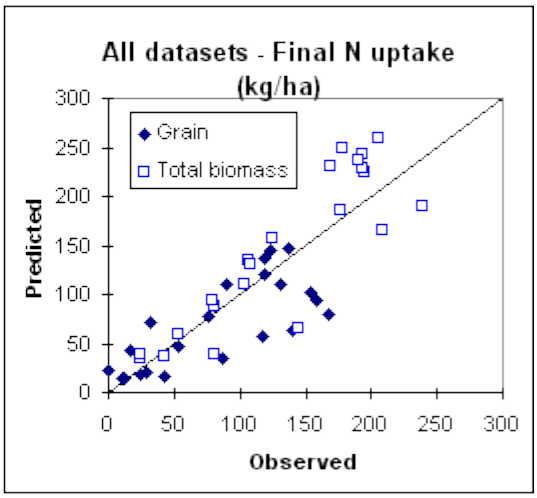
| Factors | Location | Reference |
|---|---|---|

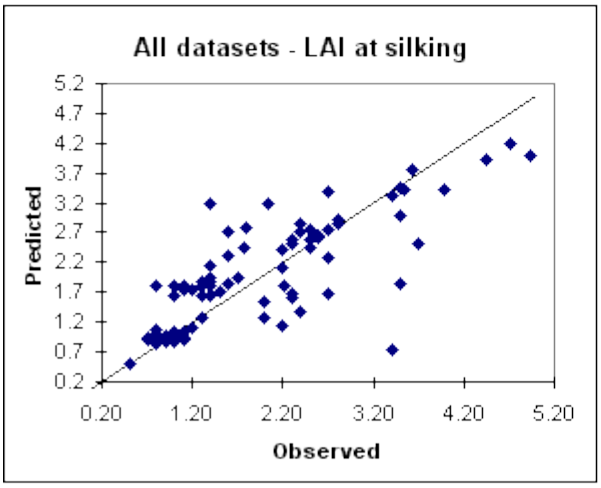
| | | |
|---|---|---|
| Sowing date, water supply, N fertiliser rate, plant population density | Tropical Australia | Muchow (1989a,b), Carberry et al., (1989), Sinclair and Muchow (1995) |
| Sowing date, N fertiliser rate | Sub-tropical Australia | Wilson , et al. (1995), Muchow (1994) |
| Sowing date, N fertiliser rate, variety, water supply, plant population density | Semi-arid Kenya | Keating et al. (1992) |
| Sowing date, plant population density | USA | Muchow et al. (1990) |

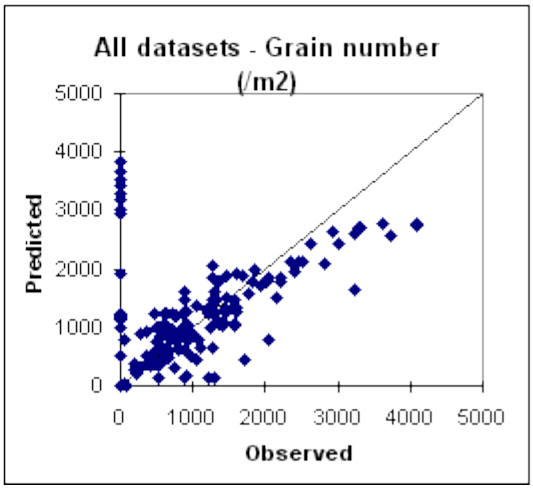


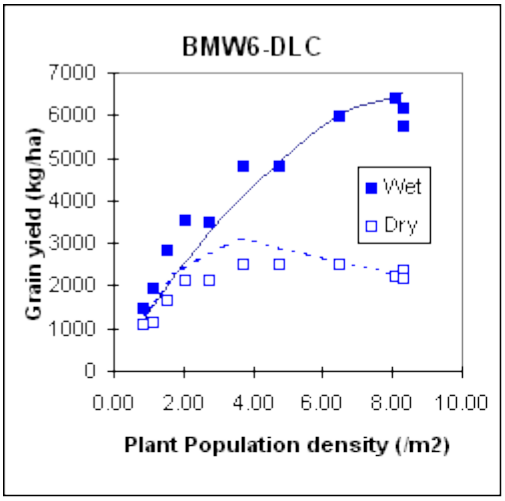



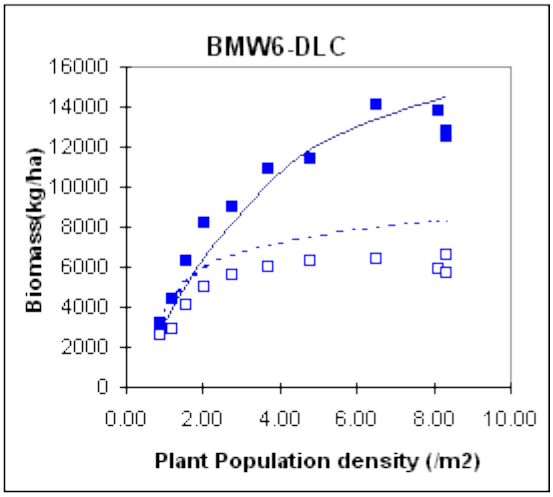



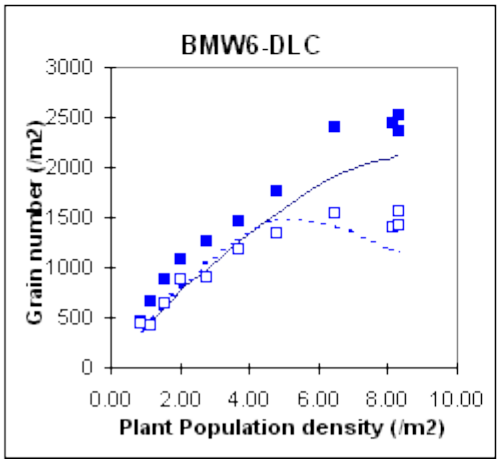



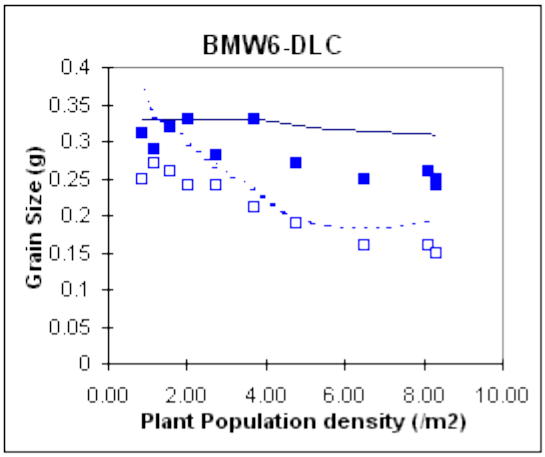




Inspection of model performance for individual experiments shows that it is simulating the key responses to major agronomic variables. For example the following figures show the model performance for responss to plant population density under both deficit and favourable water (bmw6 experiment conducted at Katumani, Kenya with both the dryland composite DLC and Katumani composite KCB cultivars) and nitrogen (jmw2 experiment conducted at Kiboko, Kenya with the KCB cultivar) supply.

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# Millet

## MILLET MODULE SCOPE

The millet module simulates the growth and development of a pearl millet crop in a daily time step. The module is specifically designed to deal with the tillering nature of the millet crop.

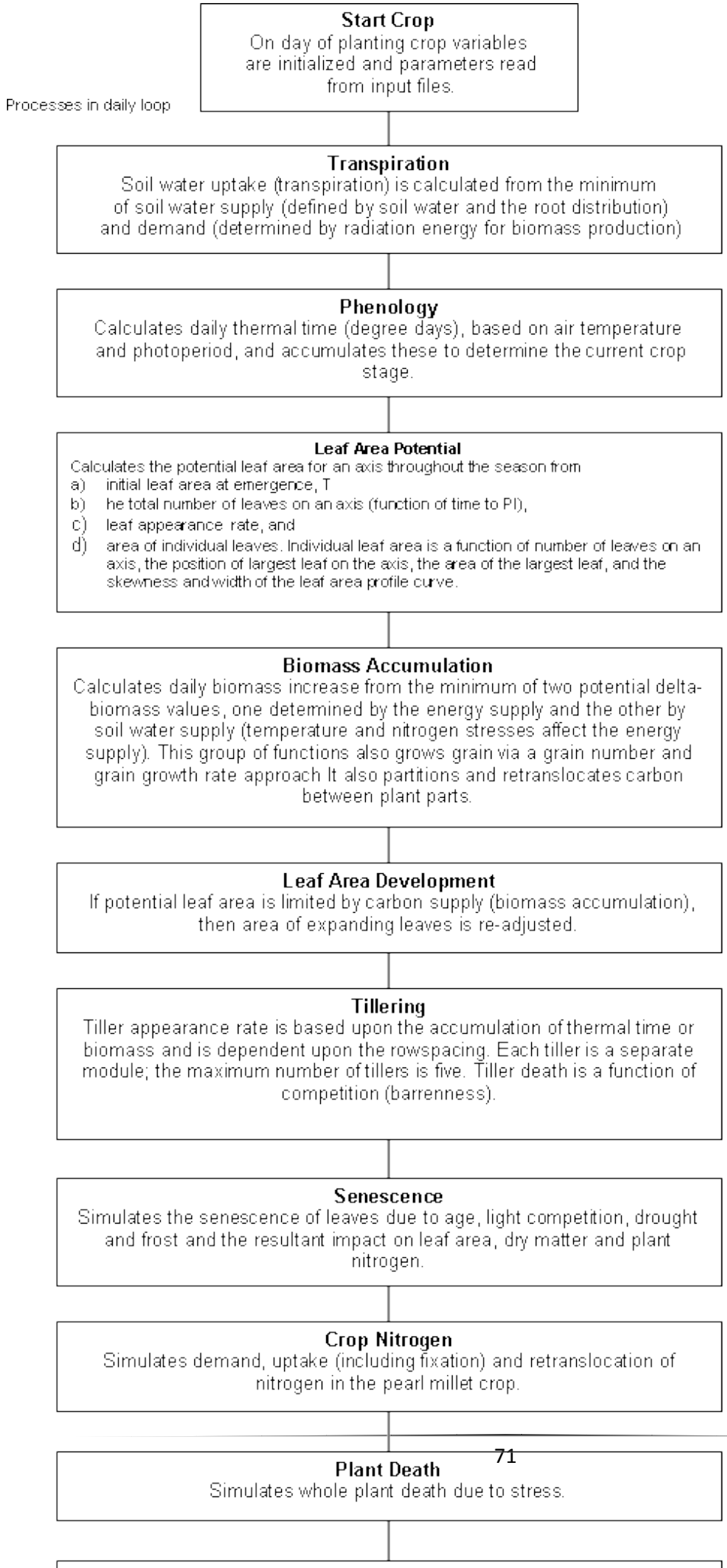
Each axis of the crop is considered to be a different crop, and the competition for resources between the axes is simulated analogous to an intercrop. Pearl millet growth responds to climate (temperature, rainfall, radiation), soil water supply (from soilwat2 module), and soil nitrogen (from soiln2 module)and returns information on soil water and soil nitrogen to the soilwat2 and soiln2 modules on a daily basis for resets of these systems.

Information on crop cover is also provided to the soilwat2 module to calculate evaporation rates and runoff. Pearl millet stover and root residues are passed from millet to the residue2 and soiln2 module respectively at harvest of the millet crop.

A list of the module outputs is provided in the 'Millet module outputs' section towards the end of the document. The module simulates biomass (above and below ground), grain yield, leaf area development, N-contenets for individual plant parts, and yield components, all on a daily time step for individual axes.

## MILLET MODULE HISTORY

The module was adapted from CERES-MAIZE, and is currently very similar to the Crop template in APSIM. The major difference with any other module in APSIM is that it simulates the growth and development of individual tillers, by considering the entire crop as an intercrop of the different axes. The module has been parameterised based on data from experiments conducted at the ICRISAT research station at Patancheru , India , under optimum growing conditions, covering a range of plant densities and genotypes (van Oosterom et al., 2001a and b). The module adequately predicts biomass, grain yield, and LAI across a range of plant densities, photoperiods, and genotypes. However, all the validation data sets were obtained from experiments conducted at Patancheru.


Start Crop
On day of planting crop variables are initialized and parameters read from input files.
Processes in daily loop
Transpiration
Soil water uptake (transpiration) is calculated from the minimum of soil water supply (defined by soil water and the root distribution) and demand (determined by radiation energy for biomass production)
Phenology
Calculates daily thermal time (degree days), based on air temperature and photoperiod, and accumulates these to determine the current crop stage.
Leaf Area Potential
Calculates the potential leaf area for an axis throughout the season from
a) initial leaf area at emergence, T
b) he total number of leaves on an axis (function of time to PI),
c) leaf appearance rate, and
d) area of individual leaves. Individual leaf area is a function of number of leaves on an axis, the position of largest leaf on the axis, the area of the largest leaf, and the skewness and width of the leaf area profile curve.
Biomass Accumulation
Calculates daily biomass increase from the minimum of two potential delta-biomass values, one determined by the energy supply and the other by soil water supply (temperature and nitrogen stresses affect the energy supply). This group of functions also grows grain via a grain number and grain growth rate approach It also partitions and retranslocates carbon between plant parts.
Leaf Area Development
If potential leaf area is limited by carbon supply (biomass accumulation), then area of expanding leaves is re-adjusted.
Tillering
Tiller appearance rate is based upon the accumulation of thermal time or biomass and is dependent upon the rowspacing. Each tiller is a separate module; the maximum number of tillers is five. Tiller death is a function of competition (barrenness).
Senescence
Simulates the senescence of leaves due to age, light competition, drought and frost and the resultant impact on leaf area, dry matter and plant nitrogen.
Crop Nitrogen
Simulates demand, uptake (including fixation) and retranslocation of nitrogen in the pearl millet crop.
Plant Death
Simulates whole plant death due to stress.

# MILLET MODULE COMPONENTS

## Phenology

There are 11 crop stages and ten phases (time between stages) in the millet module. Commencement of each stage is determined by accumulation of thermal time, except for sowing to germination which is driven by soil moisture. Each day the phenology routines calculate today's thermal time (in degree days) from 3-hourly air temperatures interpolated from the daily maximum and minimum temperatures. Thermal time is calculated using 10°C, 33°C, and 47°C as the base, optimum, and maximum temperature, with linear interpolations between these points. The eight 3-hourly estimates are averaged to obtain the daily value of thermal time. These daily values are summed into a thermal time sum which is used to determine the duration of each phase. Between the stage of emergence and flag leaf, the calculated daily thermal time is reduced by water or nitrogen stresses, resulting in delayed phenology when the plant is under stress. The duration and timing of most crop phases are determined by genotype- and axis-specific, fixed thermal time values input in the millet.par file. Sowing to germination is dependent on soil water levels; the phase germination_to_emergence includes an effect of sowing depth on the thermal time target; and the phase between end_of_ juvenile and floral initiation is determined by a cultivar's photoperiod (daylength) sensitivity - note that pearl millet is a short-day plant. The crop phases from germination to maturity and their thermal time duration for cv. BJ104 (main shoot) are listed below.

tt(germ to emerg) = 10.7 °Cd+ (sowing depth * 1.17) °Cdays (sowing depth in mm)

tt(emerg_end_juvenile) = 239 °Cdays

tt(end_juvenile_floral-intiation) = 112 * active photoperiod °Cdays (base photoperiod 12.9 h)

tt(emergence_to_flag leaf) = leaf number * 36.4 °Cdays

tt(flagleaf_to_flowering) = 66.1 °Cdays

tt(flowering_to_start-grainfill) = 80 °Cdays

tt(flowering_to_maturity)= 457 °Cdays

tt(maturity to harvest-ripe) = 1 °Cdays

The period between flowering and maturity is divided into three phases. The first phase, which covers the period from flowering to the start of grain filling, is genotype-specific (see above). The third phase is the period from end of grain filing until maturity, and is set to 5% of the total period. The actual grain growth phase is finally calculated as the difference between the duration of the total period and the other two phases.

The final leaf number on the main shoot is calculated as the sum of the number of leaves present in the seed (four) and the product of the time from germination to end juvenile and the leaf initiation rate (27.2 °Cd/leaf). For tillers, however, leaf number is estimated from the leaf number on the main shoot, as detailed data on time from initiation to end juvenile are not available for tillers. In general, tiller 1 (which appears from axil of leaf 3) has 4 leaves less than the main shoot.

### Biomass accumulation (Photosynthesis)

Each day two estimates of the daily biomass production are calculated, one limited by available water for transpiration (eqn. 1), and the other limited by radiant energy (eqn. 2). The minimum of these two estimates is the actual biomass production for the day

dlt_dm_transp = sw_supply_sum * millet_transp_eff (1)

In this equation, sw_supply_sum is the total water supply over all soil layers where roots are present. Transpiration efficiency (TE) is derived from the TE coefficient and the vapour pressure deficit (vpd), which in turn is estimated from daily temperatures.

dlt_drymatter_potential = rue *radiation_interception (2)

Radiation use efficiency (RUE) is calculated as:

rue = rue(current_phase) * millet_rue_reduction (3)

rue(current_phase) is 1.9 before anthesis and 1.4 thereafter. The rue reduction is a factor that incorporates temperature and nitrogen stresses. Radiation interception is a function light interception by the crop and daily radiation.

## Biomass partitioning

Daily biomass production is partitioned to different plant parts; the ratios depend on the crop stage.

## Roots

Roots are grown daily in a fixed proportion to the tops production. This proportion (root shoot ratio) is specified for each growth stage and declines from 1.0 beforel panicle initiation to 0.0 from the start of grain filling onwards:

| eme | juv | PI | flag | flow |
|---|---|---|---|---|
| 1 | 1 | 0.33 | 0.33 | 0.087 |

Between **emergence and panicle initiation** , 67% of the biomass is allocated to the leaves, and 33% to the stems, which include the leaf sheath.

Between **panicle initiation and flag leaf** , stem elongation and flower development start. Therefore, partitioning to leaves declines linearly from 67% at panicle initiation to 0% at flag leaf. If the amount of carbon partitioned to leaves is more than is required for the calculated increase in leaf area (the leaves have a maximum thickness) then the residual is partitioned to flowers and stems:

dlt_dm_green(flower) = (dlt_dm_axis - dlt_dm_green(leaf)) * frac_stem2flower (4)

where frac_stem2flower is set to 0.19.

dlt_dm_green(stem) = dlt_dm_axis - (dlt_dm_green(leaf) + dlt_dm_green(flower)) (5)

If the carbon partitioned to leaves is insufficient to grow the potential increase in leaf area, leaf area increase is reduced (see leaf area development section).

Between **flag leaf and start of grain filling,** only stems and flowers grow. It is assumed that 19% of the produced dry matter is allocated to flowers and 81% to stems.

Between the **start of grain filling and maturity,** biomass is partitioned to grains, whereas stems will continue growing if they can. Grain demand for carbohydrate (biomass) is driven by grain number and grain growth rate. Grain number is a

function of the rate of dry matter accumulation between the flag leaf stage and the start of grain filling. Grain growth rate is limited by temperature and drought stress. It is genotype specific and thus accounts for genotypic differences in grain mass and harvest index.

## Biomass retranslocation

If the grain demand for carbohydrate cannot be met through partitioning of daily biomass production, it is retranslocated from other plant parts to meet (if possible) this grain demand. The carbohydrate in stem and leaf that is available for transfer, is calculated from the difference between potential and minimum weight for stem and leaf. Dry matter is first translocated from the stems; if not all the demand can be met, the remaining dry matter will be translocated from the leaves.

## Leaf development

**Potential leaf area.** Potential crop leaf area is simulated from the area of individual leaves. Leaf area might be reduced if insufficient dry matter is produced in the subsequent routine on biomass accumulation.

First, leaf area is initialised at emergence and the final leaf number (on an axis) is calculated. Final leaf number is calculated at panicle initiation, but an approximate number is set at germination to allow other calculations to proceed until the correct number is known. The number of fully expanded leaves throughout the season is calculated from the appearance rate of fully expanded leaves, which is set at 36.4 °Cdays. An adjustment in leaf number is made to account for the area of the expanding leaves. Individual leaf area is calculated from a cubic function:

Y=Y 0 exp(a(X-X 0 ) 2 +b(X-X 0 ) 3 ) (6)

where Y = mature leaf area of individual leaf, Y 0 = mature area of largest leaf, X 0 = position of largest leaf, a = empirical constant determining the breadth of the leaf area profile curve, b = empirical constant determining the skewness of the leaf area profile. The four coefficients (X 0 , Y 0 , a, b) are functions of final leaf number. Parameter Y 0 is genotype-, density-, and axis-specific, whereas the other parameters are mainly axis-specific.

Because of sensitivity of cell expansion to water deficits, leaf area development is reduced under drought stress.

Actual leaf area . The actual LAI is less than the potential if there is not sufficient biomass partitioned to leaves on that day. The maximum specific leaf area (sla_max) defines the maximum leaf area (m 2 ) that can be expanded per gram of leaf biomass. The maximum SLA is set to 650 cm 2 /g 1 if LAI (for an individual axis) < 2, and declines linearly to 450 cm 2 /g 1 if LAI (for an individual axis) drops from 2.0 to 5.0.

Leaf senescence. The number of senesced leaves on an axis is a linear function of time, although the slope of the function is higher before flag leaf stage (0.0167 leaves/°Cd) than after (0.0120 leaves/°Cd). The slopes are independent of genotype and axis, but the onset of senescence is later in tillers than in the main shoot.

The senesced leaf area (as a function of age) for each axis is calculated from the senesced leaf number. In addition, senesced leaf area is calculated as a function oflight competition, water stress, and temperature stress. The maximum of these four is used as the actual leaf area that has sensesced during that particular day.

## Tillering

**Tiller appearance** . Tillering starts at 150 o Cd, at a rate of 34 o Cd per tiller. Tillers may appear until flag leaf stage, but the maximum tiller number is set to 5. A switch gives the option to make tillering a function of thermal units or dry

matter. At the moment, it is driven by thermal units. The rate of tiller appearance is not dependent on genotype, as genotypic differences in tillering are a result of differences in tiller survival, rather than tiller appearance.

**Tiller death** . Tillers that capture insufficient resources to produce a panicle are killed at the start of grain filling. The mechanism employed is barrenness, a condition where the tiller will not set any grain, because the average growth rate between flag leaf and start grain filling is below a critical value, which is currently set at 0.10 g/plant/day.

## Regrowth

There are no regrowth routines in **millet**

## Water uptake

To determine the amount of water supply to the crop on any day, first the total available water above the lower limit for all soil layers with roots is summed (eqn. 7). If roots are only partially through a layer, available soil water is scaled to that portion that contains roots. The kl constant (value differs for each soil layer) is then used to limit the amount of water available on any day (eqn. 8). The kl factor is empirically derived, incorporating both plant and soil factors which limit rate of water uptake. Figure 1 shows how kl limits water uptake as soil water approaches the lower limit.

do layer = 1, deepest_layer (do loop to calculate available water for all layers)

sw_avail = sw(layer) - ll (layer) (7)

sw_supply(layer) = sw_avail * kl (layer) (8)

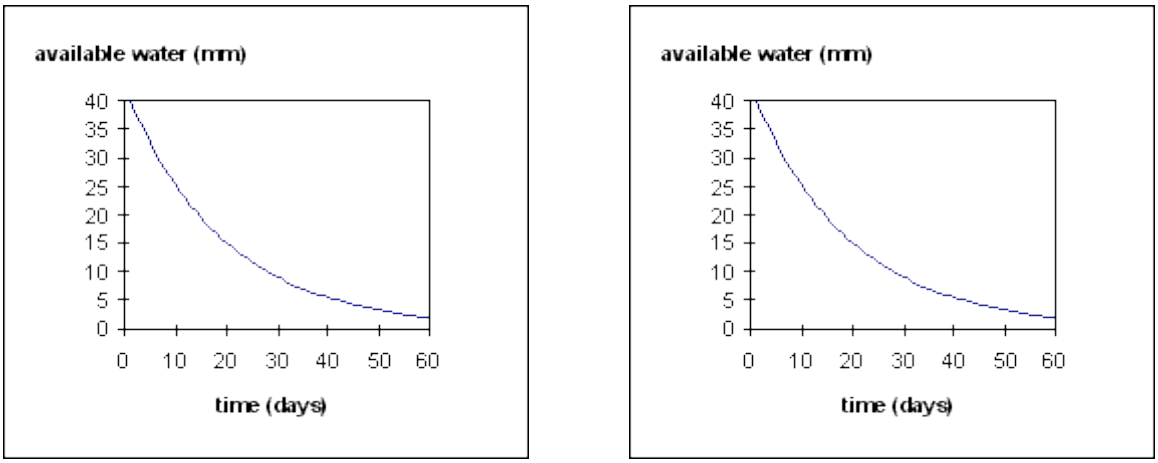



*Figure 1:Relationship between water availability and rate of water extraction as determined by the kl value. Soil water demand is calculated as in the 'biomass accumulation' section above where potentail biomass production is a function of light interception and rue (eqn. 3). This potential biomass production is converted to water demand using transpiration efficiency. sw_demand = dlt_dm_pot / millet_transp_eff (9) Water uptake is the minimum of the supply and demand.*

## Water deficits affecting plant growth

Soil water deficit factors are calculated to simulate the effects of water deficits on different plant growth processes. Three water deficit factors are calculated which correspond to three plant processes each having different sensitivity to water stress: photosynthesis (photo), phenology (pheno), and leaf-expansion (expansion). The effect of water deficits on phenology is a function of the water availability ratio, which is calculated by dividing the available soil water (soil water (sw) - lower limit (ll)) by the potential available soil water (drained upper limit (dul) - lower limit (ll)) (Fig 2a). A factor of 0 is complete stress and 1 no stress. For photosynthesis and leaf expansion , the effect of water deficits is a function of

the soil water demand ratio, which is calculated as the soil water supply divided by the demand (Fig. 2b). The relationships in Fig. 2b reflect the greater sensitivity of leaf expansion (as compared to photosynthesis) to drought.

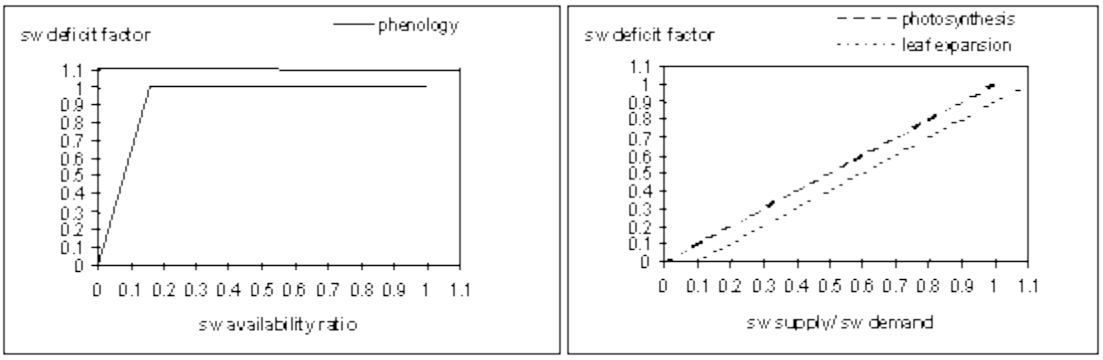



*Figure. 2 a:* Soil water deficit factor for phenology as a function of the soil water availability ratio. b) soil water deficit factors for photosynthesis and leaf expansion as a function of soil water supply/demand ratio.

## Nitrogen uptake and retranslocation

In order to calculate nitrogen demand today, first potential biomass production is re-calculated unlimited by water, nitrogen or temperature i.e. as a function of rue and radiation-interception (eqn. 3). This dry matter (biomass) is then partition into plant parts according to their current relative weights. The millet module has a defined minimum, critical and maximum N concentration for each plant part. Demand for nitrogen in each part attempts to maintain nitrogen at the critical (non stressed) level. Nitrogen demand on any day is the sum of the demands from the pre-existing biomass of each part required to reach critical N content, plus the N required to maintain critical N concentrations in today's potentially assimilated biomass. A nitrogen uptake maximum is defined as the nitrogen uptake required to bring all plant part N contents to the maximum allowable concentration. Nitrogen supply is the sum of nitrogen available via mass flow (eqn. 10) and by diffusion (eqn. 11). no3_massflow (layer) = no3_conc * delta_sw (layer) (eqn. 10) no3_diffusion (layer) = no3_conc * sw_avail_frac (eqn. 11) where sw_avail_frac is ratio of extractable soil-water over total soil-water. The layer values are summed to root depth. If nitrogen demand cannot be satisfied by mass flow then it is supplied by diffusion. Uptake of N above the critical concentration can only occur through mass flow. Excess N can be stored in plant parts as concentration above the critical N-concentration but below the maximum concentration. Nitrogen available for uptake is distributed to plant parts in proportion to their individual demands. Nitrogen for grain is retranslocated from other plant parts and is thus not directly taken up from the soil or atmosphere to meet grain demand. Nitrogen is available for retranslocation from all parts except grain and roots; all other plant parts will translocate nitrogen until they reach their defined minimum N concentration. Grain nitrogen demand is again driven by critical N content but this demand is lowered if the plant is under N stress. Grain N demand is also affected by temperature and water stress using eqns. 12 and 13 below: N_grain_temp_fac = 0.69 + 0.0125 * aver_temp (eqn. 12) N_grain_sw_fac = 1.125 - 0.125 * millet_swdef (expansion) (eqn. 13) The greatest of these two factors is multiplied by the previously calculated N demand i.e. if temperature is high or drought occurs, the N demand will be increased above the level required to reach the critical N concentration.

## N fixation

No N fixation is assumed to occur (N fixation rate = 0.0). Nitrogen deficits affecting plant growth N availability factors (0-1) are calculated for the following processed: 1) grain N potential, 2) photosynthesis, 3) leaf senescence, grain N concentration, and cell expansion, 4) grain number. The N-concentration ratio which is calculated for the stover (stem + leaf) in eqn 14 is used as a measure of N stress: N_conc_ratio = (N_conc_stover - N_conc_stover_min) /

(N_conc_stover_crit - N_conc_stover_min) (eqn.14) Different constants are used to convert this ratio to a deficit factor for each of the processes: N_def = N_fact_(process) * N_conc_ratio (eqn. 15) where N_factor equals 1.25 (photosynthesis), 1.0 (grain concentration), 10.0 (phenology). As lower values of N_deficiency indicate more stress, phenology is least sensitive to nitrogen deficiency and grain N the most.

## Root growth and distribution

Root depth is initialised at 110 mm. Between emergence and grain filling, the increase in root depth is a daily rate (20 mm/day) multiplied a soil water availability factor. Root depth is constrained by the soil profile depth. Growth of root biomass is unrelated to depth and is as described in the 'biomass partitioning' section above. Roots are not senesced during the life of the crop, but are incorporated in the soiln2 module at harvest and distributed as fresh organic matter in the profile according to an exponential relationship of depth and root biomass.

## Temperature stress

There are no generic temperature factors, as for water and nitrogen stress, but as discussed in sections above temperature does influence grain N content, rate of senescence and radiation use efficiency (rue).

## Plant death

All or some of the plants can be killed due to a variety of stresses; If the crop hasn't germinated within 40 days of sowing, due to lack of germinating moisture, all plants are killed. If the crop does not emerge with 150 o Cdays of germination, because it was sown too deep, then all plants are killed. If crop is past floral initiation and LAI = 0, then all plants are killed due to total senescence. If the cumulative phenological water stress factors exceed 99, all plants are killed due to water stress prolonging phenology. In addition, a fraction of the total number of plants can die due to: • high soil surface temperatures immediately following emergence. • drought stress, if a critical leaf number (set to 10) has not yet been reached. • barrenness at the start of grain filling.

## Detachment

The detachment routines in millet are disabled in the current code.

# MILLET MODULE PARAMETERISATION

Crop lower limit and kl values are need for each soil layer extraction

*icrisat_alf1.millet.parameters*

ll = 0.146 0.207 0.244 0.236 0.218 0.173 0.173 (mm/mm) ! millet lower limit

kl = 0.120 0.120 0.120 0.100 0.060 0.055 0.030 () ! rate of soil water extraction extraction

*icrisat_alf2.millet.parameters*

ll = 0.066 0.090 0.117 0.123 0.129 0.137 0.148 (mm/mm) ! lower limit extraction

*jodhpur_aridisol.millet.parameters*

ll = 0.040 0.043 0.043 0.043 0.040 0.040 0.040 (mm/mm) ! millet lower limit

kl values here are same as for icrisat_alf1. Needs to be changed for sandy soil texture of soil at Jodphur.

Phenology parameters needed for each cultivar:

default.millet.bj104

tt_emerg_to_endjuv = 239.4 (°Cd) ! TT from emergence to end of juvenile phase

est_days_emerg_to_init = 17 (d) ! estimated days from emergence to floral init.

pp_endjuv_to_init = 112.4 (° Cd/h) ! photoperiod sensitivity

tt_flower_to_maturity = 457.0 ( ° Cd) ! TT from flowering to maturity

tt_flag_to_flower = 66.1 ( ° Cd) ! TT from flag leaf to flowering

tt_flower_to_start_grain = 80.0 ( ° Cd) ! TT from flowering to start grain fill

tt_maturity_to_ripe = 1 ( ° Cd) ! TT from maturity to harvest ripe

## Leaf area parameters needed for each cultivar:

y0_const = -12390.0 () ! intercept with y-axis of regression of the area of the largest leaf on total leaf number

y0_slope = 1710.0 () ! slope of regression of the area of the largest leaf on total leaf number

Grain yield parameters needed for each cultivar:

hi_incr = 0.0 (1/day) ! rate of HI increase (optional)

hi_max_pot = 0.55 () ! maximum harvest index

head_grain_no_max = 3300.0 (grain/head) ! potential grains per head

grain_gth_rate = 0.61 (mg/grain/d) ! potential grain growth rate

All the above parameters are genotype specific, whereas tt_emerg_to_endjuv , y0_const, and y0_slope are also axis dependent.

## Validation

The millet module was developed validated on a limited set of data collated mainly from on-station experiments at ICRISAT research station at Patancheru , India , and the CAZRI research station at Jodhpur , India . The validation data sets were largely independent of the development data set (van Oosterom et al., 2001b). For most of the recent experiments (1995 onwards), soil chemical and physical characteristics are available. For most of the older data sets, however, this was not the case, and experiments were simulated assuming a fixed amount of water or nutrients being available in the soil. Since most of these experiments were supposedly non-limiting in water and nutrients, and since in most experiments received abundant rainfall and fertilizer, this should not have been a major problem.

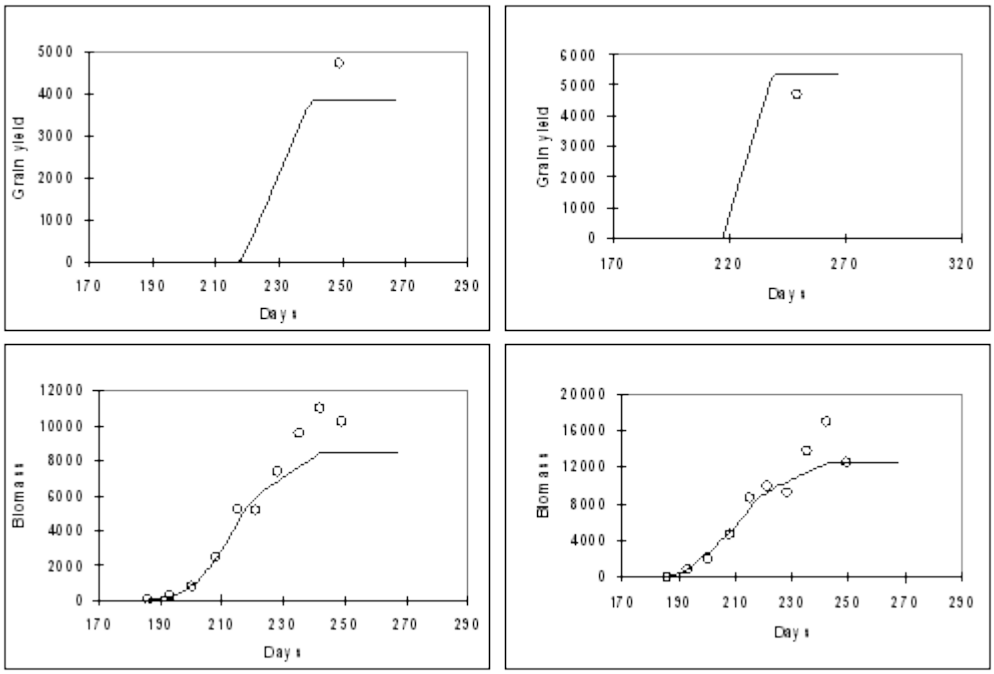



*Figure 3 :Simulation of grain yield, biomass, and LAI for BJ 104, grown at Patancheru in 1982 at densities of 4 (left) and 29 (right) plants /m 2 .*

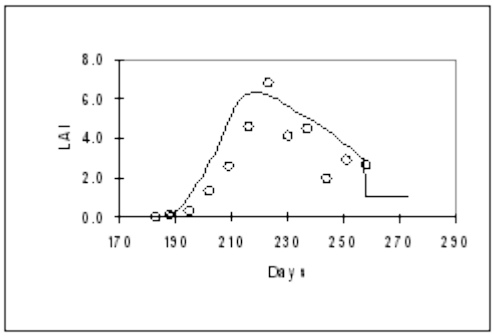



*Figure 4:Simulation of grain yield, biomass, and LAI for BJ 104, grown at Patancheru in 1986 under normal daylength of 14 h (left) and extended daylength of 15.5 h (right). In general, the model adequately captured the effects of density (Fig. 3), daylength (Fig. 4), genotype (Fig. 5) and N-supply (Fig. 6) on biomass accumulation, grain yield, and LAI. The results of Fig. 6 are particularly encouraging; whereas as most of the model development work was carried out at Patancheru (alfisols), in de absence of nitrogen and water stress, Fig. 6 shows an adequate simulation of the effects of N-stress at Jodhpur (sandy soils)*

## MILLET MODULE ISSUES

Biomass partitioning Panicle initiation is used as the trigger for the onset of stem elongation. In reality, however, the onset of stem elongation is not related to panicle initiation; the occurrence of panicle initiation is more sensitive to variation in daylength than the onset of stem elongation. Onset of stem elongation can therefore better be expressed

relative to anthesis. Work on this issue is currently (December 2000) ongoing to better pinpoint the trigger for the onset of stem elongation.

## Tiller death

Non-productive tillers cease producing leaves during stem elongation, but the size of the leaves that are prodcued is very similar to the leaf size of productive tillers. Hence, the low leaf area of non-productive tillers is a result of a reduction in leaf number, rather than leaf size. In the module, non-productive tillers die at anthesis due to barreness. They thus produce the same number of leaves as productive tillers, and the low leaf area in the module is thus a result of a reduction in leaf size. Although the module simulates the low leaf area of non-productive tillers adequately (Fig. ), the mechanisms behind the simulation are a simplification of reality.

## Tiller number

The millet module simulates a maximum of five tillers. Although more tillers are produced throughout the life cycle of the crop, especially if secondary tillers are considered, most of these tillers become non-productive even at low plant densities (Craufurd and Bidinger, 1988a). Their contribution to total GLAI is expected to be relatively small and that to biomass even smaller, as these non-productive tillers do not elongate. They will hence contribute little to photosynthesis, as their leaves are located at the bottom of the canopy. The number of tillers that can be simulated by APSIM-MILLET can be increased, but the errors introduced by simulating a maximum of five tillers are expected to be minor in most circumstances.

## Validation

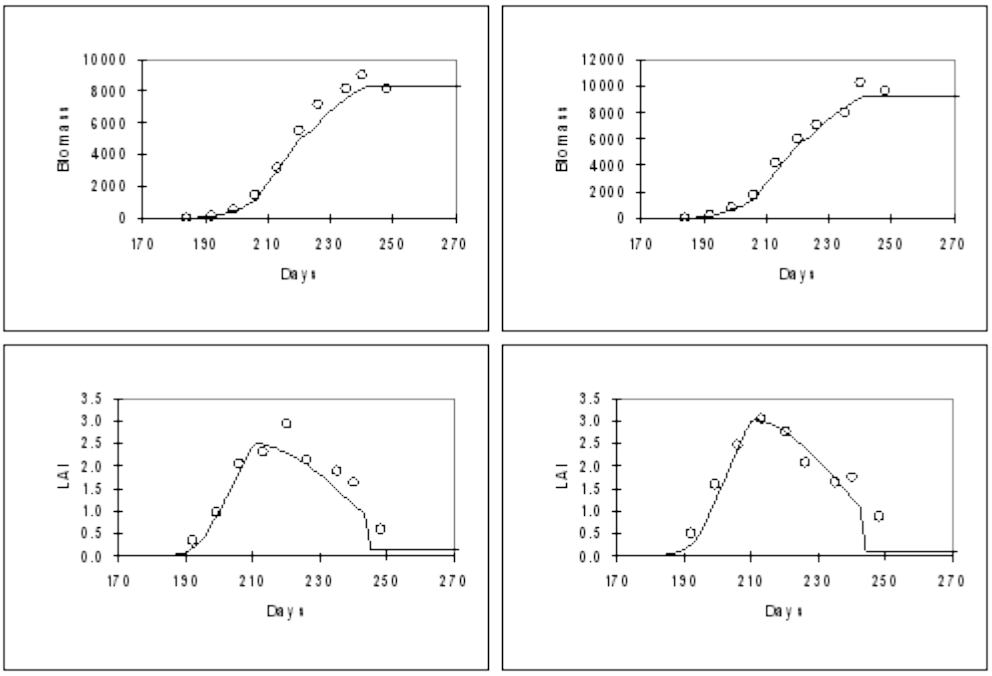



*Figure. 5: Simulation of grain yield, biomass, and LAI for a high-tillering genotype (WRajPop, left) and a low-tillering genotypes (RCB-IC 911, right), grown at Patancheru in 1995*

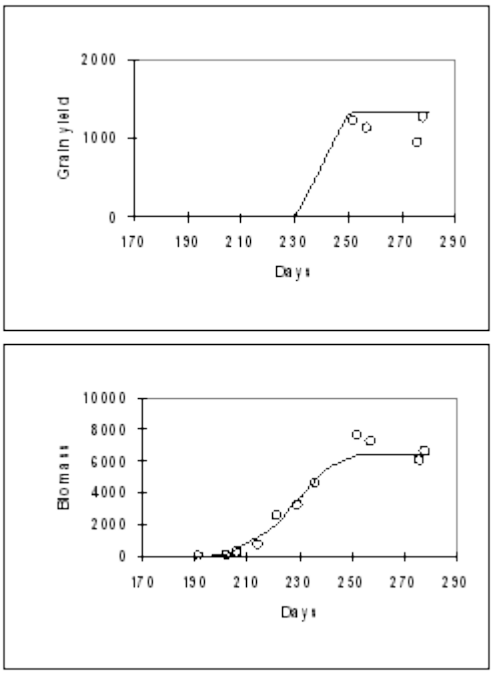



*Figure 6:Simulation of grain yield, biomass, and LAI for a WRajPop, grown at Jodhpur , Rajathan , India , with N-fertiliser of 0 kg/ha (lefl) and 40 kg/ha (right) applied.*

## References

Van Oosterom, E.J., Carberry, P.S., O'Leary, G.J. (2001a). Simulating growth, development, and yield of tillering pearl millet. 1. Modeling leaf area profiles on main shoots and tillers. Field Crops Research (submitted Dec. 2000)

Van Oosterom, E.J., Carberry, P.S., Hargreaves, J.N.G., O'Leary, G.J. (2001b). Simulating growth, development, and yield of tillering pearl millet. 2. Simulation of canopy development. Field Crops Research (submitted Dec. 2000)

# Mucuna

## Introduction

The mucuna module was developed Michael Robertson. The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-Mucuna. The paper by Robertson et al. (2004) outlines the science content of the module, and some testing in Malawi. This document outlines some mucuna-specific issues that are not covered by the plant science document.

## Notable features of APSIM-MUCUNA

The module simulates the main variety grown in southern Africa - Kalagonda

The module does not simulate production from second and further flushes of flowers and pods.

APSIM-Mucuna is not phosphorus-responsive, this is currently under development.

Crop growth is not sensitive to waterlogging.

Goto generic Plant model documentation

## Cultivars and crop classes

There is one crop class.

There is one cultivar able to be simulated: mucuna_gen. This cultivar is typical of that found growing under smallholder conditions in southern Africa.

## Validation

APSIM-Mucuna has received testing in Malawi only, with factors such as sowing date and soil types. Table 1 summarises module performance reported by Robertson et al (2004).

Table 1: Observed (O) and simulated (S) biomass at flowering and maturity and grain yield for velvet bean crops used for model testing. All variables are in kg/ha.

| Location | Season | DAS[a] | Grain yield | | Biomass N at maturity | | Grain N at maturity | | Biomass at flowering | | Biomass at maturity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | O | S | O | S | O | S | O | S | O | S |
| Chitala[b] | 1998-9 | 72 | | | | | | | 848 | 1623 | | |
| Chitedze | 1998-9 | 202 | 2126 | 2382 | 256 | 221 | 96 | 102 | 2374 | 1791 | 6848 | 8609 |
| Chitedze | 1997-8 | 202 | 2820 | 2752 | 314 | 270 | NM[c] | NM | 7640 | 4747 | 10420 | 9189 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lisasadzi | 1998-9 | 182 | 2187 | 1851 | 163 | 211 | 98 | 83 | 2401 | 2628 | 5418 | 6268 |
| Makoka | 1998-9 | 181 | 1343 | 2352 | 117 | NM | 60 | 105 | 2610 | 923 | 5925 | 8364 |
| N'gabu | 1998-9 | 173 | 1852 | 1643 | 257 | 277 | 83 | 85 | 2135 | 1017 | 8651 | 5893 |

a=days after sowing of maturity harvest

b=crop at Chitala suffered late leaf diseases, therefore only sampling at flowering is recorded

c NM=not measured

## In which environments should this module be used with confidence?

APSIM-Mucuna can be used with most confidence in southern Africa. No testing has been done elsewhere.

## References

MJ Robertson, Sakala W, Benson T, Shamudzarira Z (2004) Simulating response of maize to previous velvet bean (Mucuna pruriens) crop and nitrogen fertiliser in Malawi. Field Crops Research (in press).

# MungBean

## Introduction

The mungbean module was developed by Peter Carberry and Michael Robertson . The module is described in the paper by Robertson et al. (2002). The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-Mungbean. This document outlines some mungbean-specific issues that are not covered by the plant science document.The mungbean module simulates mungbean (black gram or green gram).

## Notable features of APSIM-MUNGBEAN

The phenology of mungbean cultivars are photoperiod insensitive.

The module does not simulate grain weathering, although some users have simulated the number of rainfall events during pod-fill (using the manager module) and used this as a surrogate of weathering damage.

The module does not simulate production from second and further flushes of flowers and pods.

APSIM-Mungbean is not phosphorus-responsive, this is currently under development.

Crop growth is not sensitive to waterlogging.

Goto generic Plant model documentation

## Cultivars and crop classes

There is one crop class.There are 9 cultivars able to be simulated: King, Berken, Satin, Shantung , Emerald, Green Diamond, Delta, Putland, Celera. Cultivars differ in terms of biomass partitioning to grain and phenology.

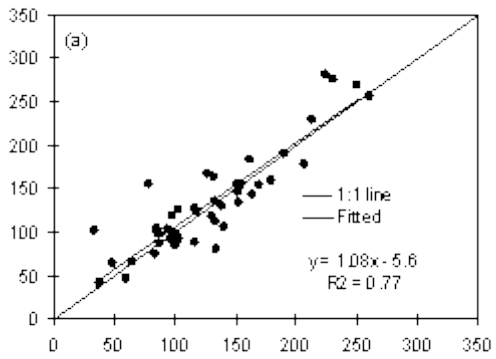



*Figure 1: Performance of the mungbean module (observed versus simulated grain yield in g/m2) against test datasets reported by Robertson et al. (2002).*

## Validation

APSIM-Mungbean has received testing across the northern Australian wheatbelt, with factors such as cultivars, sowing date, irrigation, soil type, row spacing varying. Papers describing validation of APSIM-Mungbean are by Robertson et al. (2000) and Robertson et al. (2002). The accompanying figure demonstrates the performance of the module against Australian datasets.

## In Which Environments Should This Module Be Used With Confidence?

APSIM-Mungbean can be used with a high degree of confidence in northern Australia.

## References

Robertson, M.J., Carberry, P.S., Huth, N.I., Turpin, J.E., Probert, M.E., Poulton, P.L., Bell, M., Wright, G.C., Yeates, S.J., and Brinsmead, R.B. 2002. Simulation of growth and development of diverse legume species in APSIM, Australian Journal of Agricultural Research 53:429-446.

Robertson, M. J.; Carberry, P. S., and Lucy. M. 2000 Evaluation of cropping options using a participatory approach with on-farm monitoring and simulation: a case study of spring-sown mungbeans. Australian Journal of Agricultural Research. 51:1-12.

# Peanut

## Introduction

The peanut module was developed by Michael Robertson with contributions of data from Graeme Wright, RCN Rao and Mike Bell (QDPI) Kingaroy. The module was developed from the original QNUT model (Hammer et al. 1995) with numerous enhancements. The model is described in the paper by Robertson et al. (2002). The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM – Peanut. This document outlines some peanut-specific issues that are not covered by the plant science document.

## NOTABLE FEATURES OF APSIM-PEANUT

The phenology of peanut cultivars is responsive to temperature, but not to photoperiod and vernalisation

However, harvest index of peanut cultivar is adversely sensitive to long photoperiods.

Water deficit effects on phenology have been incorporated.

Account is taken of the energy cost involved in synthesizing the high-energy content grain in peanut.

Oil content is not simulated dynamically in response to any cultivar or environmental effects.

APSIM-peanut is not phosphorus-responsive, this is currently under development.

Crop growth is not sensitive to waterlogging.

The module does not simulate the differences between bunch and runner types in terms of canopy expansion and indeterminacy.

Goto generic Plant model documentation

## CULTIVARS AND CROP CLASSES

There is one crop class.

There are 9 cultivars able to be simulated: Early bunch, Virginia bunch, Streeton, McCubbin, Chico, NC7, VB97, Florunner, Conder. Cultivars differ in terms of biomass partitioning to grain and phenology.

## WATER DEFICIT AFFECTING PHENOLOGY

Observations made in Burnett district in the Southeast Queensland, Australia and elsewhere, have shown that severe water deficits delayed flowering and maturity of Virginia peanut cultivars. The APSIM peanut model has been parameterised to account for phenological sensitivity to severe water deficits at different stages and a recovery upon this stress being relieved either by rain or irrigation.

A water availability ratio is calculated by dividing actual soil water supply (sw – ll) by the potential soil water supply (dul – ll). This ratio is used in the relationship illustrated in the Figure 1 to derive a stress factor for phenological

development. A factor of 0 is complete stress and 1 no stress. This enables slowing down of thermal time addition whenever water availability ratio declines to less than 0.29.

x_sw_avail_ratio = 0.16 0.29 1.0 () ! water availability

y_swdef_pheno = 0.55 1.0 1.0 () ! stress index for phenology

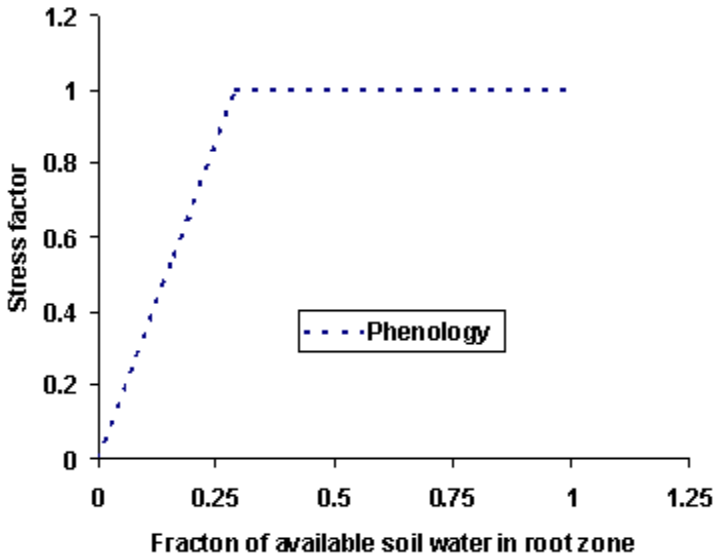
x_sw_avail_ratio_flower = 0.16 0.29 1.0 () ! water availability

y_swdef_pheno_flower = 0.55 1.0 1.0 ()! stress index for flowering

x_sw_avail_ratio_grainfill = 0.16 0.29 1.0 () ! water availability

y_swdef_pheno_grainfill = 0.55 1.0 1.0 () ! stress index for grain filling

**Figure 1: Water deficit factors for pre-flowering, flowering and grain filling periods**




## PHOTOPERIOD AFFECTING HARVEST INDEX

Although peanut has been presumed to be day-neutral with respect to flowering, more recently it has been demonstrated that continuous photoperiod significantly reduces harvest index (Rowell et al. 1999). To account for photoperiod effects on harvest index, changes in maximum potential harvest index have been made. The maximum harvest index (pod yield / biomass) under continuous photoperiod (24 h) has been parameterised as 45% and under 1 h photoperiod as 75%.

## VALIDATION

The APSIM –Peanut has received testing across northern Australia with factors such as cultivars, sowing date, irrigation, soil type, plant population density, and row spacing varying. Figure 2 demonstrates the performance of the module against Australian datasets.

## REFERENCES

Hammer GL, Sinclair TR, Boote, KJ, Wright GC, Meinke H, and Bell MJ 1995 A peanut simulation model: I Model development and testing. Agronomy Journal 87, 1085-93.

Robertson MJ., Carberry, PS, Huth NI, Turpin JE, Probert ME, Poulton, PL, Bell M Wright GC, Yeates SJ and Brinsmead, RB 2002 Simulation of growth and development of diverse legume species in APSIM. Australian Journal of Agricultural Research 53, 429-446.

Rowell T , Mortley DG, Loretan PA, Bonsi, CK and Hill WA 1999 Continuous daily light period and temperature influence peanut yield in nutrient film technique. Crop Science 39, 1111-1114.

# PigeonPea

## Introduction

The pigeonpea module was developed by Michael Robertson and Peter Carberry at APSRU, and YS Chauhan, R Ranganathan, and G O'Leary of ICRISAT. APSIM-Pigeonpea belongs to the LEGUME family of crop modules in APSIM. The reader is referred to the science document for the legume module for a comprehensive description of the processes simulated by APSIM-Pigeonpea and to Robertson et al. (2001) for parameter derivation and model testing. This document outlines some pigeonpea-specific issues that are not covered by the legume science document.

## Notable features of APSIM-PIGEONPEA

The phenology of pigeonpea cultivars are responsive to temperature and photoperiod, but not vernalisation.

APSIM-Pigeonpea is not phosphorus-responsive, this is currently under development.

Crop growth is not sensitive to waterlogging.

Goto generic Plant model documentation

## Cultivars and crop classes

There is one crop class. There are three generic cultivars able to be simulated: extra short duration, short duration and medium duration. A long duration type was not able to be parameterised due to lack of data, however the module owner would be able to give advice on a long duration type if this were required by a user. Cultivar types differ in terms of biomass partitioning to grain and phenology.

## Validation

APSIM-Pigeonpea has received testing in Central India , with factors such as cultivars, sowing date, irrigation, soil type, plant population density, row spacing varying. Validation of APSIM-Pigeonpea is described by Robertson et al. (2001). The accompanying figure demonstrates the performance of the module for grain yield and biomass.

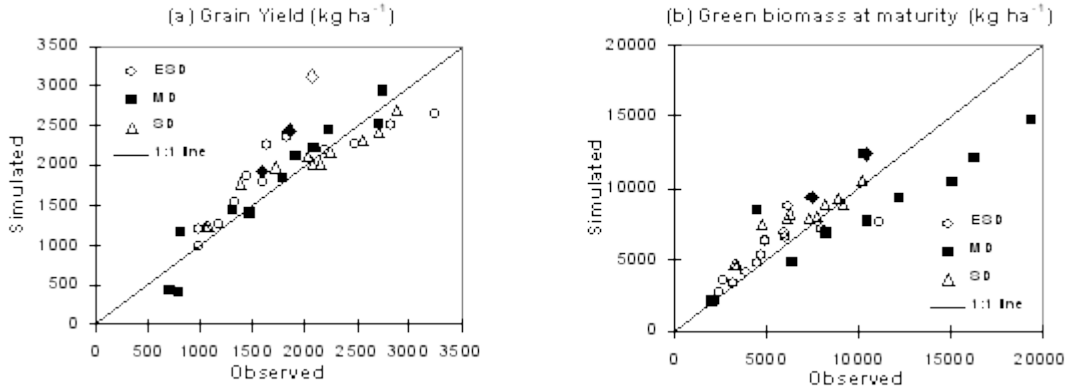



*Figure 1: Performance of the pigeonpea module (observed versus simulated grain yield and final biomass in kg/ha) against test datasets reported by Robertson et al. (2001).*

## References

Robertson MJ, Silim SN, Chauhan YS, Ranganathan R 2000a Predicting growth and development of pigeonpea: biomass accumulation and partitioning. Field Crops Research 70, 89-100.

# Plant

## Plant module Scope

The **Plant module** simulates the growth of a number of different species on a daily time-step (on an area basis not single plant). Plant growth in this model responds to climate (temperature, rainfall and radiation from the **Met** module), soil water supply (from the **Soilwat** module) and soil nitrogen (from the **SoilN** module). The **Plant module** returns information on its soil water and nitrogen uptake to the **Soilwat** and **SoilN**modules on a daily basis for reset of these systems. Information on crop cover is also provided to the **Soilwat** module for calculation of evaporation rates and runoff. Plant tops and root residues are 'passed' from **Plant** to the **Residue** and **SoilN** module respectively at harvest of the plant crop.

Currently, the crops that are included in the Plant module are chickpea, mungbean, cowpea, soybean, pigeonpea, stylosanthes, peanut, faba bean, lucerne, canola, weed, mucuna, lupin, wheat and navybean (Table 1).

A list of the module outputs is provided in the 'Plant module outputs' section listed below. The module will predict on a daily basis: phenological variables (leaf and node appearance, occurrence of stages of development, thermal time progression), leaf area development, nitrogen content and biomass of plant parts (including grain), depth and distribution of roots in the soil profile, root water and nitrogen uptake, water, oxygen and nitrogen deficit stress factors, and nitrogen fixation from the atmosphere.

## Plant module History

The **Plant module** replaces previous modules covering the relevant crops. The module was developed so that disparate pieces of source code residing with different plant modules could be consolidated into the one module, thus cutting down on on-going maintenance costs, source code management, and version control problems. The underlying premise was that the basic physiological principles needed to be simulated were essentially the same across species and that species differences could be captured successfully through different parameter inputs. The functions on which the crop growth module is based originate from a mixture of sources including; values/functions from published literature/models (e.g. Sinclair, 1986), functions derived directly from experimental data and model calibration to experimental data sets.

While the original intent of the **Plant module** was to simulate legume species, it now simulates non-legume species such as **canola, wheat** and **weeds** .

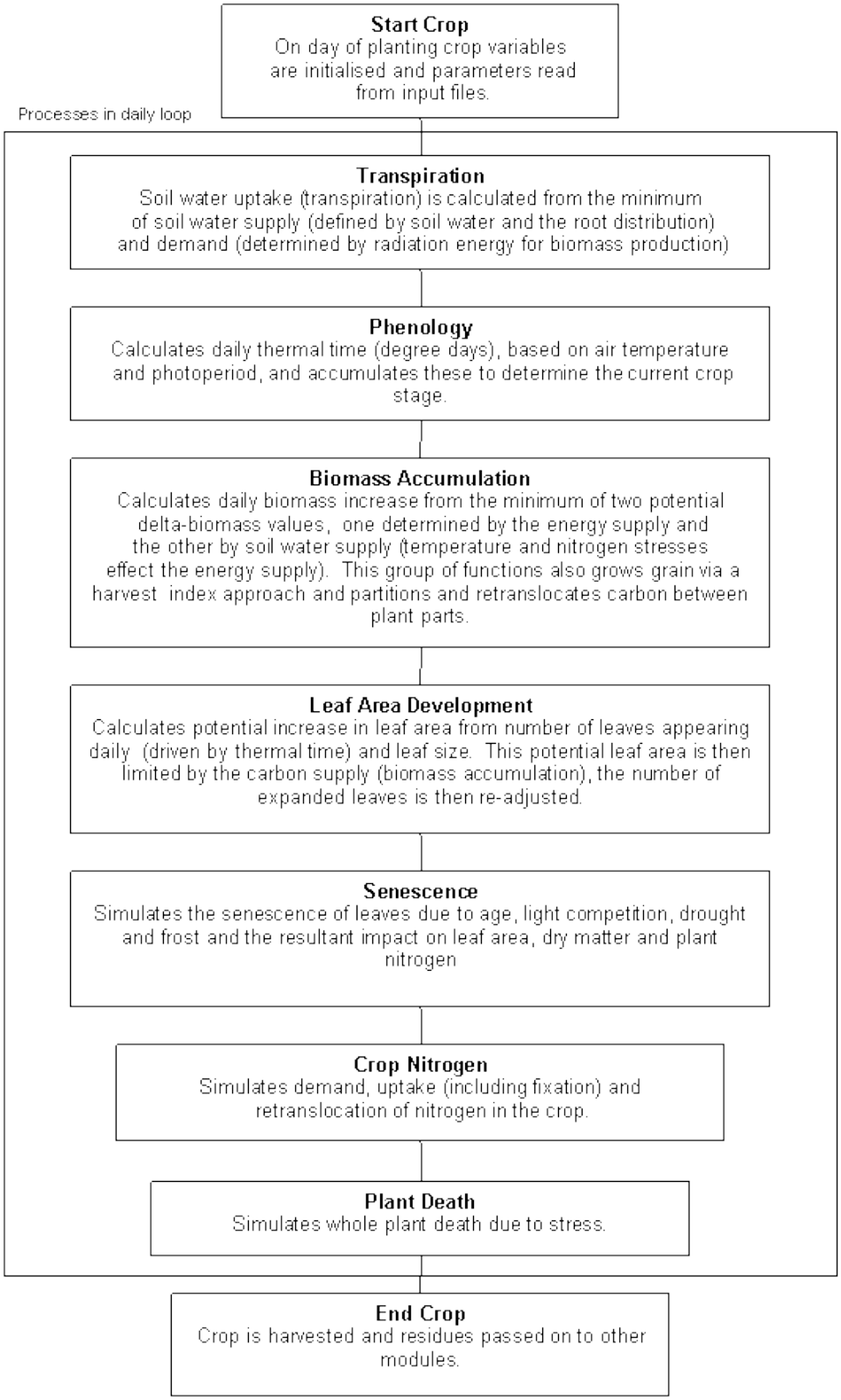
Ownership of the crop species science remains with the original module owners. Documentation of the history of the evolution of the Plant module is available upon request from the module convener, Michael Robertson.

*Table 1: Plant species simulated by APSIM-Plant*

| Plant species | Species science "owner" | Former APSIM module |
|---|---|---|
| **Current** | | |
| Chickpea | Michael Robertson CSIRO / APSRU | APSIM-Chickpea (Carberry, 1996; Turpin et al., 1998) |

| | | |
|---|---|---|
| Mungbean | Michael Robertson CSIRO / APSRU | APSIM-Mungbean (Carberry, 1996) |
| Cowpea | Michael Robertson CSIRO / APSRU | APSIM-Cowpea (Adiku et al. 1993) |
| Soybean | Michael Robertson CSIRO / APSRU | APSIM-Soybean (Carberry, 1996) |
| Pigeonpea | ICRISAT(Gary O'Leary) & CSIRO / APSRU (Peter Carberry) | None |
| Stylo | Peter Carberry CSIRO / APSRU | APSIM-Stylo (Carberry et al., 1996) |
| Navybean | Michael Robertson CSIRO / APSRU | None |
| | Graeme Wright QDPI | |
| Lucerne | Michael Robertson CSIRO / APSRU | Probert et al. (1998) |
| Peanut | Mike Bell QDPI | QNUT |
| | Graeme Wright QDPI | |
| | Michael Robertson CSIRO / APSRU | |
| Fababean | Michael Robertson CSIRO / APSRU | None |
| Lupin | Michael Robertson CSIRO / APSRU | None |
| Mucuna | Michael Robertson CSIRO / APSRU | None |
| Canola | Michael Robertson CSIRO / APSRU | None |
| Weed | Michael Robertson CSIRO / APSRU | None |
| Wheat | Neil Huth CSIRO / APSRU | APSIM Wheat, APSIM NWheat, APSIM IWheat |

## Plant module Structure



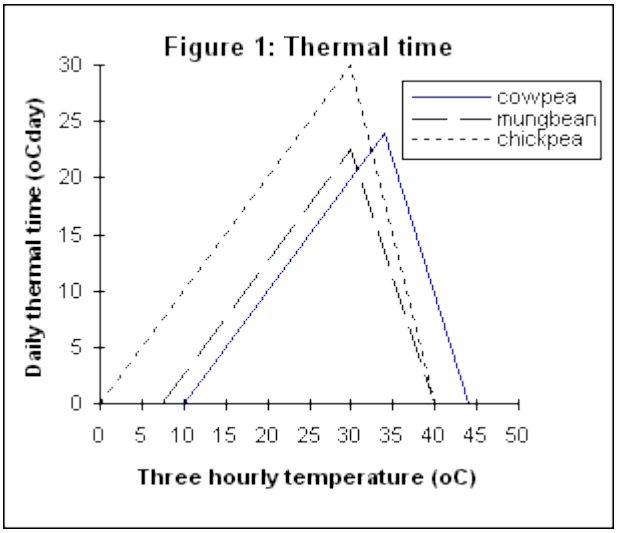
## Phenology

There are 11 crop stages and 10 phases (time between stages) in the **Plant module** (Table 2), and commencement of each stage (except for*sowing to germination* which is driven by soil moisture) is determined by accumulation of thermal time.

*Table 2: Stages of crop development simulated in the module*

| Stage code | Stage name |
|---|---|
| 1 | Sowing |
| 2 | germination |
| 3 | emergence |
| 4 | end_of_juvenile |
| 5 | floral_initiation |
| 6 | flowering |
| 7 | start_grain_fill |
| 8 | end_grain_fill |
| 9 | maturity |
| 10 | harvest_ripe |
| 11 | end_crop |

Each day the phenology routines calculate today's thermal time (in degree days) from 3-hourly air temperatures interpolated from the daily maximum and minimum temperatures. Thermal time is calculated using the relationship in Figure 1 (base temperature, optimum and maximum) with the eight 3-hour estimates averaged to obtain the daily value of thermal time (in growing degree days) for the day. These daily thermal time values are accumulated into a thermal time sum which is used to determine the duration of each phase. Between the stages of emergence and flowering the calculated daily_thermal_time is reduced by water or nitrogen stresses, resulting in delayed phenology when the plant is under stress.




The duration and timing of 6 of the 10 crop phases are determined by fixed thermal time values input in the parameters section of the ini file.

*Sowing to germination* is dependent on soil water levels. If soil water in the soil layer in which the seed is sown is sufficient (specified by*pesw_germ* ) then germination takes place one day after sowing.

The phase *germination to emergence* includes an effect of sowing depth on the thermal time target. The thermal time target equals a lag period before linear shoot growth starts ( *shoot_lag* ) plus a shoot elongation rate ( *shoot_rate* ) which determines the thermal time taken to reach the soil surface and emerge.

The thermal duration of the phase *emergence* to *end_of_ juvenile* in some species is affected by the number of cumulative vernalising days experienced during the period. The relationship between a fraction of a vernalising day and mean daily temperature is specified by the table *x_vernal_temp* vs *y_vernal_days* .

The phase between *end_of_ juvenile* and *floral initiation* is determined by a cultivar's photoperiod (daylength) sensitivity - note that the Plant module can cope with short-day species (e.g. cowpea), long-day species (e.g. chickpea) and species that exhibit the qualitative response (e.g. pigeonpea). The photoperiod sensitivity is specified in the parameters section of the ini file with a table for the relationship between photoperiod and thermal time between end-of-juvenile and floral intiation

## Biomass accumulation (Photosynthesis)

Radiation_interception is a function of the fraction of radiation intercepted and daily radiation. The fraction of radiation intercepted is determined by the leaf area index and the extinction coefficient, which varies as a function of row spacing, inter-row skip-row configuration and intra-row ‘skip-plant' configuration.

In crop species that produce a significant layer of green photosynthesising pods (eg canola) it is possible to specify the rue, extinction coefficient and specific pod area (that converts pod weight to area) of the pods ( *rue_pod, extinct_coef_pod, spec_pod_area* ).

Each day two estimates of the daily biomass production are calculated, one limited by available water for transpiration (eqn 1), and the other limited by radiant energy (eqn 2). The minimum of these two estimates is the actual biomass production for the day.

delta_drymatter_transpiration = soil_ water_ supply * transpiration_efficiency eqn 1.

Note: transpiration_efficiency is derived from the transpiration_efficiency_coefficient and the vapour pressure deficit (vpd) estimated from daily temperatures.

dlt_drymatter_potential = rue *radiation_interception eqn 2.

Note: *rue* (radiation use efficiency) incorporates temperature, oxygen deficit (waterlogging) and nitrogen stresses. The value of *rue* is not limited by temperature over a range between the first and second optima. Temperatures outside this range reduce *rue* to zero at a base and maximum temperature. *Rue* is linearly interpolated between the phenological stages specified in a table.

## Biomass partitioning

Daily biomass production is partitioned to six different plant parts in different ratios depending on crop stage (Table 3).

*Table 3: Plant parts and their description in the Plant module.*

| Element in the plant part array | Plant part | Description |
|---|---|---|
| 1 | root | Below-ground fibrous roots |
| 2 | leaf | Leaf lamina |
| 3 | stem | Stem |
| 4 | pod | Hull (or pod wall) |
| 5 | meal | Grain (or seed) meal, excluding the oil |
| 6 | oil | Oil contained in the grain |

**Roots** are grown daily in a fixed proportion to the tops production. This proportion ( *ratio_root_shoot* ) is specified for each growth stage.

On the day of emergence, biomass (and nitrogen) in plant parts are initialised. Between emergence and flowering a proportion of biomass produced ( *frac_leaf* ) is partitioned to leaf and the remainder to stem. However, if the amount of carbon partitioned to leaves is more than is required for the calculated increase in leaf area (the leaves have a maximum thickness, *sla_min* ) then the residual is partitioned to stems. Likewise if the carbon partitioned to leaves is too little to grow the potential increase in leaf area, leaf area increase is reduced (see leaf area development section).

Between **flowering and start-of-grainfill** the same procedure is used for determining leaf biomass ( *frac_leaf* ). Of the remaining carbon a proportion goes to stem and pod in the ratio specified by the parameter *frac_pod* .

Between the **start-of-grainfill and maturity** biomass is partitioned between grain, pod and stem. Partitioning to grain depends on calculated grain-demand (see below). The pod wall accounts for a fraction of the grain demand ( *frac_pod* ). If (because grain demand is lower than supply) there is any biomass remaining it goes to leaf as specified by *frac_leaf* , with the remainder going to stem. In this way if there is low demand for assimilate by grain during grainfill, leaf area may be produced, as occurs in indeterminate species and cultivars.

**Grain demand for carbohydrate** (biomass) is driven using a cultivar-specific daily rate of harvest index (HI) increase ( *hi_incr* ). The demand for biomass to be partitioned to grain on any day is calculated using HI i.e. the ratio of grain-biomass to tops-biomass. Each day HI is increased by *hi_incr* until it reaches a maximum *hi_max_pot* . In species in which there is an energy cost to grain dry weight synthesis (e.g. oilseeds such as soybean), above that which is standard for grain carbohydrate, account must be taken of the extra assimilate required. This is specified by the parameters *grain_oil_conc* and *carbo_oil_conv_ratio* (fractional oil content of grain and carbohydrate:oil conversion ratio respectrively), and these are used to calculate the energy used to produce the oil content and accumulate the *oil* plant part. *Energy* is not included in the summing of plant parts to give the weight of biomass, but must be accounted for when calculating grain demand for carbohydrate. Grain weight at commercial moisture content (variable = yield-wet) is calculated using the parameter *grn_water_cont* .

Crop height (mm) is a function of stem weight per plant, as specified for each cultivar.

## Biomass retranslocation

If the grain demand for carbohydrate cannot be met through partitioning of daily biomass production it is retranslocated from other plant parts to meet (if possible) this grain demand. The **Plant module** allows a total retranslocation of no more than *leaf_trans_frac* of leaf weight,*stem_trans_frac* of stem weight, and *pod_trans_frac* of podwall weight that is present at the start of grain filling.

## Leaf development

On the day of emergence, leaf area per plant ( *initial_tpla* ) and leaf number per plant ( *leaf_no_at_emerg* ) are initialised. **Node appearance rate** per plant is driven by thermal time, specified by the lookup table between *x_node_no_app* vs *y_node_app_rate* . **Leaf appearance** is driven by a number of leaves appearing per node as specified by the *x_node_no_leaf* vs *y_ leaves _per_node* relationship.

**Potential LAI** is a product of potential leaf number, leaf-size (which is a function of nodal position) ( *x_node_no* vs. *y_leaf_size* (mm 2 )), number of plants per m 2 and the water stress factor for expansion (see water deficits section below)

**Actual LAI** is less than the potential LAI if there is not sufficient biomass partitioned to leaf on that day. Maximum specific leaf area ( *sla_max* ) defines the maximum leaf area (m 2 ) that can be expanded per gram of biomass. *sla_max* declines with increasing LAI i.e. smaller, younger crops are able to produce thinner leaves.

## Leaf senescence

There are four causes of leaf senescence; age, light competition, water stress and frost. The **plant** senescence routines calculate a senesced LAI for each stress each day and take the maximum of the four values as the day's total senescence.

A fraction of the oldest green leaf dies each day after flowering. This **senescence due to age** occurs a rate of leaves per day. This is calculated from the day's thermal time, the rate of node senescence per o Cd ( *node_sen_rate* ) and a fraction of the total green leaves on the plant that senesce for each node that is senescing ( *fr_lf_sen_rate* ). This number of dead leaves is then converted to a senesced LAI.

A rate of senescence of other plant parts can also be specified (such as stems) in terms of a fraction of dry weight senesced for each fraction of canopy senesced.

Above an LAI of 4.0 **light competition** causes leaf area to be lost. The LAI senesced because of light competition is related to the amount LAI exceeding *lai_sen_light* .

**Water stress** during crop growth will cause leaf senescense

sensLAI_water_fac = 0.05 * (1 - plant_swdef(photo))

delta_sensLAI_water = LAI * sensLAI_water_fac

Note: the calculation of the water stress factor plant_swdef(photo) is descibed in the 'water deficits' section below.

**Frost senescence.** Low minimum temperatures will cause a linearly increasing loss of leaf area from 0 to 100% respectively, as defined by the relationship between *temp_senescence* and *senescence_fac* .

From the values of senesced LAI the Plant module calculates the biomass and nitrogen in that leaf area that is senesced, however a proportion of the carbon and nitrogen of these leaves is retranslocated to stem before senescence.

## Regrowth

Depending upon the relative height of harvesting, differing fractions of leaf and stem can be left remaining ( *fr_height_cut* vs *fr_stem_remain* ).

Regrowth routines allow growth after harvest in the Plant module. Regrowth in ensured if the parameter *min_tpla* is set to a value greater than zero. At present this only occurs in the lucerne module. The phenological stage that the crop is set back to upon harvest is specified by the table*stage_code* vs *stage_stem_reduction_harvest* . Re-setting of phenology can also occur when the growing point is killed by a "kill_stem" action. This could be due to frost damage, grazing, herbicide, insect damage. The stage at which phenology is reset to is specified by *stage_code* vs*stage_stem_reduction_kill_stem* .

In some species harvesting or similar actions cause the module to use a different set of " *crop_class* " parameters listed in a separate section of the ini file. The section(s) of the ini file that are read upon the receipt of a particular action are listed at the top of the ini file. For example in lucerne.ini the table:

class_action = harvest kill_stem

class_change = regrowth regrowth

means that a harvest action will cause a change of crop class to regrowth, while a kill_stem action will cause a similar change of crop class.

## Water uptake

To determine the amount of water supply to the crop on any day, first the total available water above the lower limit for all soil layers with roots is summed. If roots are only partially through a layer, available soil water is scaled to that portion that contains roots. The *kl* constant (value differs for each soil layer) is then used to limit the amount of water available on any day. The *kl* factor is empirically derived, incorporating both plant and soil factors which limit rate of water uptake - it represents the fraction of available soil water that can potentially be taken up on that day from that layer, and values typically vary between 0.01 for deep layers with low root length densities to 0.10 for surface layers with high root length densities

do layer = 1, deepest_layer (do loop to calculate available water for all layers)

sw_avail = sw(layer) - ll (layer)

sw_supply(layer) = sw_avail * kl (layer)

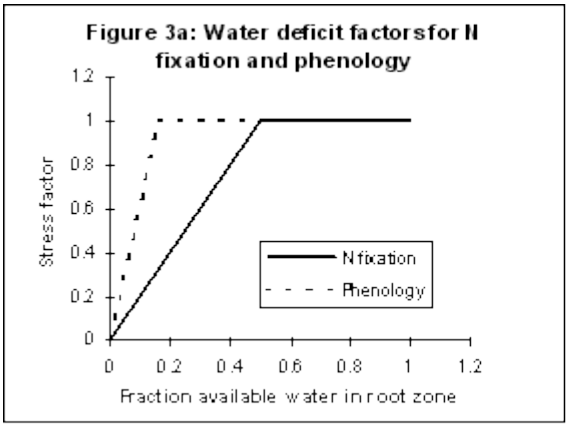
**Soil water demand** is calculated as in the 'biomass accumulation' section above where potential biomass production is a function of radiation interception and *rue* . This potential biomass production is converted to water demand using transpiration efficiency. Transpiration efficiency is calculated from the transpiration effieicny coefficient ( *transp_eff_cf* ), which can vary with growth stage, and vapour pressure deficit. Soil water demand is capped by the atmospheric evaporative demand (eo) adjusted by the proportion of green canopy cover (cover_green) and a crop factor (eo_crop_factor) i.e. *eo_crop_factor * eo * cover_green* .

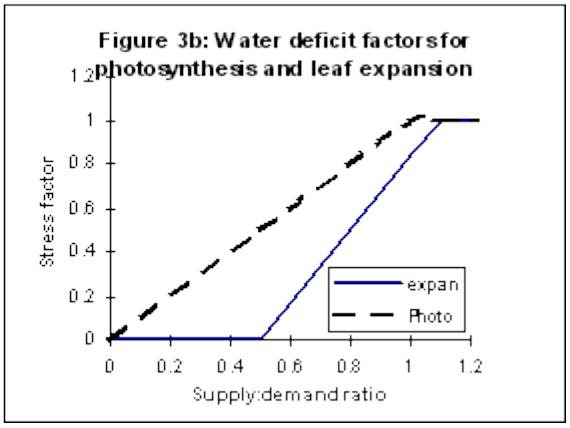
**Water uptake** is the minimum of the supply and demand.

## Water deficits affecting plant growth

Soil water deficit factors are calculated to simulate the effects of water stress on different plant growth processes. Four water deficit factors are calculated which correspond to four plant processes each having different sensitivity to water stress i.e. photosynthesis (photo), phenology (pheno), leaf-expansion (expansion) and nitrogen fixation (fixation).

A water availability ratio is calculated by dividing actual soil water supply (sw - ll) by the potential soil water supply (dul - ll). This ratio is used in the relationships illustrated in Figure 3a to derive stress factors for nitrogen fixation and phenological development. A factor of 0 is complete stress and 1 no stress. Likewise, Figure 3b shows the relationship between the stress factors for photosynthesis and leaf expansion and the ratio of supply to demand for soil water.




## Nitrogen uptake and retranslocation

In order to calculate **nitrogen demand** today, first, potential biomass production is re-calculated unlimited by water, nitrogen or temperature i.e. as a function of rue and radiation-interception. This dry matter (biomass) is then partitioned into plant parts according to their current relative weights. The Plant module has a defined minimum, critical and maximum N concentration for each plant part. Demand for nitrogen in each part attempts to maintain nitrogen at the critical (non stressed) level. Nitrogen demand on any day is the sum of the demands from the pre-existing biomass of each part required to reach critical N content, plus the N required to maintain critical N concentrations in today's potentially assimilated biomass..

A **nitrogen uptake maximum** is defined as the nitrogen uptake required to bring all plant part N contents to the maximum allowable concentration.

**Nitrogen supply** is the sum of nitrogen available via mass flow and by diffusion (otherwise known as active uptake).

no3_massflow (layer) = no3_conc * delta_sw (layer)

no3_diffusion (layer) = sw_avail_frac *no3_conc

note: these layer values are summed to root depth and sw_avail_frac is ratio of extractable soil-water over total soil-water.

If nitrogen demand cannot be satisfied by mass flow then it is supplied by either diffusion or fixation. The preference by a species for diffusion or fixation is specified by the parameter *n_supply_preference* (options are “active” or “fixation”) . Demand can only be exceeded by supply from mass flow (up to the nitrogen uptake maximum). If both mass flow and diffusion supplies can't satisfy demand then nitrogen is sought from N fixation (see next section).

Nitrogen available for uptake is distributed to plant parts in proportion to their individual demands.

Nitrogen for grain is retranslocated from other plant parts, N is not directly taken up from the soil or atmosphere to meet grain demand. Nitrogen is available for retranlocation from all parts except for grain and roots; other plant parts will translocate nitrogen until they reach their defined minimum N concentration. Grain nitrogen demand is again driven by critical N content but this demand is lowered if the plant is under N stress. Grain N demand is also affected by temperature and water stress using eqns below.

N_grain_temp_fac = 0.69 + 0.125 * aver_temp

N_grain_sw_fac = 1.125 - 0.125 * swdef (expansion)

The greatest of these two factors is multiplied by the previously calculated N demand i.e. if temperature is high or swdef(expansion) is low (water stressed) the N demand will be increased above the level required to reach the critical N concentration.

During leaf senescence, leaf nitrogen is reduced in the newly senesced leaves and the excess is retranslocated to green stem.

## N fixation

The daily rate of nitrogen fixation at potential, is a function of the crop N fixing capacity ( *N_fix_rate* ), which varies with growth stage, crop biomass (i.e. the size of the crop) and soil water stress.

N_fixation = N_fix_rate * biomass * swdef (fixation)

## Nitrogen deficits affecting plant growth

There are three N availability factors (0-1), one each for the photosynthesis, phenology and grain filling processes. A N concentration ratio is calculated for the stover (stem + leaf), which is used as a measure of N stress, then different constants are used to convert that ratio to a deficit factor for each of the processes. A factor of 1 is used for affecting grain N concentration, 1.25 for photosynthesis (reduces rue) and 5.75 to slow phenological development. As a value of 1 is no stress and 0 complete stress, phenology is least sensitive to nitrogen deficiency and grain N the most.

N_conc_ratio = (N_conc_stover - N_conc_stover_min) / (N_conc_stover_crit - N_conc_stover_min)

## Root growth and distribution

Root depth at emergence is initialised at *initial_root_depth* . Between emergence and grain filling, the increase in root depth is a daily rate (*root_depth_rate* ) multiplied by an exploration factor ( *xf* ), a soil water availability factor for the layer than the deepest roots are currently passing across, and a temperature factor ( *x_temp_root_advance* vs. *y_rel_root_advance* ). In severe water deficit the roots depth increase can be slowed and even stopped by the function between *sw_supply_demand_ratio* and root depth increase, expressed by *x_ws_root* vs.*y_ws_root_fac* . The parameter *root_depth_rate* varies with growth stage and is typically zero after the start of grain filling. Root depth is constrained by the soil profile depth.

The amount of biomass partitioned daily to the root system is described in the 'biomass partitioning' section above. Root biomass is partitioned among the soil layers currently occupied by roots according to three factors: the exploration factor ( *xf* ), the soil water availability factor, and the root branching factor ( *rel_root_rate* ). Root biomass is converted to root length using the parameter *specific_root_length* (currently assumed as 60000 mm/g for all species).

Roots are senesced during the life of the crop (0.005 of the length in each layer per day), and are immediately detached and sent to the **SoilN**module. At harvest all roots senesce and distributed as fresh organic matter in the profile according to their distribution on the day of harvest.

## Oxygen deficits (waterlogging) affecting plant growth

Oxygen deficit (waterlogging) affects photosynthesis. The oxygen deficit stress factor is calculated as the fraction of the whole plant root length that is exposed to water contents above the drained upper limit (i.e. near-saturated soil conditions).

## Temperature stress

There are no generic temperature factors, as for water and nitrogen stress, but as discussed in sections above temperature does influence grain N content, rate of senescence and radiation use efficiency (rue).

## Plant death

All or some of the plants can be killed due to a variety of stresses;

If the crop hasn't germinated within 40 days of sowing, due to lack of germinating moisture, all plants are killed.

If the crop does not emerge with 150 o Cdays of sowing, because it was sown too deep, then all plants are killed.

If crop is past floral initiation and LAI = 0, then all plants are killed due to total senescence.

If the cumulative phenological water stress factors exceed 25, all plants are killed due to water stress prolonging phenology.

A fraction of plants will be killed by high temperatures immediately following emergence.

A fraction of plants can be killed by a *kill_stem* action from the manager to simulate the effect of severe frost.

A specified fraction of plants can be killed by a *kill_crop* action from the manager.

## Detachment

In the module the user can specify the fraction detached from each part of a dead plant or senesced pool per day. Currently, only senesced roots are assumed to be detached.

## Plant Module Parameterisation

Crop lower limit, *kl* values, and exploration factor ( *xf* ) values are need for each soil layer. An optional parameter *uptake_source* can also be specified for simulations where the uptake of water and solutes (in this case $NO_3$ ) is calculated by another module in APSIM. The possible setting for this parameter are 'calc' (= calculate own uptakes) or 'apsim' (= get uptake data using the APSIM messaging system). The default value of 'calc' is used in the absence of the parameter specifier.

test. cowpea.parameters

uptake_source = calc ! calculate uptake of water and nitrate

ll = 0.200 0.200 0.200 0.220 0.250 () ! crop lower limit

kl = 0.08 0.06 0.04 0.02 0.01 () ! kl need calibrating for each crop and soil type

xf = 1.00 1.00 1.00 1.00 1.00 (0-1)  ! exploration factor for root growth

Cultivar parameters are needed, and are specified in the ini file. The example below is for cowpea cv. Banjo.

*standard.cowpea.banjo*

| | | | | |
|---|---|---|---|---|
| x_pp_hi_incr | = | 1 24 | (hours) | ! photoperiod |
| y_hi_incr | = | 0.014 0.014 | (1/days) | ! rate of HI increase |
| x_hi_max_pot_stress | = | 0.0 1.0 | () | ! average stress at flowering |
| y_hi_max_pot | = | 0.6 0.6 | () | ! maximum harvest index potential |
| cum_vernal_days | = | 0 100 | | |
| tt_emerg_to_endjuv | = | 552.0 552.0 | (oCd) | ! TT from emergence to end of juvenile phase |
| est_days_emerg_to_init | = | 20 | (days) | ! estimated days from emergence to floral init. |
| x_pp_endjuv_to_init | = | 13.3 18.0 | (hours) | ! photoperiod |
| y_tt_endjuv_to_init | = | 0 229 | (oCd) | ! TT from end juvenile to floral initiation |
| x_pp_init_to_flower | = | 1 24 | (hours) | ! photoperiod |
| Y_tt_init_to_flower | = | 20.0 20.0 | (oCd) | ! TT from initiation to flowering |
| x_pp_flower_to_start_grain | | 1 24 | (hours) | ! photoperiod |
| y_tt_flower_to_start_grain | = | 100.0 100.0 | (oCd) | ! TT from flowering to start grain fill |
| x_pp_start_to_end_grain | = | 1 24 | (hours) | ! photoperiod |
| y_tt_start_to_end_grain | = | 280.0 280.0 | (oCd) | ! TT from start grain fill to end grain fill |
| tt_end_grain_to_maturity | = | 20 | (oCd) | ! TT from end grain fill to maturity |
| tt_maturity_to_ripe | = | 5.0 | (oCd) | ! TT from maturity to harvest ripe |
| x_stem_wt | = | 0 15 | (g/plant) | ! stem weight |
| y_height | = | 0 1000 | (mm) | ! plant height |

## PLANT MODULE OUTPUTS

The following Plant variable can be output through the report module

| Variable Name | Units | Description |
|---|---|---|
| plant_status | character | Status of crop (e.g. alive, dead, out) |
| stage | | Current phenological stage (real value) |
| dlt_stage | | Daily increase in phenological stage |
| stage_code | | Current phenological stage (integer value) |
| stage_name | | Current phenological stage (description) |
| crop_type | character | crop type (e.g. mungbean, chickpea, cowpea, etc) |
| crop_class | | crop class (e.g. plant, regrowth, etc) |
| dlt_tt | o Cd | Daily increase in thermal time |
| phase_tt (max_stage = 12) | o Cd | Thermal time target for each phenological phase |
| tt_tot (max_stage = 12) | o Cd | Thermal time elapsed for each phenological phase |
| days_tot (max_stage = 12) | d | days elapsed for each phenological phase |
| das | days after sowing | Days since sowing |
| flowering_date | day of year | Flowering date |
| flowering_das | days after sowing | Flowering date |
| maturity_date | day of year | Maturity date |
| maturity_das | days after sowing | Maturity date |
| leaf_no (max_node = 1000) | | number of fully expanded leaves during each node development |
| node_no (max_stage = 12) | | number of nodes on the mainstem, developed in each phase |

| | | |
|---|---|---|
| dlt_leaf_no | | daily increase in number of leaves |
| dlt_node_no | | daily increase in number of nodes |
| leaf_no_dead (max_node = 1000) | | no of dead leaves in each phenological phase |
| leaf_area (max_leaf = 1000) | mm 2 | leaf area of each leaf |
| height | mm | canopy height |
| root_depth | mm | depth of roots |
| plants | plants/m 2 | plant density |
| cover_green | 0-1 | fraction of radiation reaching the canopy that is intercepted by the green leaves of the canopy |
| cover_tot | 0-1 | total crop cover fraction |
| lai_sum | m 2 /m 2 | leaf area index of all leaf material live + dead |
| tlai | m 2 /m 2 | total lai (senseced plus green) |
| slai | m 2 /m 2 | area of leaf that senesces from plant |
| lai | m 2 /m 2 | live plant green lai |
| tlai_dead | m 2 /m 2 | total lai of dead plants |
| root_wt | g/m 2 | root biomass |
| leaf_wt | g/m 2 | leaf biomass |
| stem_wt | g/m 2 | stem biomass |
| pod_wt | g/m 2 | pod biomass |
| grain_wt | g/m 2 | grain biomass |
| dm_green (max_part = 6) | g/m 2 | live plant dry weight (biomass) of each plant part |
| dm_senesced (max_part = 6) | g/m 2 | senesced plant dry wt of each plant part |
| dm_dead (max_part = 6) | g/m 2 | dead plant dry weight of each plant part |
| yield | kg/ha | grain yield dry wt |
| biomass | kg/ha | total above-ground biomass |

| | | |
|---|---|---|
| green_biomass | kg/ha | total above-ground biomass of green material |
| biomass_wt | g/m 2 | total above-ground biomass |
| | | |
| dlt_dm | g/m 2 | the daily biomass production |
| dlt_dm_green (max_part = 6) | g/m 2 | daily plant biomass growth of each plant part |
| dlt_dm_green_retrans (max_part = 6) | g/m 2 | daily plant biomass retranslocation of each plant part |
| dlt_dm_detached (max_part = 6) | g/m 2 | daily biomass detached from live plants of each plant part |
| dlt_dm_dead_detached (max_part = 6) | g/m 2 | daily biomass detached from dead plants of each plant part |
| n_green (max_part = 6) | g/m 2 | plant nitrogen content of each plant part |
| n_senesced (max_part = 6) | g/m 2 | plant n content of senesced plant of each plant part |
| n_dead (max_part = 6) | g/m 2 | plant n content of dead plants of each plant part |
| dlt_n_green (max_part = 6) | g/m 2 | actual n uptake into plant of each plant part |
| dlt_n_retrans (max_part = 6) | g/m 2 | nitrogen retranslocated out from parts to grain of each plant part |
| dlt_n_detached (max_part = 6) | g/m 2 | actual n loss with detached plant of each plant part |
| dlt_n_dead_detached (max_part = 6) | g/m 2 | actual n loss with detached dead plant of each plant part |
| swdef_pheno | | water deficit factor for phenology |
| swdef_photo | | water deficit factor fo photosynthesis |
| swdef_expan | | water deficit factor for leaf expansion |
| swdef_fixation | | water deficit factor for nitrogen fixation |
| oxdef_photo | | oxygen deficit (waterlogging) factor for photosynthesis |
| ep | mm | Transpiration (Total water uptake from profile) |
| cep | mm | cumulative water uptake |

| | | |
|---|---|---|
| sw_uptake(max_layer = 100) | mm | Water uptake from each profile layer |
| sw_demand | mm | total crop demand for water |
| sw_supply | mm | Total water supply over profile |
| sw_supply_layr(max_layer = 100) | mm | water supply in each profile layer |
| esw_layr (max_layer = 100) | mm | plant extractable soil water in each profile layer |
| n_conc_stover | % | sum of tops (leaf, stem and pod) actual n concentration |
| n_conc_crit | % | sum of tops (leaf and stem) critical n concentration |
| n_conc_leaf | % | actual n concentration in leaf |
| n_conc_stem | % | actual n concentration in stem |
| n_conc_grain | % | actual n concentration in grain |
| n_conc_min | % | minimum n concentration in tops (leaf and stem) |
| n_uptake or biomass_n | g/m 2 | cumulative total n uptake (minus roots): live, dead & senesced |
| green_biomass_n | g/m 2 | cumulative total n uptake by live (green) parts (minus roots) |
| n_uptake_stover | g/m 2 | n uptake by stover (green leaf, stem and pod) |
| no3_tot | g/m 2 | total no3 in the root profile |
| n_demand | g/m 2 | sum n demand for plant parts |
| n_supply_soil | g/m 2 | n supply from soil |
| dlt_n_fixed_pot | g/m 2 | daily potential N fixation |
| dlt_n_fixed | g/m 2 | actual daily N fixation |
| n_fixed_tops | g/m 2 | cumulative N fixed in above-ground biomass |
| nfact_photo | | N deficit factor for photosynthesis |
| nfact_grain | | N deficit factor for grain N content |
| rlv (num_layers) | mm/mm 3 | root length density in soil layer |

| | | |
|---|---|---|
| no3_demand | kg/ha | plant demand for nitrate (when using APSSWIM) |
| root_length (max_layer = 100) | mm/mm 2 | total root length per unit ground surface area in each profile layer |

## Validation

The Plant module has been described by Robertson et al. (2002). Previous models covering the species now in the Plant module have been validated by Adiku et al. (1993) (cowpea), Carberry (1996) (chickpea, mungbean, cowpea, soybean), Carberry et al. (1996a,b) (stylosanthes), lucerne (Probert et al. 1998), fababean (Robertson et al., in press), canola (Robertson, et al.,1999) and pigeonpea (Robertson et al., 2002).

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Robertson MJ, Carberry PS, Huth NI, Turpin JE, Probert ME, Poulton PL , Bell M, Wright, GC, Yeates SJ and Brinsmead RB 2002. Simulation of growth and development of diverse plant species in APSIM. *Australian Journal of Agricultural Research* **53** , 643-651.

Sinclair, T.R. 1986. Water and nitrogen limitations in soybean grain production. Field Crops Res. 15: 125-141.

J.E. Turpin, M.J. Robertson, C. Haire, W.D. Bellotti, A.D. Moore and I. Rose (in press). Simulating fababean development, growth and yield in Australia . *Australian Journal of Agricultural Research.*

# Rice (Oryza2000)

The APSIM Rice module is an implementation of the Oryza2000 model produced by IRRI.

Please see the official IRRI documentation for Oryza2000 for more information.

IRRI official site

There is also a Text Book called **"Oryza2000: Modeling Lowland Rice"**
by B.A. Bouman, M.J. Kropff, T.P. Tuong, M.C.S. Wopereis, H.F.M. ten Berge, H..H. van Laar. **ISBN** is **971-22-0171-6**

# Slurp

## Description

The APSIM slurp module provides a user-defined sink for soil water that can be used to fill the role of a crop within a simulated system.

Inputs for the slurp module consist of plant root (root length profile and extraction potential) and canopy (live LAI, dead LAI, extinction coefficients and canopy height) information. There is also a switch to state whether slurp is to calculate its own soil water uptake or receive this information from another APSIM module.

The slurp module can operate in two modes. The first and simplest mode is where the uptake_source is set to 'APSIM'. In this type of operation slurp is simply a provider of information to other modules in the APSIM system that perform extraction of water and solutes (eg APSwim). In the second mode of operation the uptake_source is set to 'calc' and the soil water demand is taken from the soil by SLURP (if adequate reserves exist) and root length is used to partition uptake between layers.

# Sorghum

## SORGHUM Module Scope

The sorghum module simulates the growth of a sorghum crop in a daily time-step (on an area basis not single plant). Sorghum growth in this model responds to climate (temperature, rainfall and radiation from the met module), soil water supply (from the soilwat module) and soil nitrogen (from the soiln module). The sorghum module returns information on its soil water and nitrogen uptake to the soilwat and soilnmodules on a daily basis for reset of these systems. Information on crop cover is also provided to the soilwat module for calculation of evaporation rates and runoff. Sorghum stover and root residues are 'passed' from sorghum to the residue and soiln module respectively at harvest of the sorghum crop.

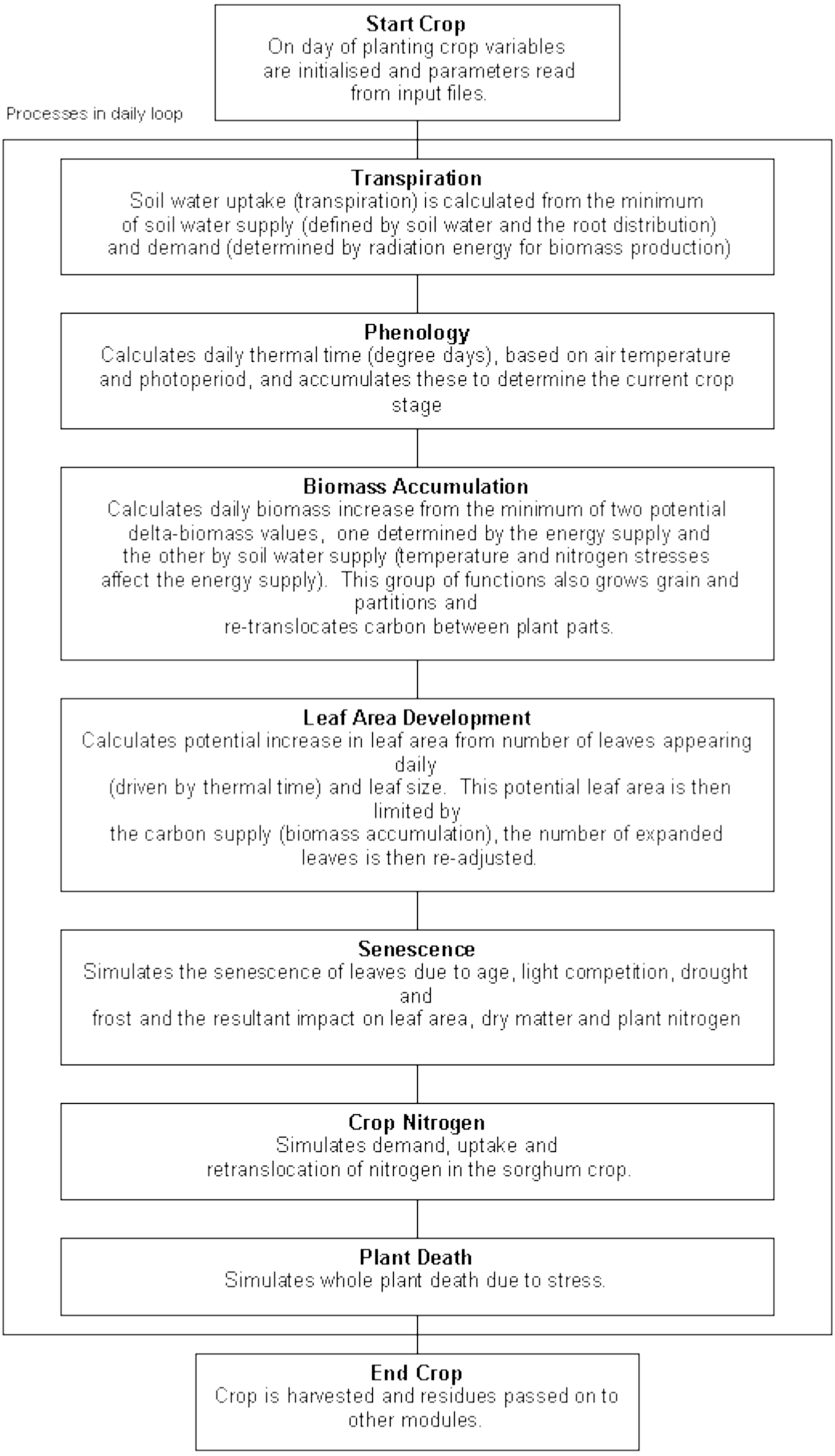
A list of the module outputs is provided in the 'Sorghum module outputs' section below, but basically the module will predict leaf area development, N% and biomass of stover; depth, N% and biomass of roots; grain N% and biomass; grain yield and N%, grain size and grain number all on a daily basis.

## Sorghum Module History

The sorghum module was originally developed from the QSORG model (Hammer and Muchow 1991) with features of the AUSIM model (Carberry and Arbrecht 1991) but has been extensively revised and improved since then.

## Sorghum Module Structure

*Figure 1: Order of key simulation steps in the sorghum module.*


Start Crop
On day of planting crop variables are initialised and parameters read from input files.
Processes in daily loop
Transpiration
Soil water uptake (transpiration) is calculated from the minimum of soil water supply (defined by soil water and the root distribution) and demand (determined by radiation energy for biomass production)
Phenology
Calculates daily thermal time (degree days), based on air temperature and photoperiod, and accumulates these to determine the current crop stage
Biomass Accumulation
Calculates daily biomass increase from the minimum of two potential delta-biomass values, one determined by the energy supply and the other by soil water supply (temperature and nitrogen stresses affect the energy supply). This group of functions also grows grain and partitions and re-translocates carbon between plant parts.
Leaf Area Development
Calculates potential increase in leaf area from number of leaves appearing daily (driven by thermal time) and leaf size. This potential leaf area is then limited by the carbon supply (biomass accumulation), the number of expanded leaves is then re-adjusted.
Senescence
Simulates the senescence of leaves due to age, light competition, drought and frost and the resultant impact on leaf area, dry matter and plant nitrogen
Crop Nitrogen
Simulates demand, uptake and retranslocation of nitrogen in the sorghum crop.
Plant Death
Simulates whole plant death due to stress.
End Crop
Crop is harvested and residues passed on to other modules.

# Sorghum Module Components

## Phenology

There are 11 crop stages and nine phases (time between stages) in the **sorghum** module (Table 1), and commencement of each stage (except for sowing to germination which is driven by soil moisture) is determined by accumulation of thermal time. Each day the phenology routines calculate today's thermal time (in degree days) from 3-hourly air temperatures interpolated from the daily maximum and minimum temperatures. Thermal time is calculated using the relationship in Figure 1 with the eight 3-hour estimates averaged to obtain the daily value of thermal time (in growing degree days) for the day. Different thermal time relationships are used for development before and during drain-filling. These daily thermal time values are cumulated into a thermal time sum which is used to determine the duration of each phase. Between the stage of emergence and flowering the calculated daily_thermal_time is reduced by water or nitrogen stresses, resulting in delayed phenology when the plant is under stress.

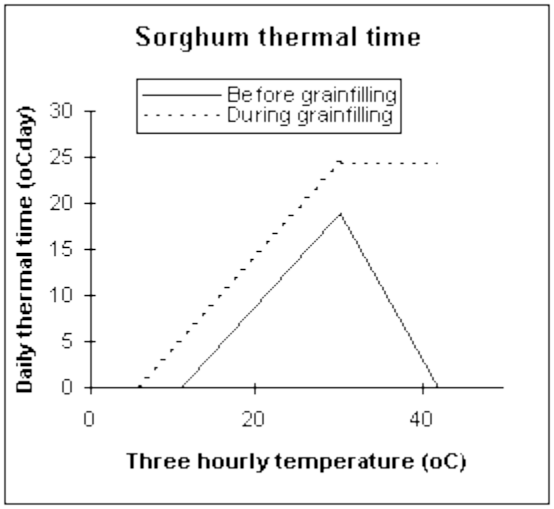



*Figure 2: Relationship between temperature and thermal time accumulation. In the sorghum module different relationships are used for development before and during grainfilling.*

*Table 1: Phenological stages simulated in the sorghum module.*

| Stage code | Stage name | Stage description |
|---|---|---|
| 1 | sow | Sowing |
| 2 | germ | Germination |
| 3 | emerg | Seedling emergence |

| | | |
|---|---|---|
| 4 | End_juv | End of the juvenile phase |
| 5 | fi | Floral initiation |
| 6 | flag | Appearance of the flag leaf |
| 7 | Start_grain_fill | Start of linear phase of grain filling |
| 8 | End_grain_fill | End of linear phase of grain filling |
| 9 | maturity | Physiological maturity |
| 10 | Harvest_ripe | Ready for harvest |
| 11 | End_crop | Crop finished and absent from simulation |

The thermal time between sowing and germination is dependent upon soil water status. The phase between germination and emergence includes an effect of the depth of sowing on the thermal time target. The duration between emergence and flag leaf appearance is determined by the total number of leaves destined to appear on the plant, and the rate at which they appear, which is determined by temperature (see below). The total number of leaves is equal to the number in the seed at germination (4) plus the number subsequently initiated at a rate of 21 o Cdays per leaf, until floral initiation is reached. Hence the timing of floral initiation will determine the total leaf number and the timing of the appearance of the flag leaf and flowering. The phase between emergence and floral initiation is composed of a cultivar-specific period of fixed thermal time, commonly called the basic vegetative or juvenile phase. Between the end of the juvenile phase and floral initiation the thermal development rate is sensitive to photoperiod (calculated as a function of day of year and latitude) if the cultivar is photoperiod sensitive. The model assumes that sorghum, as a short day plant, will have a longer phase (dependent upon cultivar) between the end of the juvenile phase and initiation if photoperiods exceed the base photoperiod. There are cultivar-specific fixed thermal time durations for the subsequent phases between flowering and the start of grain fill, between the start and end of grainfill, between the end of grainfill and maturity, and between maturity and harvest ripe. Table 2 gives phenology parameters currently available in the sorghum module.

## Biomass accumulation (Photosynthesis)

Each day two estimates of the daily biomass production are calculated, one limited by available water for transpiraton (eqn 1), and the other limited by radiant energy (eqn 2). The minimum of these two estimates is the actual biomass production for the day.

delta_drymatter_transpiration = soil_ water_ supply * transpiration_efficiency eqn 1.

Note: transpiration_efficiency is derived from the transpiration_efficiency_coefficient (=0.009 kPa) and the vapour pressure deficit (vpd) estimated from daily temperatures.

dlt_drymatter_potential = rue *radiation_interception eqn 2.

Note rue (radiation-use efficiency) is 1.25 g MJ-1 from emergence to end of grain filling. Radiation interception is calculated from leaf area index and a radiation extinction coefficient, which varies with row spacing (Fig. 3). If row spacing is not supplied in the sowing command, the default row spacing of 0.75 m is used, corresponding to an extinction coefficient of 0.40.

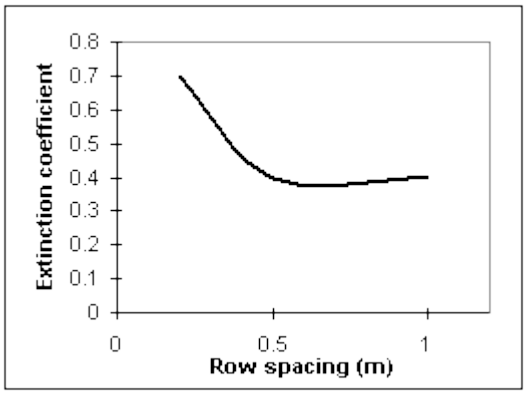


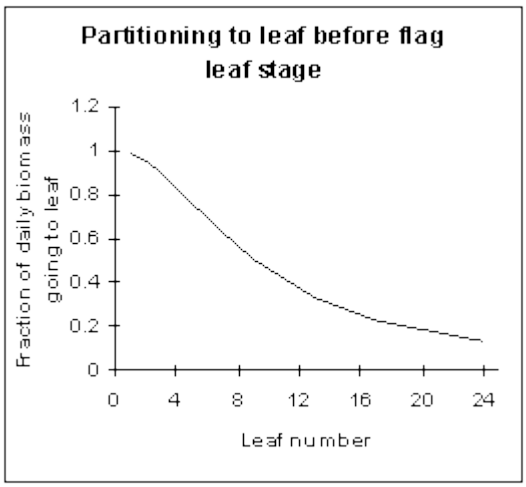

*Figure 3: Relationship between the radiation extinction coefficient and row spacing used in the sorghum module.*

## Biomass partitioning

Daily biomass production is partitioned to different plant parts in different ratios depending on crop stage.

Until the end of juvenile phase the root:shoot ratio is maintained at 1.0, and then decreases to a value of 0.087 at flowering.

Between emergence and flag leaf appearance the proportion of biomass produced that is partitioned to leaf increases exponentially as leaves appear (Fig. 4).




Between the stage floral initiation and flag leaf appearance, the biomass remaining after allocation to leaf is allocated between stem and developing panicle in the ration 1:0.30. After leaf growth has ceased at flag leaf appearance, biomass is partitioned between stem and panicle only until the start of grain filling, whereupon partitioning to grain only occurs. The sorghum module allows a total retranslocation of no more than 15 and 20% of leaf and stem biomass present at the start of grainfilling, respectively

*Figure 4: Fraction of daily biomass produced that is partitioned to leaf as a function of leaf number.*

Grain demand for carbohydrate (biomass) is calculated as a function of grain number. The number of grains set per plant is determined by the average daily growth rate per plant between floral initiation and the start of grain filling.

## Leaf development

**Leaf appearance rate** is driven by thermal time, the last 3.5 leaves before the flag leaf appear each 20 o Cdays, before which a leaf appears every 41 o Cdays.

**Potential LAI** is a product of leaf area per plant, number of plants per m2 and the water stress factor for expansion (see water deficits section below). Leaf area per plant is simulated as a sigmoidal function of thermal time since emergence, the parameters of which are cultivar-specific (see Table 2).

**Actual LAI** is less than the potential LAI if there is not sufficient biomass partitioned to leaf on that day. Maximum specific leaf area (SLA_MAX) defines the maximum leaf area (m 2 ) that can be expanded per gram of biomass, and is set to a value of 450 cm 2 g -1 .

**Leaf senescence** There are four causes of leaf senesence; age, light competition, water stress and frost.
The **sorghum** senescence routines calculate a senesced LAI for each stress each day and take the maximum of the four values as the day's total senescence.

This **senescence due to age** occurs on a per plant basis and is a function of thermal time elapsed since flowering. The parameters defining the rate of whole-plant leaf area senescence due to age are cultivar-specific.

Above an LAI of 4.0 **light competition** causes leaf area to be lost. The LAI senesced because of light competition is related to the amount LAI exceeds 4.0 (see eqns 3 and 4).

sensLAI_light_fac = 0.008 *(LAI- 4.0) eqn 3.

delta_sensLAI_light = LAI * sensLAI_light_fac eqn 4.

**Water stress** during crop growth will cause leaf senescence (eqns 5 and 6).

sensLAI_water_fac = 0.05 * (1 - sorghum_swdef(photo)) eqn. 5.

delta_sensLAI_water = LAI * sensLAI_water_fac eqn 6.

Note: the calculation of the water stress factor sorghum_swdef(photo) is descibed in the ‘water deficits' section below.

**Frost senescence.** Temperatures between 6.0 and 0 o C will cause a linearly increasing loss of leaf area from 0 to 100% respectively.

From the values of senesced LAI the sorghum module calculates the biomass and nitrogen in that leaf area that is senesced, however a proportion of the carbon and nitrogen of these leaves is retranslocated to stem before senescence.

## Tillering

Tiller number is not dynamically-determined in the **sorghum** module but is set in the sowing command As temperature during the early part of the season and plant density is known to influence the number of tillers produced, it is necessary for the user to set the potential tiller number given an understanding of the likely tiller number produced. As a guideline in cool environments and/or early sowings under low density where maximum tillering would be expected, tiller number would vary between 1.5 and 2 m -2. With low density this would be around 0.3 tillers m -2 . On the other hand in warm environments or late sowings tiller number could vary between 0.75 and 1 m -2 at low population density and around 0.15 m -2 at high density.

## Row Configuration

Sorghum row configuration can be set to solid, single skip or double skip.

In simulating skip row sorghum the assumption of a horizontally distributed leaf area does not hold. To account for this the equation for calculating the percentage green cover of the plant is changed from equation 1 to equation 2

Eq1 %green cover = $1 - \exp(-kl)$ where k is the extinction coefficient of the crop at that row spacing and l is the leaf area index

Eq2 % green cover = $\frac{1-\exp(-KIS)}{S}$ where k is the extinction coefficient of the crop at that row spacing, l = is the leaf area index and s is the skip index (1 for no skipped rows, 1.5 for one skipped row, and 2 for two skipped rows)

With a skip row planting configuration, the wide gap between plants implies that root expansion is multi-directional, allowing more time for the roots to reach the centre of the skip rows. The root expansion front is described by a semi circular front expanding from the base of the plant at a rate of 2 cm per day in all directions. (see the output variable "root_proportion").

## Regrowth

Although in practice it is possible to ratoon sorghum, there are no regrowth routines in **sorghum** .

## Water uptake

To determine the amount of water supply to the crop on any day, first the total available water above the lower limit for all soil layers with roots is summed (eqn 7). If roots are only partially through a layer available soil water is scaled to that portion that contains roots. The kl constant (value differs for each soil layer) is then used to limit the amount of water available on any day (eqn 8). The kl factor is emphirically derived, incorporating both plant and soil factors which limit rate of water uptake.

do layer = 1, deepest_layer (do loop to calculate available water for all layers)

sw_avail = sw(layer) - ll (layer) eqn 7.

sw_supply(layer) = sw_avail * kl (layer) eqn 8.

**Soil water demand** is calculated as in the 'biomass accumulation' section above where potentail biomass production is a function of light interception and rue (eqn 1). This potential biomass production is converted to water demand using transpiration efficiency.

**Water uptake** is the minimum of the supply and demand.

## Water deficits affecting plant growth

Soil water deficit factors are calculated to simulate the effects of water stress on different plant growth processes. Three water deficit factors are calculated which correspond to four plant processes each having different sensitivity to water stress i.e. photosynthesis (photo), phenology (pheno), and leaf-expansion (expansion) (Figure 5).

A water availability ratio is calculated by dividing actual soil water supply (sw - ll) by the potential soil water supply (dul - ll). This ratio is used in the relationships illustrated to derive the stress factors for photosynthesis and leaf expansion. A factor of 0 is complete stress and 1 no stress.

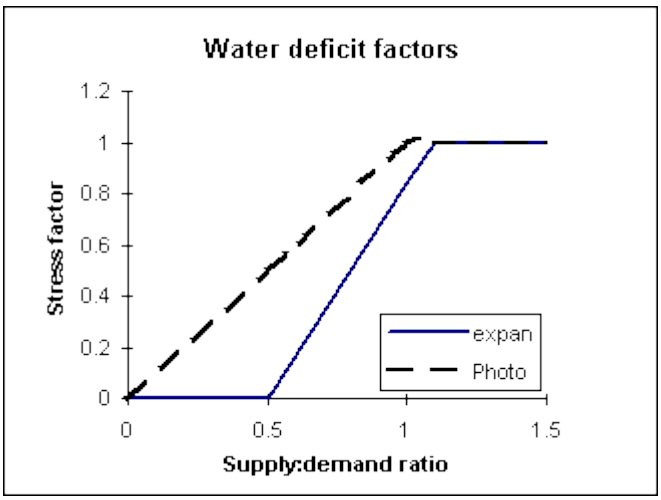



*Figure 5: Relationship between daily soil water supply:demand ratio and the level of stress on photosynthesis and leaf expansion.*

A fraction of plants (0.044) will be killed each day due to water stress once the cumulative water stress factor for photosynthesis exceeds 4.6.

## Nitrogen uptake and retranslocation

In order to calculate **nitrogen demand** today, first potential biomass production is re-calculated unlimited by water, nitrogen or temperature i.e. as a function of rue and radiation-interception (eqn 2). This dry matter (biomass) is then partition into plant parts according to their current relative weights.

Nitrogen demand by root and flower is the N required to attain a Nitrogen target concentration.

| | Root | Flower |
|---|---|---|
| Nitrogen target concentration = | 0.002 | 0.005 |

Stem Nitrogen demand is N required to achieve a Nitrogen target concentration depending on current phenological stage.

| Emergence | Flowering |
|---|---|

| | | |
|---|---|---|
| Stem Nitrogen target concentration = | 0.055 | 0.010 |

Nitrogen demand in the leaf up to Flag leaf stage is N required to keep leaf at target SLN of 1.5. After flag, N Required to maintain SLN.

## Grain Demand

Grain Fill rate 0.001 mg/grain / degreeday for first 100 dd

Grain N demand attempts to stay at this fill rate.

**Nitrogen supply** is the sum of nitrogen available via mass flow (eqn 9) and by diffusion (eqn 10).

no3_massflow (layer) = no3_conc * delta_sw (layer) eqn 9.

no3_diffusion (layer) = sw_avail_frac *no3_conc eqn 10.

note: these layer values are summed to root depth and sw_avail_frac is ratio of extractable soil-water over total soil-water.

If nitrogen demand cannot be satisfied by mass flow then it is supplied by diffusion. Demand can only be exceeded by supply from mass flow (up to the nitrogen uptake maximum

Nitrogen available for uptake is distributed to plant parts in proportion to their individual demands.

Grain N demand is a function of the grain number and a specific N demand per grain.

## Nitrogen deficits affecting plant growth

There are three N availability factors (0-1), one each for the photosynthesis, expansion, phenology and grain filling processes. A N concentration ratio is calculated for the stover (stem + leaf) in eqn 14 which is used as a measure of N stress, then different constants are used to convert that ratio to a deficit factor for each of the processes. A factor of 1 is used for effecting grain N concentration, 1.25 for photosynthesis (reduces rue), 0.8 for expansion (reduces leaf area expansion) and 5.75 to slow phenological development. As a value of 1 is no stress and 0 complete stress, phenology is least sensitive to nitrogen deficiency and grain N the most.

N_conc_ratio = (N_conc_stover - N_conc_stover_min) / (N_conc_stover_crit - N_conc_stover_min) eqn14.

## Root growth and distribution

Root depth is initialised at the depth of sowing. Between emergence and grain filling, the increase in root depth is a daily rate multiplied a soil water availability factor. The daily rate is 10-15 mm/day during emergence and 33mm/day from end-of-juvenile to the start of grain-filling. Root depth is constrained by the soil profile depth. The increase of root depth through a layer can be constrained by known soil constraints through the use of the 0-1 parameter **xf,** which is input for each soil layer.

Growth of root biomass is partitioned with depth using an exponential decay function from the soil surface and converted to root length density using a fixed specific root length.

Roots are not senesced during the life of the crop, but are incorporated in the **soiln** module at harvest and distributed as fresh organic matter in the profile

### Temperature stress

There are no generic temperature factors, as for water and nitrogen stress, but as discussed in sections above temperature does influence the rate of leaf senescence and radiation use efficiency.

### Plant death

All or some of the plants can be killed due to a variety of stresses;

If the crop hasn't germinated within 40 days of sowing, due to lack of germinating moisture, all plants are killed.

If the crop does not emerge with 150 o Cdays of sowing, because it was sown too deep, then all plants are killed.

If crop is past floral initiation and LAI = 0, then all plants are killed due to total senescence.

If the cumulative phenological water stress factors exceed 25, all plants are killed due to water stress prolonging phenology.

A fraction of plants will be killed by high temperatures immediately following emergence.

### Detachment

The detachment routines in **sorghum** are disabled in the current code.

## Sorghum Module Parameterisation

Crop lower limit (ll), root water extraction constants (kl) and root extension factors (0-1, xf) values are needed for each soil layer

*test.sorghum.parameters*

ll = 0.200 0.200 0.200 0.220 0.250 () ! crop lower limit

kl = 012 0.08 0.06 0.04 0.02 () ! kl need calibrating for each crop and soil type

xf = 1.0 1.0 1.0 1.0 1.0 ()

Phenology, leaf area and grainfilling parameters are needed for each cultivar. An example is given below of those for the three generic maturity classes.

*Table 2: Cultivar parameters for generic early, mid and late-season cultivars in the sorghum module.*

| | **Parameter values for cultivars of maturity classes** |
|---|---|

| Parameter name | Parameter units | Early | Medium | Late |
|---|---|---|---|---|
| tt_emerg_to_endjuv | ( o C day) | 100 | 100 | 100 |
| est_days_endjuv_to_init | () | 15 | 20 | 20 |
| pp_endjuv_to_init | | 30 | 30 | 30 |
| tt_endjuv_to_init | ( o C day) | 115 | 120 | 255 |
| photoperiod_crit1 | (hours) | 12.3 | 12.3 | 12.3 |
| photoperiod_crit2 | (hours) | 14.6 | 14.6 | 14.6 |
| photoperiod_slope | ( o C/hour) | 25 | 38.4 | 38.4 |
| tt_flower_to_maturity | ( o C day) | 695 | 695 | 695 |
| tt_flag_to_flower | ( o C day) | 100 | 100 | 80 |
| tt_flower_to_start_grain | ( o C day) | 30 | 30 | 50 |
| tt_maturity_to_ripe | ( o C day) | 1 | 1 | 1 |
| Main_stem_coeff | (1/oC) | 2.95 | 2.88 | 2.95 |
| Tpla_prod_coef | (1/oC) | 0.015 | 0.018 | 0.018 |
| Tpla_inflection | (oC) | 320 | 355.7 | 400.8 |
| Spla_prod_coef | (1/oC) | 0.007 | 0.007 | 0.005 |
| Spla_intercept | -250 | -250 | -280 | -321 |
| dm_per_seed | (g) | 0.00083 | 0.00083 | 0.00083 |
| x_stem_wt vs y_height | Mm vs g | 0 80 | 0 80 | 0 80 |
| | | 0 2000 | 0 2000 | 0 2000 |

## Module Dependencies

The minimum module configuration required to run **sorghum** in APSIM is the inclusion of the report, met, manager, soilwat2, soiln2 and residue2 and sorghum modules.

Within the manager file the following syntax is used for harvest and planting the sorghum crop:

```
if (sorghum.stage_name = 'harvest_ripe' and sorghum.plant_status = 'alive') then
   sorghum harvest
   sorghum kill_crop
   sorghum end_crop
endif
if (sorghum.plant_status = 'dead') then
   report do_output
   sorghum harvest
   sorghum end_crop
endif
if (day > 120 and day < 240 and sorghum.plant_status = status_out ) then
   sorghum sow plants = 15 (p/m2), sowing_depth = 50 (mm), row_spacing = 0.35 (m), cultivar = early
   , fertile_tiller_no = 1.5, skip = double
endif
```

(note: row_spacing and skip in sowing command is optional)

## Sorghum Module Outputs

*Table 3: The following Sorghum variable can be output through the report module*

| Variable Name | Units | Description |
|---|---|---|
| stage | | current phenological stage |
| stage_code | | |
| stage_name | | |
| crop_type | | |
| leaf_no | | number of fully expanded leaves |
| leaf_no_dead | | no of dead leaves |
| leaf_area (max_leaf = 1000) | mm 2 | leaf area of each leaf |
| height | mm | canopy height |

| | | |
|---|---|---|
| root_depth | mm | depth of roots |
| rlv | mm.mm -3 | root length per volume of soil in each soil layer |
| hi | | Harvest index |
| plants | plants/m 2 | plant density |
| grain_no | grains/plant | grain number |
| grain_size | g | individual grain wt |
| cover_green | 0-1 | fraction of radiation reaching the canopy that is intercepted by green leaves |
| cover_tot | 0-1 | total crop cover fraction |
| lai_sum | | leaf area index of all leaf material live + dead |
| tlai | | tot lai |
| slai | | area of leaf that senesces from plant |
| lai | m 2 /m 2 | live plant green lai |
| tlai_dead | m 2 /m 2 | total lai of dead plants |
| root_wt | g/m 2 | root biomass |
| leaf_wt | g/m 2 | leaf biomass |
| stem_wt | g/m 2 | stem biomass |
| grain_wt | g/m 2 | grain biomass |
| grain_wt | g/m 2 | grain biomass |
| dm_green (max_part = 6) | g/m 2 | live plant dry weight (biomass) |
| dm_senesced (max_part = 6) | g/m 2 | senesced plant dry wt |
| dm_dead (max_part = 6) | g/m 2 | dry wt of dead plants |
| yield | kg/ha | grain yield dry wt |
| biomass | kg/ha | total above-ground biomass |
| dlt_dm | g/m 2 | the daily biomass production |
| dlt_dm_green (max_part = 6) | g/m 2 | plant biomass growth |

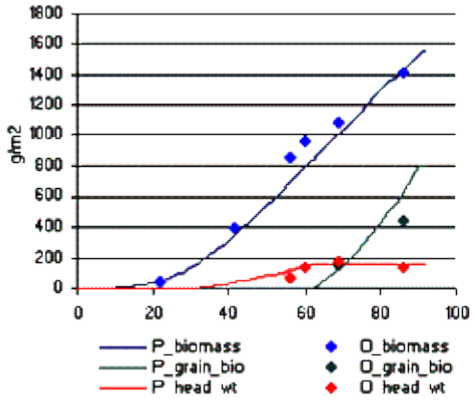
| | | |
|---|---|---|
| n_green (max_part = 6) | g/m 2 | plant nitrogen content |
| n_senesced (max_part = 6) | g/m 2 | plant n content of senesced plant |
| n_dead (max_part = 6) | g/m 2 | plant n content of dead plants |
| dlt_n_green (max_part = 6) | g/m 2 | actual n uptake into plant |
| dlt_n_retrans (max_part = 6) | g/m 2 | nitrogen retranslocated out from parts to grain |
| dlt_n_detached (max_part = 6) | g/m 2 | actual n loss with detached plant |
| dlt_n_dead_detached (max_part = 6) | g/m 2 | actual n loss with detached dead plant |
| swdef_pheno | 0-1 | water deficit factor for phenology |
| swdef_photo | 0-1 | water deficit factor fo photosynthesis |
| swdef_expan | 0-1 | water deficit factor for leaf expansion |
| ep (num_layers) | mm | water uptake in each layer |
| cep | mm | cumulative water uptake |
| sw_demand | mm | total crop demand for water |
| sw_supply | mm | total supply over profile |
| esw_layr (num_layers) | mm | plant extractable soil water |
| n_conc_stover | % | sum of tops actual n concentration |
| n_conc_crit | % | sum of tops critical n concentration |
| n_grain_pcnt | % | grain n concentration percent |
| n_uptake_grain | g/m 2 | n uptake by grain |
| n_uptake | g/m 2 | cumulative total n uptake by plant |
| n_uptake_stover | g/m 2 | n uptake by stover |
| no3_tot | g/m 2 | total no3 in the root profile |
| n_demand | g/m 2 | sum n demand for plant parts |
| n_supply | g/m 2 | n supply for grain |
| n_supply_soil | g/m 2 | n supply from soil |

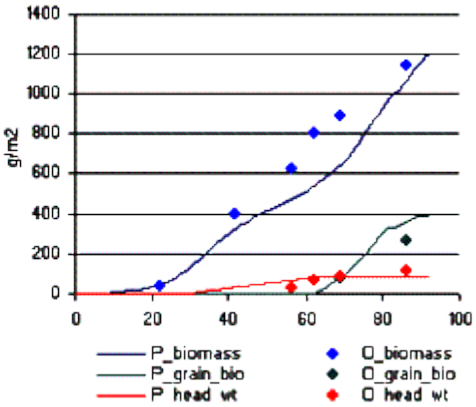
| | | |
|---|---|---|
| n_fix_pot | g/m 2 | potential N fixation |
| nfact_photo | | N deficit factor for photosynthesis |
| nfact_grain | | N deficit factor for grain N content |
| nfact_photo | 0-1 | Nitrogen stress factor for photosynthesis |
| nfact_expan | 0-1 | Nitrogen stress factor for cell expansion |
| dlt_tt | o Cday | daily thermal time |
| das | | days after sowing |

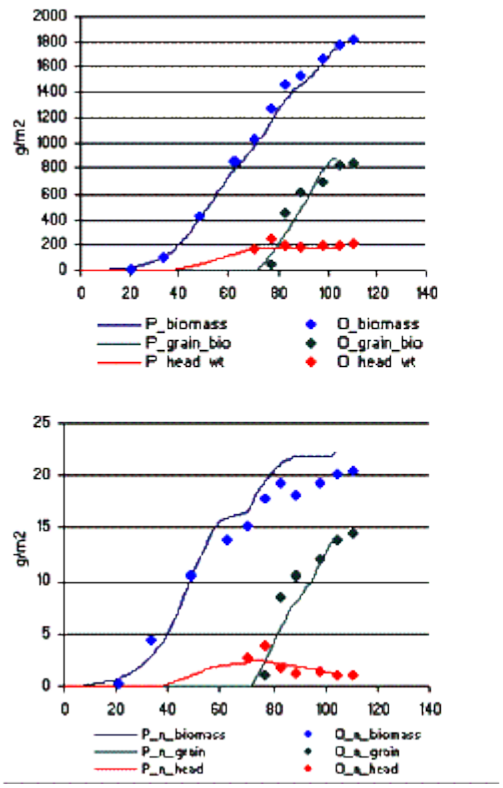
## Sorghum Module Validation

The following are some examples of module validation.

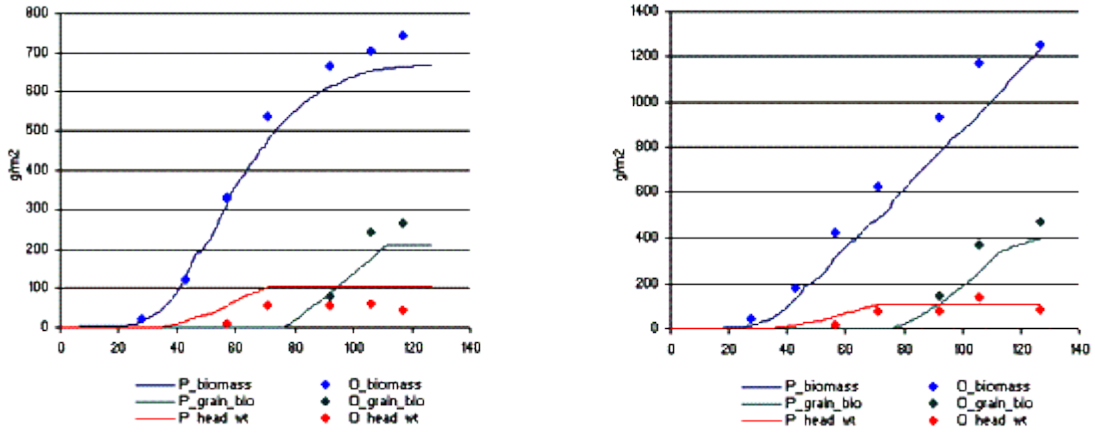
Katherine – effects of water deficit

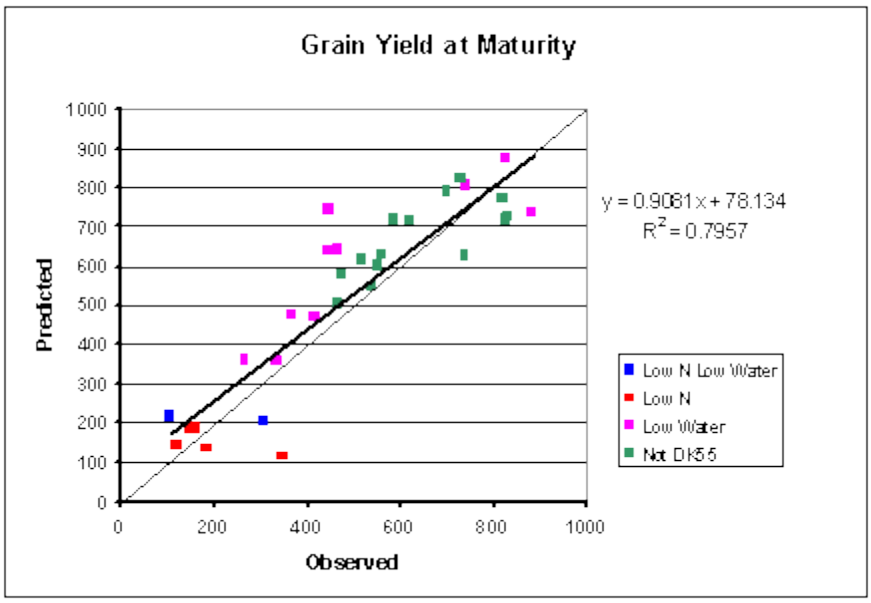


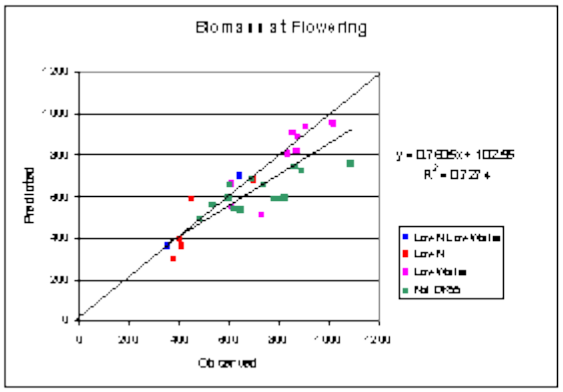



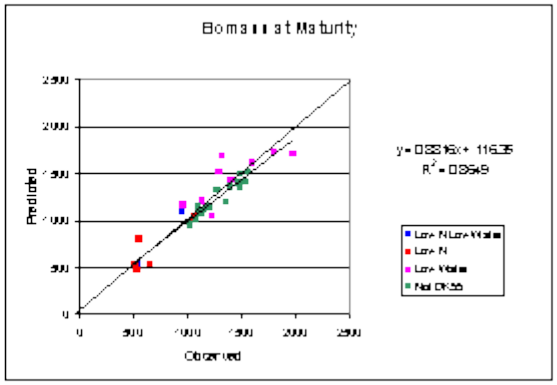



Gatton – differences in applied nitrogen. The rate of 240 kgN/ha is in the LHS graphs and 0 kgN/ha on the RHS.






## REFERENCES

Hammer, G. L., & Muchow, R.C. (1991). Quantifying climatic risk to sorghum in Australia's semi-arid tropics and subtropics: model development and simulation. In *Climatic Risk in Crop Production: Models and Management for the Semi-arid Tropics and Subtropics,* eds R.C. Muchow & J.A. Mellamy. Ch. 16, Wallingford, CAB International, pp 205-32.

Carberry, P.S. & Abrecht, D.G. (1991) Tailoring crop models to the semi-arid tropics. In *Climatic Risk in Crop Production: Models and Management for the Semi-arid Tropics and Subtropics,* eds R.C. Muchow & J.A. Bellamy. CAB International, Wallingford, pp 157-82.

# SoyBean

## Introduction

The soybean module was developed Michael Robertson with contributions from Peter Carberry. APSIM-Soybean belongs to the PLANT family of crop modules in APSIM. The reader is referred to the science document for the plant module for a comprehensive description of the processes simulated by APSIM-Soybean. This document outlines some soybean-specific issues that are not covered by the legume science document.

Notable features of APSIM-SOYBEAN

The phenology of soybean cultivars are responsive to temperature and photoperiod, but not vernalisation. There is no photoperiod effect on post-flowering duration, even though it is known that such an effect exists.

There are a limited number of cultivars available and users should consult the module owner if they need advice specifying a new cultivar

Account is taken of the energy costs involved in synthesising the high energy content grain in soybean.

Oil content is not simulated dynamically in response to any cultivar or environmental effects.

APSIM-Soybean is not phosphorus-responsive, this is currently under development.

Crop growth is not sensitive to waterlogging.

The module does not simulate the differences between determinant and indeterminant types in terms of canopy expansion and flowering.

Goto generic Plant model documentation

## Cultivars and crop classes

There are two crop classes. One is the conventional type, and the other is a promiscuous nodulator, often grown in the developing world. The promiscuous crop class has low N fixation capacity.

There are 8 cultivars able to be simulated: Davis, Buchanan, CPI26671, Durack, Valiant, Roan, Magoye and Dragon. Cultivars differ in terms of biomass partitioning to grain and phenology. Cultivar Magoye, listed below, is a promiscuous type. It has a lower harvest index.

## Validation

APSIM-Soybean has received testing across northern Australia, with factors such as cultivars, sowing date, irrigation, soil type, plant population density row spacing varying. Papers describing validation of APSIM-Soybean are by Robertson and Carberry (1998) and Denner et al. (1998). The accompanying figure demonstrates the performance of the module against Australian datasets.

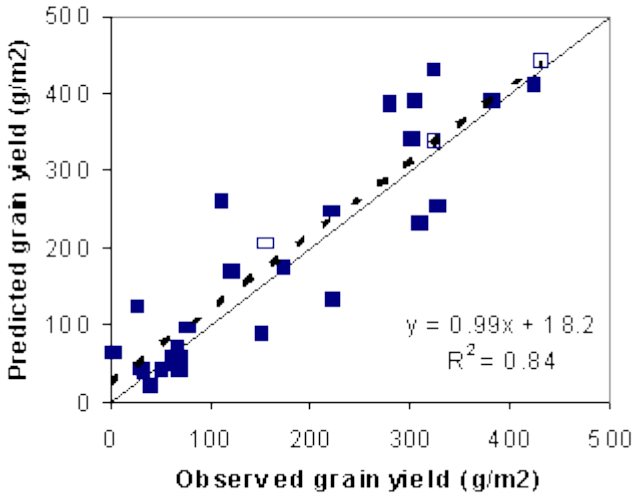



*Figure 1: Performance of the soybean module (observed versus simulated grain yield in g/m2) against test datasets reported by Robertson and Carberry (1998).*

## References

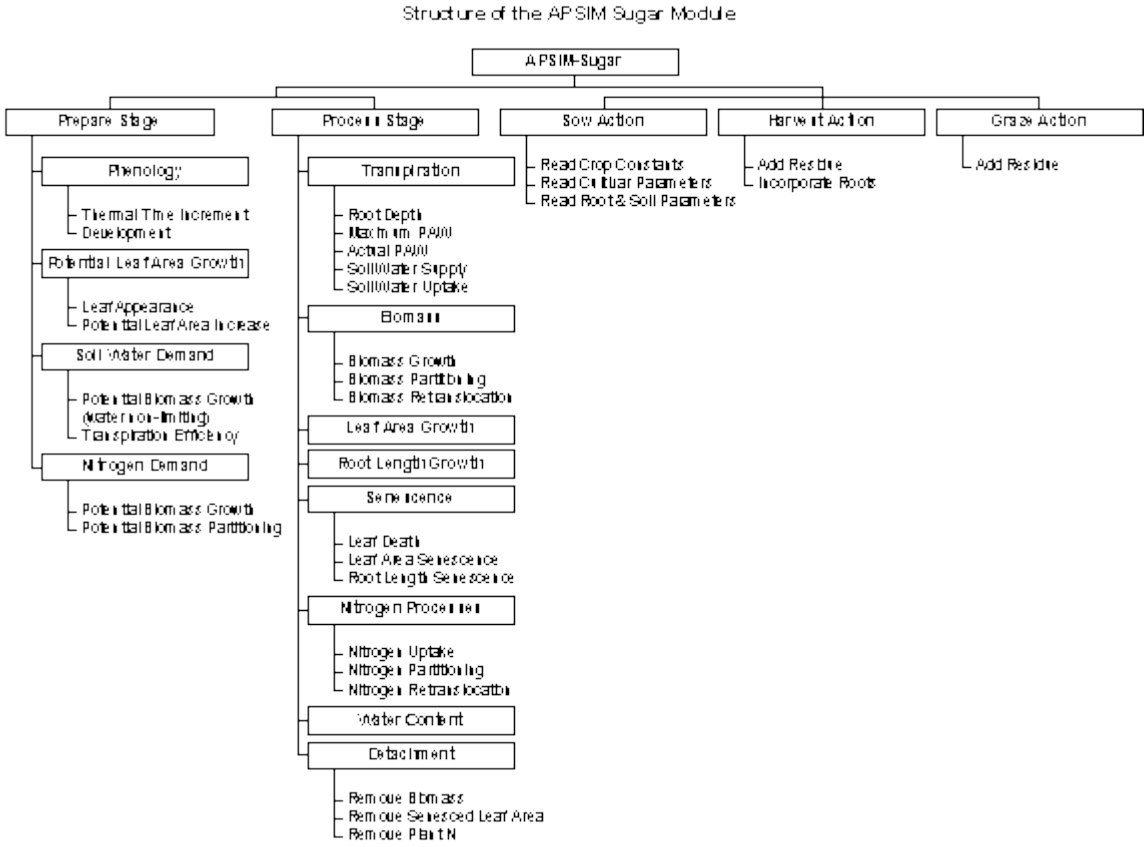
Denner, M. T.; James, A. T.; Robertson, M. J., and Fukai, S. 1998. Optimum soybean cultivars for possible expansion area: a modelling approach. Proceedings 10th Australian Soybean Conference, Brisbane 15-17 September, 1998:137-141.

Robertson, M. J. and Carberry, P. S. 1998. Simulating growth and development of soybean in APSIM. Proceedings 10th Australian Soybean Conference, Brisbane 15-17 September, 1998:130-136.

# Sugar

## Introduction

The structure of the APSIM sugar model can be described as follows:




## Order of Calculations

For each APSIM time step the calculation of sugar model states and transitions are performed in a set order in different stages of the APSIM cycle through each time step.

Phenology and potential growth and demands are calculated during the prepare stage and actual growth and changes to state variables are calculated during the process stage.

## Parameterisation

### Structure of the INI file

There are **five** separate categories of variables in the sugar module's ini file.

They are listed below with some examples of the type of parameters included in each.

*Constants*

Upper and lower bounds for met and soil variables

*Plant_crop*

Growth and partitioning parameters

Water Use Parameters and Water and temperature Stress Factors

Frosting Factors

Nitrogen Contents and Nitrogen Stress Factors

*Ratoon_crop*

Same as Plant crop section but there is the ability to change the parameters between plant and ratoon crops.

*Cultivar Plant Crop*

Leaf Development Parameters

Phenology

Sucrose and cane stalk Partitioning Parameters

*Cultivar Ratoon Crop*

Same as Plant crop section but there is the ability to change the parameters between plant and ratoon crops.

# Model Components

## Overview

Crop dry weight accumulation is driven by the conversion of intercepted radiation to biomass, via a radiation-use efficiency (RUE).

RUE is reduced whenever extremes of temperature, soil water shortage or excess, or plant nitrogen deficit limit photosynthesis.

The crop leaf canopy, which intercepts radiation, expands its area as a function of temperature, and can also be limited by extremes of temperature, soil water shortage or excess, or plant nitrogen deficit.

Biomass is partitioned among the various plant components (leaf, cabbage, structural stem, roots and sucrose) as determined by crop phenological stage.

Nitrogen uptake is simulated, as is the return of carbon and nitrogen to the soil in trash and roots.

In many sugarcane production systems, commercial yield is measured as the fresh weight of sugarcane stems and their sucrose concentration. Hence, the water content in addition to the dry weight of the stem is simulated.

Since sugarcane is grown both as a plant and ratoon crop, the model also needs to be able to simulate differences between crop classes based on any known physiological differences between these classes.

## Crop growth in the absence of nitrogen or water limitation

### Thermal time

Thermal time is used in the model to drive phenological development and canopy expansion.

In APSIM-Sugarcane, thermal time is calculated using a base temperature of 9 $^{o}$C, optimum temperature of 32 $^{o}$C, and maximum temperature of 45 $^{o}$C.

The optimum and maximum temperatures were taken from those used for maize (Jones and Kiniry, 1986).

Base temperatures for sugarcane have been variously reported between 8 $^{o}$C and 15 $^{o}$C (Inman-Bamber 1994b, Robertson *et al*, in press).
The base of 9 $^{o}$C used in APSIM sugarcane was chosen to be consistent with those studies which sampled the greatest temperature range, namely Inman-Bamber 1994b and Robertson et al (in press) who identified base temperatures of 10 $^{o}$C and 8 $^{o}$C respectively.

For thermal time calculations in the model, temperature is estimated every three hours from a sine function fitted to daily maximum and minimum temperatures, using the method described by Jones and Kiniry (1986).

### Phenology

The sugar model uses six different stages to define crop growth and status.

| Stage | Description |
|---|---|
| sowing | From sowing to sprouting |
| sprouting | From sprouting to emergence |
| emergence | From emergence to the beginning of cane growth |
| begin_cane | From the beginning of cane growth to flowering |
| flowering | From flowering to the end of the crop |
| end_crop | Crop is not currently in the simulated system. |

Sprouting occurs after a lag period, set to 350 $^{o}$Cdays for plant crops and 100 $^{o}$Cdays for ratoon crops.
Provided the soil water content of the layer is adequate, shoots will elongate towards the soil surface at a rate of 0.8 mm per $^{o}$Cday.

The thermal duration between emergence and beginning of stalk growth is a genotype coefficient in the range 1200 to

1800 $^{o}$Cdays.

Although, sugarcane does produce flowers, the number of stalks producing flowers in a field is highly variable, and its physiological basis is not fully understood.
While the model structure has been developed to include flowering as a phenological stage, it has been deactivated until a better physiological basis for prediction is available.

### Canopy expansion

The experimental basis for the canopy expansion model is described by Robertson et al (in press).
Briefly, green leaf area index is the product of green leaf area per stalk and the number of stalks per unit ground area.

Green leaf area per stalk is simulated by summing the fully-expanded area of successive leaves that appear on each stalk, and adding a correction factor for the area of expanding leaves (set to 1.6 leaves per stalk).
Profiles of leaf area per leaf are input as genotype coefficients.
Robertson et al (in press) found leaf appearance rates declined as a continuous function of cumulative thermal time, so that at emergence leaves took 80 $^{o}$Cd to appear while leaf 40 required 150 $^{o}$Cd.
These responses are reproduced in the model (via a series of linear interpolations) in both plant and ratoon crops.

Stalk number rises rapidly to a peak during the first 1400 $^{o}$Cdays from emergence, thereafter declining to reach a stable stalk number (e.g. Inman-Bamber, 1994b).
Ratoon crops commonly reach an earlier peak stalk number than plant crops, with consequently faster early canopy expansion in ratoons (Robertson et al., 1996).
In the model, the complexity of simulating the dynamics of tillering in order to predict LAI during early growth is avoided.
Instead, the crop is conceived to have a notional constant stalk number throughout growth, usually set at 10 stalks $m^{-2}$ , although this value can be varied as an input.
The additional leaf area associated with tillers that appear and subsequently die, is captured via a calibrated tillering factor, that effectively increases the area of the leaves that are produced over the early tillering period.

The known faster early expansion of LAI in ratoon crops is simulated via two effects.
Firstly, the lag time for regrowth of shoots after harvest is shorter in a ratoon crop than is the equivalent thermal time for a plant crop to initiate stalk elongation.
Secondly, tillering is recognised in the model coefficients as making a larger contribution to leaf area development in a ratoon crop than a plant crop.

The daily rate of senescence of green leaf area is calculated as the maximum of **four** rates determined by the factors of **ageing**, **light competition**, **water stress** and **frost**.

In the model, ageing causes senescence by not allowing at any time more than 13 fully-expanded green leaves per stalk.

Light competition is simulated to induce senescence once fractional radiation interception reaches 0.85.

Water stress induces senescence once the soil water deficit factor for photosynthesis declines below 1.0.

Frosting removes 10% of the LAI per day if the minimum temperature reaches 0 $^{o}$C, and 100% if it reaches -5 $^{o}$C.

## Root growth and development

Root biomass is produced independently from the shoot, so that a proportion of daily above-ground biomass production is added to the root system.
The proportion decreases from a maximum of 0.30 at emergence and asymptotes to 0.20 at flowering.

Root biomass is converted to root length via a specific root length of 18000 mm $g^{-1}$ .
The depth of the root front in plant crops increases by 1.5 cm $day^{-1}$ (Glover, 1967) from emergence, with the maximum depth of rooting set by the user.

At harvest, 17% of roots in all the occupied soil layer die (Ball-Coelho et al., 1992).

## Biomass accumulation and partitioning

The sugar model partitions dry matter to **five** different plant pools. These are as follows:

| Plant Part | Description |
|---|---|
| Root | Below-ground biomass |
| Leaf | Leaf |
| Sstem | Structural component of millable stalk |
| Cabbage | Leaf sheath and tip of growing stalks etc |
| Sucrose | Sucrose content of millable stalk |

In addition to the five **live** biomass pools outlined above, **senescent** leaf and cabbage is maintained as trash on the plant or progressively detached to become residues on the soil surface.
In APSIM, the RESIDUE module (Probert et al., 1996) takes on the role of decomposition of crop residues.

LAI is used in the model to intercept incident solar radiation following Beer's Law, using a radiation extinction coefficient of 0.38, determined by Muchow et al. (1994b) and Robertson et al. (1996).
Intercepted radiation is used to produce daily biomass production using a radiation-use efficiency (RUE) of 1.80 g $MJ^{-1}$ for plant crops and 1.65 g $MJ^{-1}$ for ratoon crops.
The values of RUE used in the model are those adjusted upwards from field-measured values (Muchow et al. 1994b; Robertson et al., 1996a) due to the underestimate of biomass production caused by incomplete recovery of senesced leaf material (Evenson et al., 1995; Robertson et al., 1996).
In the model, RUE is reduced if the mean daily temperature falls below 15 $^{o}$C or exceeds 35 $^{o}$C, and becomes zero if the mean temperature reaches 5 or 50 $^{o}$C, respectively.
These effects are similar to those used in other models of C4 crop species (e.g. Hammer and Muchow, 1994).

**Four** above-ground biomass pools are modelled: **leaf**, **cabbage**, **structural stem**, **stem sucrose**, and an additional pool for **roots** that is simulated separately from above-ground production.

Between emergence and the beginning of stalk growth, above-ground biomass is partitioned between leaf and cabbage in the ratio 1.7:1 (Robertson et al., 1996a).

After the beginning of stem growth 0.7 of above-ground biomass is partitioned to the stem (Robertson et al., 1996a), with the remainder partitioned between leaf and cabbage in the ratio 1.7:1.
After a minimum amount of stem biomass has accumulated, the daily biomass partitioned to stem is divided between structural and sucrose pools, following the framework developed by Muchow et al. (1996a) and Robertson et al. (1996a). Thereafter, the stem biomass is equal to the sum of structural and sucrose pools.

If biomass partitioned to leaf is insufficient for growth of the leaf area, as determined by a maximum specific leaf area, then daily leaf area expansion is reduced.
If biomass partitioned to leaf is in excess of that required to grow the leaf area on that day, then specific leaf area is permitted to decrease to a lower limit, beyond which the "excess" biomass is partitioned to sucrose and structural stem.

A stalk growth stress factor is calculated as the most limiting of the water, nitrogen and temperature limitations on photosynthesis.
This stress factor influences both the onset and rate of assimilate partitioning to sucrose at the expense of structural stem.

### Stem water content

A stem water pool is simulated for the purposes of calculating cane fresh weight and CCS%.
For every gram of structural stem grown, a weight of water is considered to have been accumulated by the cane stems.
This relationship varies with thermal time, ranging from 9 g $g^{-1}$ initially, to 5 g $g^{-1}$ late in the crop life cycle.
The former represents the water content of young stem (eg. cabbage) while the latter represents a combination of young stem growth and thickening of older stem.
Sucrose deposition in the stem removes water content at the rate of 1 g water $g^{-1}$ sucrose.

### Varietal effects

Currently varieties differ in only two respects in the model.

Firstly, Inman-Bamber (1991) found that varieties in South Africa differed in the fully-expanded area of individual leaves.
The distributions for NCo376 and N14 were taken from Inman-Bamber and Thompson (1989), while that for Q117 and Q96 was those assigned values that gave best fit to the time-course of LAI during the model calibration stage.

Secondly, Robertson et al. (1996a) found that varieties from South Africa and Australia differed in terms of partitioning of biomass to sucrose in the stem.
There is scope for incorporating other varietal differences as new knowledge becomes available.

## Water deficit limitation

Soil water infiltration and redistribution, evaporation and drainage is simulated by other modules in the APSIM framework (Probert et al., 1996, Verburg et al, 1997).

Water stress in the model reduces the rate of leaf area expansion and radiation-use efficiency, via two soil water deficit factors, which vary from zero to 1.0, following the concepts embodied in the CERES models (Ritchie, 1986).
Soil water deficit factor 1 (SWDEF1), which is less sensitive to soil drying, reduces the radiation-use efficiency (i.e. net photosynthesis) and hence transpiration, below its maximum.
Soil water deficit factor 2 (SWDEF2), which is more sensitive to soil drying, reduces the rate of processes governed primarily by cell expansion, i.e. daily leaf expansion rate.

SWDEF1 and 2 are calculated as a function of the ratio of (potential soil water supply from the root system) and the (transpiration demand).
Following Sinclair (1986) and Monteith (1986), transpiration demand is modelled as a function of the (current day's crop growth rate), divided by the transpiration-use efficiency.
When soil water supply exceeds transpiration demand, assimilate fixation is a function of radiation interception and radiation use efficiency.
When soil water supply is less than transpiration demand, assimilate fixation is a function of water supply and transpiration efficiency and the vapour pressure deficit (VPD).

Transpiration-use efficiency has not been directly measured for sugarcane, but calibration of the current model on datasets exhibiting water deficits (Robertson et al, unpubl. data) resulted in the use of a transpiration-use efficiency of 8 g $kg^{-1}$ at a VPD of 1 kPa.
This efficiency declines linearly as a function of VPD (Tanner and Sinclair, 1983).
This compares with reported values of 9 g $kg^{-1}$ $kPa^{-1}$ for other C 4 species (Tanner and Sinclair 1983), a value that has been used in the models of sorghum (Hammer and Muchow, 1994) and maize (Muchow and Sinclair, 1991).

Potential soil water uptake is calculated using the approach first advocated by Monteith (1986) and subsequently tested for sunflower (Meinke et al., 1993) and grain sorghum (Robertson et al., 1994).
It is the sum of root water uptake from each profile layer occupied by roots.
The potential rate of extraction in a layer is calculated using a rate constant, which defines the fraction of available water able to be extracted per day.
The actual rate of water extraction is the lesser of the potential extraction rate and the transpiration demand.
If the computed potential extraction rate from the profile exceeds demand, then the extracted water is removed from the occupied layers in proportion to the values of potential root water uptake in each layer.
If the computed potential extraction from the profile is less than the demand then SWDEF2 declines in proportion, and the actual root water uptake from a layer is equal to the computed potential uptake.

In addition to the effects on canopy expansion and biomass accumulation, water stress influence biomass partitioning in the stem in two ways.
Firstly, the minimum amount of stem biomass required to initiate sucrose accumulation declines with accumulated stress.
Secondly, the daily dry weight increment between structural stem and sucrose shifts in favour of sucrose as water deficits develop.

## Water excess limitation

The proportion of the root system exposed to saturated or near saturated soil water conditions is calculated and used to calculate a water logging stress factor.
This factor reduces photosynthetic activity via an effect on RUE.

## Nitrogen limitation

N supply from the soil is simulated in other modules in the APSIM framework (Probert et al., 1996).

Crop nitrogen demand is simulated using an approach similar to that used in the CERES models (Godwin and Vlek 1984).
Crop N demand is calculated as the product of maximum tissue N concentration and the increment in tissue weight.

Separate N pools are described for green leaf, cabbage, millable stalk and dead leaf. The sucrose pool is assumed to have no nitrogen associated with it.
Only the leaf N concentrations influence crop growth processes. Growth is unaffected until leaf N concentrations fall below a critical concentration.
Sugarcane has been shown to exhibit luxury N uptake (Muchow and Robertson 1994 ; Catchpoole and Keating 1995) and the difference between the maximum and critical N concentrations is intended to simulate this phenomenon.
Nitrogen stress is proportional to the extent to which leaf N falls between the critical and the minimum N concentration.

Senescing leaves (and the associated leaf sheaths contained in the cabbage pool) are assumed to die at their minimum N concentrations and the balance of the N in these tissues is retranslocated to the green leaf and cabbage pools.

Maximum, critical and minimum N concentrations are all functions of thermal time, and were chosen on the basis of the findings of Catchpoole and Keating (1995) and Muchow and Robertson (1994) and subsequently refined during the model calibration.
Critical green leaf concentrations used in the model differ between photosynthetic, leaf expansion and stem growth processes.
For photosynthesis they begin at 1.2% N at emergence or ratooning and asymptote towards 0.5%N at flowering.
For leaf area expansion they are 1.3 and 0.5% N
and stem growth, 1.5 and 0.5%N.

N uptake cannot exceed N demand by the crop and is simulated to take place by mass flow in the water that is used for transpiration.
Should mass flow not meet crop demand and nitrate be available in soil layers, the approach of van Keulen and Seligman (1987) is used to simulate the uptake of nitrate over and above that which can be accounted for by mass flow.
While van Keulen and Seligman (1987) referred to this approach as “diffusion”, the routine more realistically serves as a surrogate for a number of sources of uncertainty in nitrate uptake.

Nitrogen stress also influences biomass partitioning in the stem, in a similar fashion to that described above for water stress.

## Other features of the sugar module

APSIM-Sugarcane includes a number of features relevant to sugarcane production systems.

Either plant or ratoon crops can be simulated at the outset or a plant crop will regenerate as a ratoon crop if a crop cycle is being simulated.
Production systems of plant - multiple ratoon - fallow can be simulated or alternatively other APSIM crop or pasture modules can be included in rotation with sugarcane.

Trash can be burnt or retained at harvest time.

Insect or other biological or mechanical damage to the canopy can be simulated via “graze” actions.

Many sugarcane crops are “hilled-up” early in canopy development, an operation that involves the movement of soil from the interrow to the crop row.
This operation facilitates irrigation operations and improves the crop's ability to stand upright.
APSIM-Sugarcane responds to a management event of hilling-up by removal of lower leaf area and stem from the biomass pools.

Lodging is a widespread phenomenon in high-yielding sugarcane crops.
The APSIM-MANAGER (McCown et al 1996) can initiate a lodging event in response to any aspect of the system state (eg crop size, time of year and weather).
APSIM SUGARCANE responds to lodging via **four** effects:

A low rate of stalk death which has been widely observed in heavily lodged crops (Muchow et al., 1995; Robertson et al., 1996; Singh et al., 2002);

A reduction in radiation use efficiency (Singh et al., 1999; Singh et al., 2002)

A reduction in the proportion of daily biomass that is partitioned as sucrose (Singh et al., 2002); and

A reduction in the maximum number of green leaves, to capture the reported reduction in leaf appearance rate and increase in leaf senescence (Singh, 2002; Singh et al., 2002).

## Sugar Module Outputs

| Variable Name | Units | Description |
|---|---|---|
| Stage_name | | Name of the current crop growth stage |
| Stage | | Current growth stage number |
| Crop_status | | Status of the current crop (alive, dead, out) |
| ratoon_no | | Ratoon number (0 for plant crop, 1 for 1st ratoon, 2 for 2nd ratoon, …etc) |

| Variable Name | Units | Description |
|---|---|---|
| das | Days | Days after sowing (ie. crop duration) |
| Ep | mm | Crop evapotranspiration (extraction) for each soil layer |
| cep | mm | Cumulative plant evapotranspiration |
| rlv | $mm.mm^{-3}$ | root length per volume of soil in each soil layer |
| esw | mm | Extractable Soil water in each soil layer |
| root_depth | mm | Root depth |
| sw_demand | mm | Daily demand for soil water |
| biomass | $g.m^{-2}$ | Total crop above-ground biomass (Green + Trash) |
| green_biomass | $g.m^{-2}$ | Total green crop above-ground biomass |
| biomass_n | $g.m^{-2}$ | Total Nitrogen in above-ground biomass (Green + Trash) |
| green_biomass_n | $g.m^{-2}$ | Amount of Nitrogen in green above-ground biomass |
| dlt_dm | $g.m^{-2}$ | Daily increase in plant dry matter (photosynthesis) |
| dm_senesced | $g.m^{-2}$ | Senesced dry matter in each plant pool |
| n_senesced | $g.m^{-2}$ | Amount of Nitrogen in senesced material for each plant pool |
| Canefw | $t.ha^{-1}$ | Fresh Cane weight |
| ccs | % | Commercial Cane Sugar |
| Cane_wt | $g.m^{-2}$ | Weight of cane dry matter |
| leaf_wt | $g.m^{-2}$ | Weight of plant green leaf |
| root_wt | $g.m^{-2}$ | Weight of plant roots |

| Variable Name | Units | Description |
|---|---|---|
| sstem_wt | $g.m^{-2}$ | Weight of plant structural stem |
| sucrose_wt | $g.m^{-2}$ | Weight of plant sucrose |
| cabbage_wt | $g.m^{-2}$ | Weight of plant cabbage |
| n_conc_cane | $g.g^{-1}$ | Nitrogen concentration in cane |
| n_conc_leaf | $g.g^{-1}$ | Nitrogen concentration in green leaf |
| n_conc_cabbage | $g.g^{-1}$ | Nitrogen concentration in green cabbage |
| n_demand | $g.m^{-2}$ | Daily demand for Nitrogen |
| cover_green | 0-1 | Fractional cover by green plant material |
| cover_tot | 0-1 | Fractional cover by total plant material (Green + Trash) |
| lai | $mm^{-2}.mm^{-2}$ | Leaf area index of green leaves |
| tlai | $mm^{-2}.mm^{-2}$ | Total plant leaf area index (green + senesced) |
| slai | $mm^{-2}.mm^{-2}$ | Senesced leaf area index |
| n_leaf_crit | $g.m^{-2}$ | Critical Nitrogen level for the current crop |
| n_leaf_min | $g.m^{-2}$ | Minimum Nitrogen level for the current crop |
| nfact_photo | 0-1 | Nitrogen stress factor for photosynthesis |
| nfact_expan | 0-1 | Nitrogen stress factor for cell expansion |
| swdef_photo | 0-1 | Soil water stress factor for photosynthesis |
| swdef_expan | 0-1 | Soil water stress factor for cell expansion |
| swdef_phen | 0-1 | Soil water stress factor for phenology |

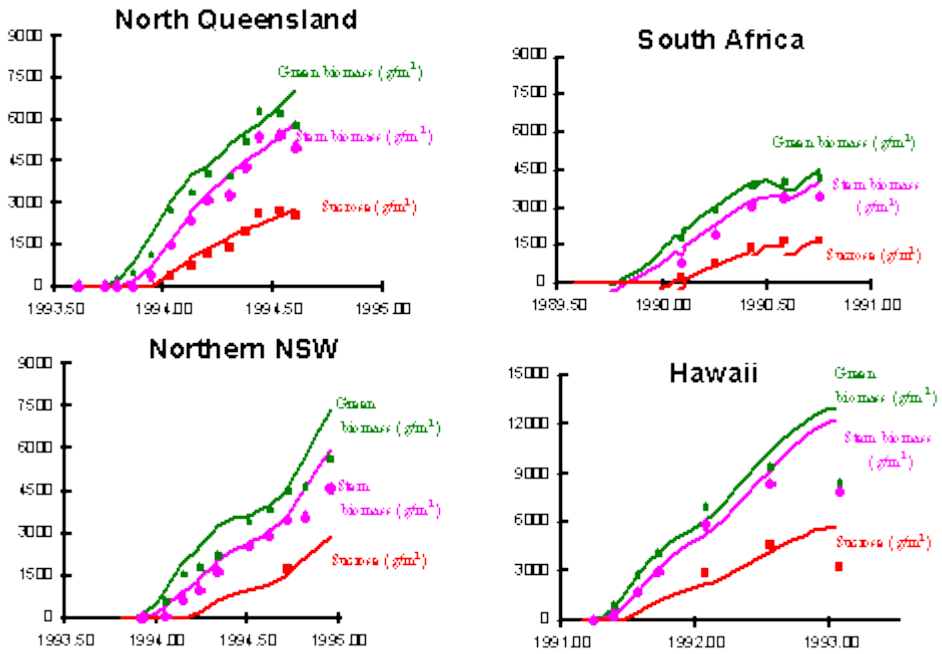
# Sugar Model Validation Examples

## Crop Growth and Development

The capability of the APSIM sugar model to describe crop growth has been tested widely in a number of areas of current model application.

The following show the response of the model in simulating growth of total biomass, cane and sucrose in varying environments.

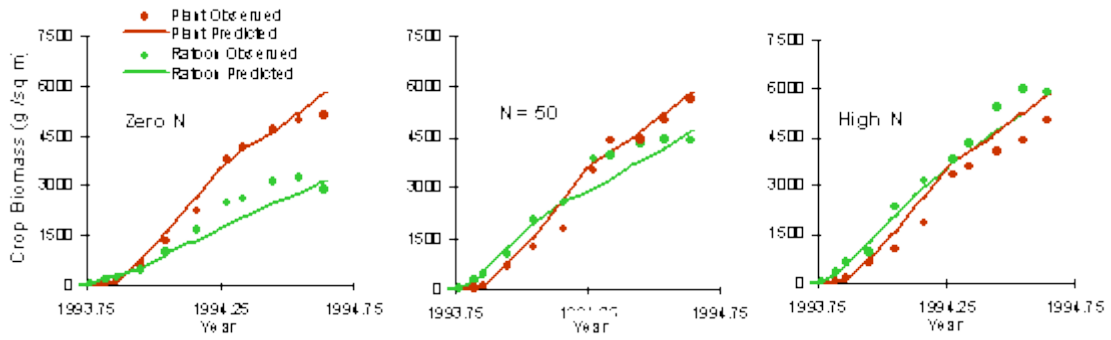
Note : Current simulations of cane water content are unreliable in some regions prior to final harvest.

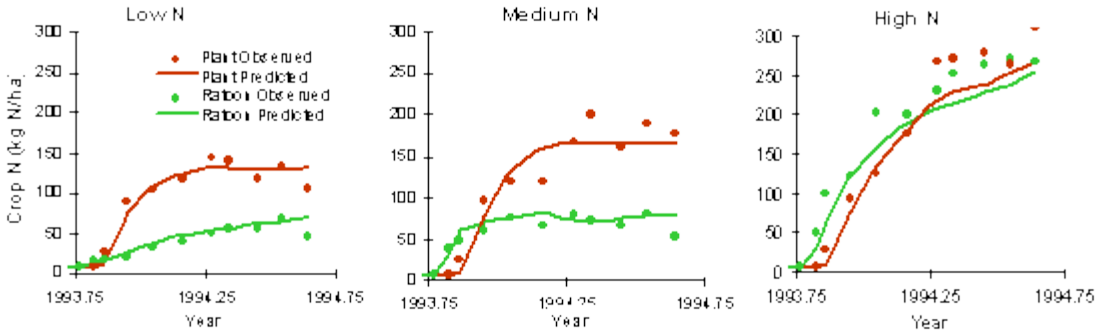



## Nitrogen Uptake and Response

The applicability of the APSIM sugar model under differing nitrogen supply has been tested with several data sets.

The following example is for a plant and ratoon crop at Macknade in 1993-1994 for three nitrogen fertiliser rates (0 and 50 kg N/ha and a continuous N non-limiting treatment).






## Nitrate Leaching under Sugarcane

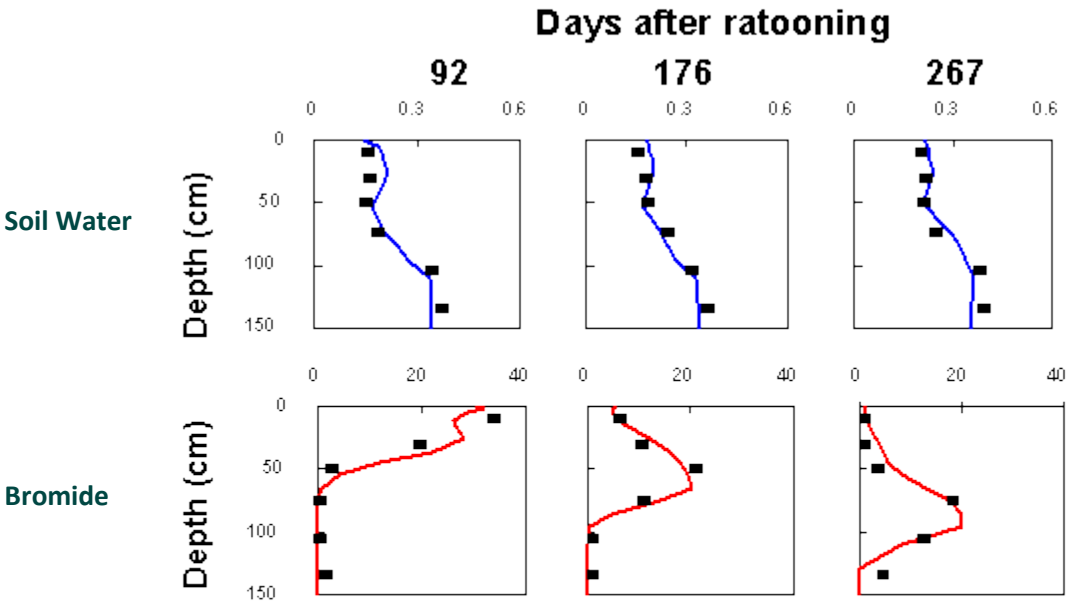
(See Evaluation of Nitrogen fertiliser management strategies under sugarcane using APSim-Swim, Verburg et al in the Appendices)

The use of APSIM sugarcane model for nitrogen leaching study has been tested using experimental data from Bundaberg field study.

The soil was a red-yellow podsolic with a marked textual change at 0.8m depth.

Crop management included 3 nitrogen rates (0, 160 and 320 kg N/ha) for an irrigated first ratoon crop of CP51-21.

A bromide tracer was applied to some of the sub-plots.



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# Weed

## WEED Module Scope

The **weed** module simulates the growth of a weed crop in a daily time-step (on an area basis not single plant). Weed growth in this model responds to climate (temperature, rainfall and radiation from the **input** module), soil water supply (from the **soilwat** module) and soil nitrogen (from the **soiln** module). The **weed** module returns information on its soil water and nitrogen uptake to the **soilwat** and **soiln** modules on a daily basis for reset of these systems. Information on crop cover is also provided to the **soilwat** module for calculation of evaporation rates and runoff. Weed stover and root residues are 'passed' from **weed** to the **residue** and **soiln** module respectively at harvest of the weed crop.

The module predicts leaf area development, N% and biomass of stover; depth, N% and biomass of roots; grain N% and biomass; grain yield and N%, grain size and grain number all on a daily basis.

## Weed Competition Documentation

Click here for documentation on running crop simulations in competition with weeds. Note that some of the models referenced my not be generally available yet, but any crop class model will work. APSIM 7.4 or above is required.

## Weed Module History

There are a range of APSIM applications that have an emerging need for a simulation capability for weeds. For example:

Weed competition is becoming recognised as an important part of the low-input cropping systems of smallholder agriculture, and must be simulated when, for instance, accounting for responses to fertility inputs

Examining the risks of releasing herbicide-tolerant crop cultivars and associated spread of herbicide tolerant weeds

In studies of soil water balance accounting for water use by fallow-growing weeds has been crucial in some circumstances

The weedy component of some vegetation types we simulate can be significant at some situations (eg annual ryegrass in lucerne stands)

Across the spectrum of applications there is a need to be able to specify the weed component to various levels of detail. In some circumstances it is necessary to specify the weed's biology and lifecycle, and for a selection of well-studied weeds this ought to be possible. In other circumstances all that may be required is something to use water and nitrogen in about the "right" amounts.

Currently, where weeds are being simulated users are using an existing crop module that is most like the dominant weed in the system. While this has proved satisfactory for those cases, it is not a sustainable situation. In particular, for users of APSFRONT, who do not have the capability to engineer a weed on the run, there is a need to provide a ready-made weeds capability. APSIM_Weed provides that capability.

APSIM_Weed is based upon APSIM-Plant. APSIM-Plant was used because of a number of features:

Its documented ability to simulate a range of vegetation types, from cool-season to warm-season adaptation, annuals and perennials, broadleaf and gramineacious crops.

The 'crop_class" feature coupled with the inheritance capability of APSIM crop modules means that a range of weed types can be configured ready-made for users, as well as set up easily on the run by more experienced users. The inheritance feature means that only those parameters known to differ from the base class parameters set need to be specified.

Goto generic Plant model documentation

## Weed Module Science

As the Weed module is an instantiation of the plant module the science is identical. Users are referred to APSIM-Plant documentation for details on science.

## Weed types

At present four generic types of weeds can be grown in the module, as different crop_classes. They are listed below with their distinguishing characteristics.

A grassy, C 3 annual weed designed to represent annual ryegrass. Parameters have been taken from the wheat module, with some additions from the literature on ryegrass.

A grassy, C 4 annual weed designed to represent Johnson grass. Parameters have largely been taken from the sorghum module.

A broadleaf, C 3 annual weed designed to represent wild radish. Parameters have been taken from the canola module.

A broadleaf, C 3 N-fixing perennial weed designed to represent volunteer lucerne or similar legume.

*Table 1:Functionalities possible for the weed types in APSIM-Weed and how these are operationalised through parameters.*

| **Desired functionality** | **How this is achieved operationally in APSIM-Weed** | **Parameters** |
|---|---|---|
| Perenniality | The crop either dies or regrows after a harvest operation or complete leaf senescence | **Min_tpla** |
| Temperature sensitivity (cool-season vs warm-season adaptation) | Tolerance to low/high temperature through | *y_tt vs x_temp* |
| | • thermal time vs temperature relationship | *y_rue vs x_temp* |
| | • rue vs temperature | *x_temp_senescence vs* |
| | • leaf senescence vs minimum temperature | *y_senescence_fac* |
| Broadleaf versus grass-type | Crop has small/large individual leaf sizes | **Leaf_size** |

| | | |
|---|---|---|
| Nitrogen requirements | Critical N requirements | *n_conc_crit_leaf, stem etc* |

*Table 2:The four weed crop_classes (i.e. types) and their differing characteristics.*

| **Parameter** | **Winter_dicot** | **Summer_grass** | **Perennial_legume** |
|---|---|---|---|
| **Perenniality** | | | |
| min_tpla | 0 | 0 | 0 | 50 |
| ratio_root_shoot | 0.50 to 0.33 | 0.50 to 0.33 | 0.50 to 0.33 | 1.0 to 0.53 |
| **Determinacy** | | | |
| frac_leaf_post_flower | 0 | 0 | 0 | 0.2 |
| frac_leaf_grain_fill | 0 | 0 | 0 | 0.2 |
| C 3 vs C 4 | | | |
| transp_eff_cf | 0.005 | 0.005 | 0.009 | 0.005 |
| Legume vs non-legume | | | |
| N_fix_rate | 0 | 0 | 0 | 0.002 |
| n_conc_crit_leaf | 0.039 to 0.018 | 0.039 to 0.018 | 0.039 to 0.018 | 0.060 to 0.020 |
| n_init_conc (root, leaf, stem) | 0.018 0.06 0.060 | | | 0.025 0.060 0.060 |
| leaf_size | 1400 to 6000 | 1000 to 20000 | 1000 to 60000 | 400 to 1200 |
| Temperature sensitivity | | | |
| ave_temp vs stress_photo | • 15.0 30.0 40.0<br>0.0 1.0 1.0 0.0 | • 15.0 30.0 40.0<br>0.0 1.0 1.0 0.0 | 8.0 25.0 35.0 40.0<br>0.0 1.0 1.0 0.0 | • 15.0 30.0 40.0<br>0.0 1.0 1.0 0.0 |
| Cardinal temps for tt | 0.0 30.0 40.0 | 0.0 30.0 40.0 | 10.0 35.0 45.0 | 0.0 30.0 40.0 |
| Minimum temps for leaf senescence | -5 to -15 o C | -5 to –15 o C | 6 to 0 o C | -5 to -15 o C |

## Issues that users should be aware of

Due to the way that crop residues are handles in APSIM, it is possible to only pass one fixed value for residue *specific_areas* regardless of the weed type being simulated.

Cultivars would differ in terms of height (and hence competitive ability) and short/long season.

Using the module parameter inheritance characteristics of APSIM-Legume, it is possible to create other permutations eg a warm-season dicot.

## Weed Module Parameterisation

As with APSIM-Legume, crop lower limit (LL) and water extraction coefficients (KL) and root exploration factors (XF) values are need for each soil layer.

*test.weed.parameters*

ll = 0.200 0.200 0.200 0.220 0.250 () ! crop lower limit

kl = 012 0.08 0.06 0.04 0.02 () ! kl need calibrating for each crop and soil type

xf = 1 1 1 1 0.5 () ! root exploration factor

Phenology, grainfilling and crop height parameters are needed for each cultivar. An example is given below of those for the early culltivar. At present the module contains two cultivars only – early and late.

*standard.weed.early*

hi_incr = 0.010 (1/days)

x_hi_max_pot_stress = 0.00 1.00 ()

y_hi_max_pot = 0.15 0.15 ()

cum_vernal_days = 0 100

tt_emerg_to_endjuv = 400 700

est_days_emerg_to_init = 83.0 (d)

photoperiod = 1 24

phase_tt_init = 500 500

tt_flower_to_maturity = 500.0 (oCd)

tt_init_to_flower = 50.0 (oCd)

tt_flower_to_start_grain = 120.0 (oCd)

tt_maturity_to_ripe = 1.0 (oCd)

x_stem_wt = 0 300 (g/m2)

y_height = 0 800 (mm)

## Module Dependencies

The minimum module configuration required to run **weed** in APSIM is the inclusion of the report, input, manager, soilwat2, soiln2, residue2 and weed modules.

Within the manager file the following syntax is used for harvest and planting the weed crop:

```
if (weed.stage_name = 'harvest_ripe' and weed.plant_status = 'alive') then
  weed harvest
  weed kill_crop
  weed end_crop
endif
if (weed.plant_status = 'dead') then
  report do_output
  weed harvest
  weed end_crop
endif
if (day > 120 and day < 240 and weed.plant_status = 'out' ) then
  weed sow plants = 15 (p/m2), crop_class=winter_grass, sowing_depth = 50 (mm), row_spacing = 0.35 (m), cultivar = late
endif
```

(note: row_spacing in sowing command is optional)

As with any of the PLANT crop modules it is possible to kill a fraction of plants upon a manager action, for instance killing by herbicide. The following line in the manager module:

```
weed kill_crop, kill_fr = 0.6
```

would kill 60% of plants

# Wheat

## WHEAT Module Scope

**APSIM-Wheat** module simulates the growth and development of a wheat crop in a daily time-step on an area basis (per square meter, not single plant). Wheat growth and development in this module respond to weather (radiation, temperature), soil water and soil nitrogen. The wheat module returns information on its soil water and nitrogen uptake to the soil water and nitrogen modules on a daily basis for reset of these systems. Information on crop cover is also provided to the water balance module for calculation of evaporation rates and runoff. Wheat stover and root residues are 'passed' from wheat to the surface residue and soil nitrogen modules respectively at harvest of the wheat crop.

Approaches used in modelling crop processes balance the need for comprehensive description of the observed variation in crop performance over diverse production environments and the need to avoid reductionist approaches of ever-greater complexity with large numbers of parameters that are difficult to measure.

A list of the module outputs is provided in the 'Wheat module outputs' section below. Basically the module simulates phenological development, leaf area growth, biomass and N concentration of leaves, stems, roots and grains on a daily basis. It also predicts grain size and grain number.

Goto generic Plant model documentation

## Wheat Module History

APSIM-Wheat was developed from a combination of the approaches used in previous APSIM wheat modules: Asseng et al. 1998a,b, Meinke et al. 1997a,b and Wang et al. 2003. The current version of the model is implemented within the APSIM Plant model framework which is currently used for other crops such as grain legumes and canola. Most of the model constants (species-specific) and parameters (cultivar specific) are externalised from the code.

# Wheat Module Structure

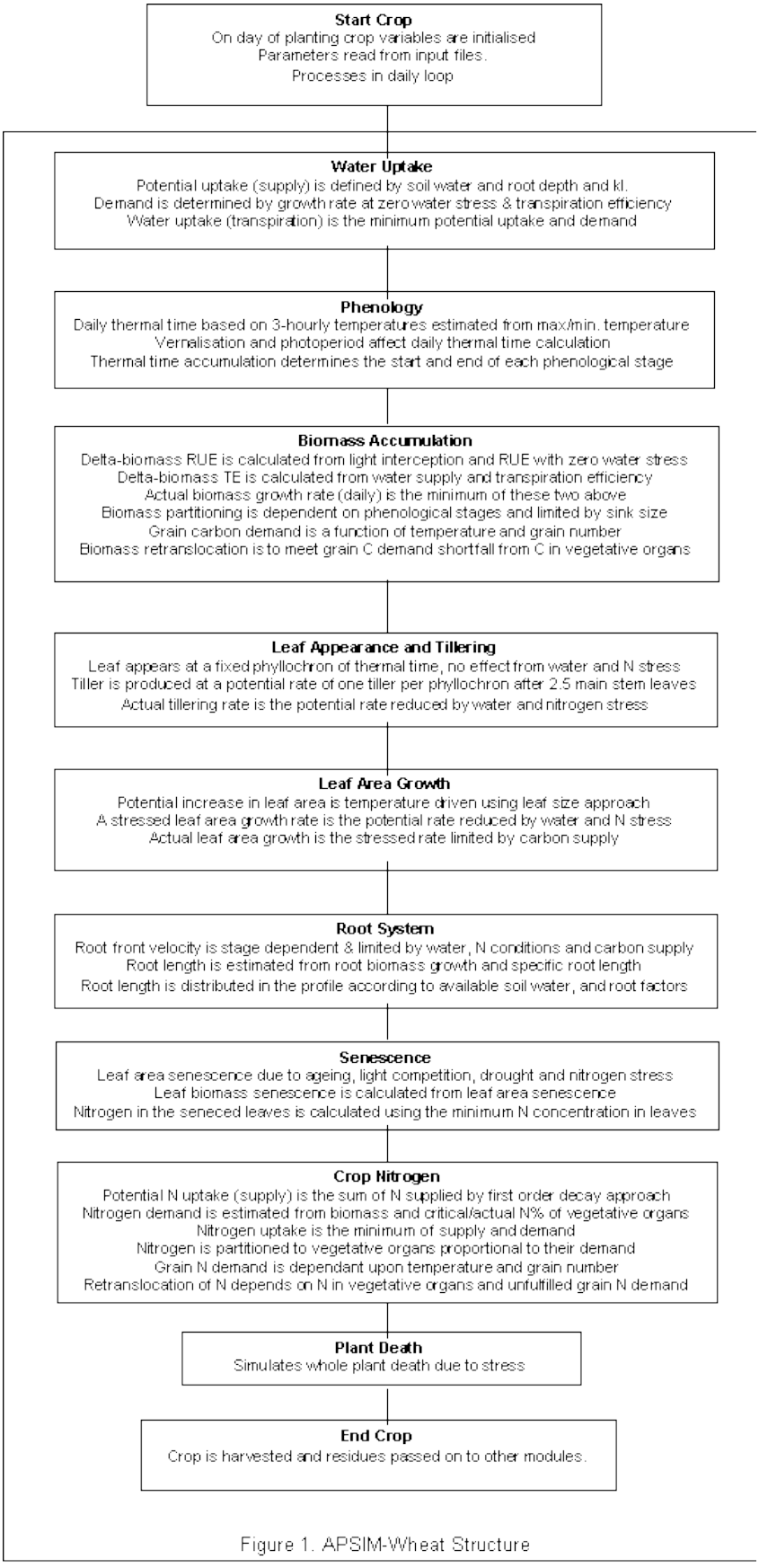



Figure 1. APSIM-Wheat Structure

# Wheat Module Components

## Phenology

APSIM-Wheat uses 11 crop stages and ten phases (time between stages). It can output stage code and names as well as equivalent Zadok's stage. ===Table 2:=== lists the stage code, name and the key processes starting at the commencement of each stage.

*Table 2: Stages of phenological development simulated in APSIM_Wheat.*

| Stage Code | Stage Name | Starting processes | Equivalent Zadok's |
|---|---|---|---|
| 1 | Sowing | Seed germination | 0 |
| 2 | Germination | Emergence, leaf initiation | 5 |
| 3 | Emergence | Vegetative growth (LAI, DM), water/N uptake | 10 |
| 4 | End of Juvenile Stage | Photoperiodism | 10 |
| 5 | Floral Initiation / terminal spikelet* | Spikelet initiation / | 15 / |
| | | Rapid stem growth | 30 |
| 6 | Anthesis | Setting grain numbers | 60 |
| 7 | Start of Grain Filling | Active grain growth | 71 |
| 8 | End of Grain Filling | Maturity | 87 |
| 9 | Physiological Maturity | Grain moisture loss | 90 |
| 10 | Harvest Ripe | | 93 |
| 11 | End Crop | | 100 |

**Because the CERES-Wheat phenology approach is used (see text below), terminal spikelet, instead of floral initiation, is simulated in the current wheat model.*

The commencement of each stage (except for sowing to germination, which is driven by soil water content) is determined by accumulation of thermal time. Each day the phenology routines calculate today's thermal time (in degree-days) from 3-hourly air temperatures interpolated from the daily maximum and minimum crown temperatures. Crown temperatures are simulated according to the original routines in CERES-Wheat. Thermal time is calculated using the relationship in Figure 2 with the eight 3-hour estimates averaged to obtain the daily value of thermal time (in

degree-days) for the day. These daily thermal time values are cumulated into a thermal time sum, which is used to determine the duration of each phase.

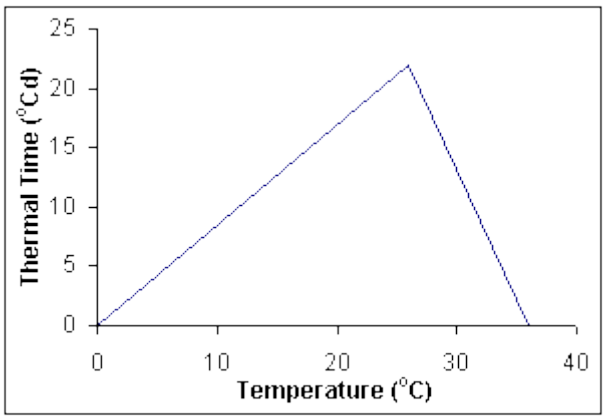



*Figure 2. Relationship between crown temperature and thermal time used in APSIM-Wheat*

Between the stage of emergence and flowering the calculated daily_thermal_time can be reduced by water or nitrogen stresses, resulting in delayed phenology when the plant is under stress. These stress factors can be specified in wheat.ini by changing the values of*x_sw_avail_ratio/y_swdef_pheno* and *N_fact_pheno* . Currently these values are set so that there are no water and nitrogen stress effects on phenological development. Research showed that moderate water stress may accelerate development, while severe water stress may delay phenology (Angus, 1977).

Germination is considered as a quick process. Germination is assumed to occur as long as the extractable soil water in the seed layer is above a given value *pesw_germ* specified in Wheat.ini. *pesw_germ* is the soil water content above the crop lower limit (mm/mm) in the seed layer inadequate for germination. The default setting is zero, meaning that germination will occur one day after sowing regardless of soil water content.

The phase between germination and emergence includes an effect of the depth of sowing on the thermal time target. The phase is comprised of an initial period of fixed thermal time during which shoot elongation is slow (the “lag” phase) and a linear period, where the rate of shoot elongation towards the soil surface is linearly related to air temperature (measured in o Cd mm -1 ). Most studies on seedling emergence have simply recorded the accumulated thermal time between germination and 50% emergence from a given sowing depth. For the purposes of model parameterisation the value of *shoot_lag* has been assumed to be around 40 o Cd, while *shoot_rate* has been derived from studies where thermal time to emergence was measured and where sowing depth was known and it is set to 1.5 o Cd per mm. This means that at a sowing depth of 4 cm emergence occurs 100 o Cd after germination (40+1.5*40).

There is the capability of increasing the time taken to reach emergence due to a dry soil layer in which the seed is germinating, through the relationship between *fasw_emerg* and *rel_emerg_rate* . Currently this effect is “turned off” in the Wheat.ini file.

The phase between emergence and end of juvenile stage is composed of a cultivar-specific period of fixed thermal time, commonly called the basic vegetative or juvenile phase, which is a period when development rate is not affected by photoperiod. The end of the juvenile phase in wheat is currently timed as occurring on the day after emergence, because it is known that the development rate of wheat is sensitive to photoperiod from emergence. The end of the juvenile phase is included in the model to make the stages compatible with other cereal crops in APSIM that do have a definable juvenile phase.

After the end of the juvenile phase the crop takes 400 o Cdays to reach terminal spikelet stage. The rate at which the crop attains this target depends upon photoperiod and vernalisation. The daily rate of accumulation of thermal development rate is sensitive to photoperiod and accumulation of vernalising days. The sensitivities to photoperiod ( *photop_sens* ) and vernalisation ( *vern_sens* ) are cultivar-specific. The model assumes that wheat, as a long day plant, will have a longer phase (dependent upon cultivar) between the end of the juvenile phase and terminal spikelet under short days.

Photoperiod is calculated from day of year and latitude using standard astronomical equations accounting for civil twlight using the parameter*twilight,* which is assumed to be –6 o . Twilight is defined as the interval between sunrise or sunset and the time when the true centre of the sun is 2.2 degrees below the horizon.

Vernalisation is simulated from daily average crown temperature and daily maximum and minimum temperatures using the original CERES approach.

Devernalisation can occur if daily maximum temperature is above 30 o C.

There are fixed thermal time durations for the subsequent phases between terminal spikelet and flag leaf (3 phyllochrons), from flag leaf to flowering (2 phyllochrons + 80 o C days). In the original CERES phenology routines, 2 phyllochrons from flag leaf marked the end of ear growth and then 80 o C days was required to reach anthesis. From flowering to the start of grain fill the thermal duration is assumed to be 120 o C days (= 200-80 o C days, in CERES 200 o C days was assumed to elapse between the end of ear growth and the start of grain filling). The duration of grain filling ( *tt_startgf_to_mat* ) is cultivar specific and usually lies between 500 and 800 o C days.

## Biomass accumulation (Photosynthesis)

## Radiation interception

Radiation interception is calculated from leaf area index and a radiation extinction coefficient ( *extinct_coeff* ) that varies with row spacing.

## Radiation Use Efficiency

The intercepted radiation is converted to above ground biomass via a RUE (radiation-use efficiency), which is 1.24 g MJ -1 from emergence to the end of grain-filling, and does not vary as a function of daily incident radiation as in NWHEAT. RUE is reduced by extremes of daily mean temperature as sown in the following figure. It is also reduced by a nitrogen stress factor *n_fact_photo* specified in Wheat.ini.

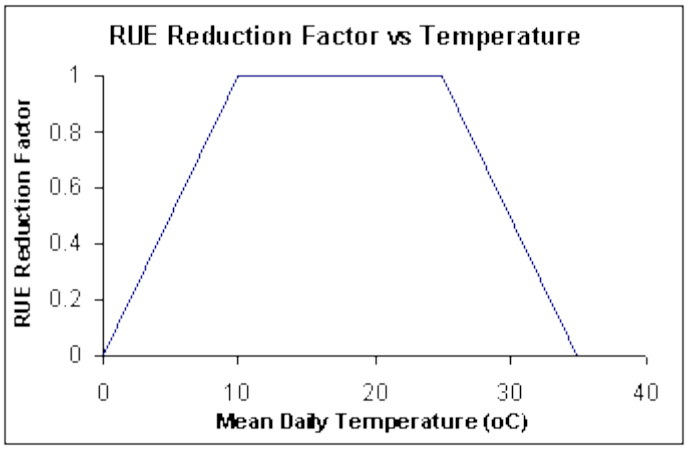



*Figure 3: Response of wheat radiation-use efficiency to temperature*

## Water-nonlimiting

Under water non-limiting condition, the biomass growth rate is given by:

dlt_dm_rue = RUE *radiation_interception eqn 1.

## Water-limiting

Each day two estimates of the daily biomass production are calculated, one limited by available water for transpiration (eqn 2), and the other limited by radiant energy (eqn 1). The minimum of these two estimates is the actual biomass production for the day.

dlt_dm_water = soil_ water_ supply * transpiration_efficiency eqn 2.

dlt_dm = min(dlt_dm_water, dlt_dm_rue)

transpiration_efficiency is derived from the transpiration_efficiency_coefficient (=0.006 kPa) and the vapour pressure deficit (vpd) estimated from daily temperatures.

## Biomass partitioning and retranslocation

## Partitioning

On the day of emergence, biomass in plant parts (leaf, root, and stem) is initialised to user-specified values. Daily biomass production is then partitioned to different plant parts in different ratios depending on crop stage. In the wheat module, leaf includes only leaf blade. Stem is defined in a functional rather than a morphological manner and includes stem proper, leaf sheaths and stem-like petioles.

The biomass increase calculated each day only accounts for the above ground organs. The minimum fraction of biomass going to roots is calculated from the stage dependent *root_shoot_ratio* specified in Wheat.ini.

Between emergence and grain filling, the above ground biomass is partitioned to leaf, stem and head based on stage dependant partitioning rules. If, on any day, the estimated specific leaf area (based on leaf biomass and LAI deltas) goes below the minimum specific leaf area, the extra biomass is diverted to stems.

At anthesis, the number of grains set per plant is determined by the stem weight. From start to end of grain filling biomass increase is used to meet grain demand first, the rest is put into stems. **Grain demand for**

**carbohydrate** (biomass) is calculated by multiplying the grain number by the potential grain growth rate ( *potential_grain_filling_rate, g/grain/day* ) specified in Wheat.ini .

## Re-translocation

If the supply of assimilate (daily biomass increase) is insufficient to meet grain demand then re-translocation may be used to meet the shortfall. The wheat module allows a total retranslocation of no more than 20% of stem biomass present at the start of grainfilling

Grain yield on a commercial moisture basis is calculated using the parameter *grn_water_cont* = 0.125.

## Leaf initiation/appearance and tillering

Leaves appear at a fixed phyllochron of thermal time, currently set to 95 o Cd in the wheat.ini. No effect from water and N stress on leaf appearance is accounted for.

## Leaf area growth

On the day of emergence leaf area per plant is initialised to a value of 200 mm 2 per plant.

## Potential LAI growth rate

Potential increase in plant leaf area is calculated from main stem node appearance rate multiplied by the leaf size (as a function of node number) multiplied by the number of leaves per main stem node (i.e. tiller number)

## Leaf area growth rate under stress

Water and nitrogen limitations affect leaf area development directly rather than via dry matter production. Water and nitrogen limitations result in either a reduction of leaf expansion or in number of tillers produced.

Two stress factors are introduced to account for the effect of water and nitrogen stress respectively on leaf area growth. It is assumed that leaf expansion growth is reduced when the supply/demand ratio for water is below 1.1 and stops when supply/demand ratio reaches 0.1. This relationship is specified in Wheat.ini in the look-up table *x_sw_demand_ratio/y_swdef_leaf* . The nitrogen stress factor is defined as:

g_nfact_expansion = N_fact_expansion * n_conc_ratio_leaf

where n_conc_ratio_leaf is the relative N concentration in leaves (N_conc_leaf - N_conc_leaf_min)/(N_conc_leaf_crit - N_conc_leaf_min). N_fact_expansion is a modifying constant specified in Wheat.ini. It is currently set to 1.0, ie. leaf expansion is reduced once leaf N concentration is below the critical N concentration, and stops when leaf minimum concentration is reached.

The leaf area growth rate under stress is given by:

g_dlt_lai_stressed = g_dlt_LAI_pot * min (g_swdef_expansion, g_nfact_expansion)

## Actual leaf area growth rate

Actual leaf area growth rate differs from stressed leaf area expansion rate (g_dlt_lai_stressed) only if carbon supply is insufficient to meet a maximum specific leaf area for the daily increase in leaf area ( *sla_max* ). Carbon supply may become limiting, for example, at high plant population densities. The current model specifies *sla_max* as varying from 27 000 to 22000 mm 2 g -1 t o constrain daily leaf area increase where carbon is limiting. However, as the value of the maximum specific leaf area operates on the daily increase in leaf area it is not readily derived from experimental data and must be calibrated by trial-and error.

## Root growth and distribution

### Root depth growth

Between germination and start of grain filling, the increase in root depth is a daily rate multiplied by a number of factors. Root depth is constrained by the soil profile depth

The optimum rate of elongation is 30mm d -1 . This can be limited by supra- or sub-optimal temperatures. Dry soil can slow roots through a layer if the soil water content is less than 25% of the way between the lower limit and drained upper limit. The increase of root depth through a layer can be constrained by known soil constraints through the use of the 0-1 parameter **xf,** which is input for each soil layer.

### Root length density

Growth of root biomass is partitioned with depth using a branching function and converted to root length density using a fixed specific root length of 105,000 mm g -1 .

Root biomass is grown daily in proportion to the tops production. This proportion ( *ratio_root_shoot* ) is specified for each growth stage, and varies from 1.0 at emergence, to 0.09 at flowering.

### Senescence

### Root senescence

A rate of 0.5% of root biomass and root length is senesced each day and detaches immediately being sent to the soil nitrogen module and distributed as fresh organic matter in the profile.

### Leaf senescence

There are four causes of leaf senescence: age, water stress, nitrogen stress and high temperature stress. The wheat senescence routines calculate stress factors for water, N and high temperature. The maximum of these is multiplied by the senesced LAI due to age each day to obtain the day's total senescence.

The stress factor for water is calculated from *swdef_photo* , for N from *nfact_photo.* Senescence due to frost commences when temperatures decrease below -5 º C.

### Nitrogen in seneseced leaves

When leaf is senesced, only a small amount of nitrogen is retained in the senesced leaf, the rest is made available for re-translocation by putting it into stem N pool. The concentration of nitrogen in senesced material is specified in the wheat ini file.

## Crop Water Relations

#### Potential water extraction rate

When the Wheat module is coupled to APSIM-SOILWAT2, potential soil water uptake is calculated using the approach first advocated by Monteith (1986). It is the sum of root water uptake from each profile layer occupied by roots. If roots are only partially through a layer available soil water is scaled to that portion that contains roots. The potential rate of extraction in a layer is calculated using a rate constant ( *kl* ), which defines the fraction of available water able to be extracted per day. The kl factor is empirically derived, incorporating both plant and soil factors which limit rate of water uptake. Root water extraction constants ( *kl* ) must be defined for each combination of crop species and soil type.

### Crop water demand

Following Sinclair (1986) and Monteith (1986), transpiration demand is modelled as a function of the current day's crop growth rate (dlt_dm_rue, see Biomass Accumulation Section), divided by the transpiration efficiency. Transpiration efficiency is related to the daylight averaged vapour pressure deficit ( *vpd* ). Transpiration demand is calculated from the daily crop growth rate limited by RUE (dlt_dm_rue), *vpd* , and the transpiration efficiency coefficient. In the model *vpd* is estimated using the method proposed by Tanner and Sinclair (1983), which requires only daily maximum and minimum temperatures. In this method, it is assumed that the air is saturated at the minimum temperature. The saturated vapour pressure is calculated at both the maximum and minimum temperatures, and the default vapour pressure deficit for the day is taken as 75% of the difference between these two vapour pressures. Crop water demand is capped to below a given multiple of potential ET (taken as Priestly-Taylor Eo from the water balance module) as specified in the wheat ini file. This limits water use to reasonable values on days with high VPD or in more arid environments.

### Water uptake

The actual rate of water extraction is the lesser of the potential extraction rate and the transpiration demand. If the computed potential extraction rate from the profile exceeds demand, then the extracted water is removed from the occupied layers in proportion to the values of potential root water uptake in each layer. If the computed potential extraction from the profile is less than the demand then, and the actual root water uptake from a layer is equal to the computed potential uptake.

### Water stresses affecting plant growth

Soil water deficit factors are calculated to simulate the effects of water stress on different plant growth processes. Three water deficit factors are calculated which correspond to four plant processes each having different sensitivity to water stress i.e. photosynthesis (photo), leaf-expansion (expansion), phenology (pheno), and tillering (tiller). A factor of 0 is complete stress and 1 no stress. Leaf expansion is considered more sensitive to stress than photosynthesis.

## Nitrogen uptake and re-translocation

### Potential nitrogen supply

The model uses a simplified formulation for NO3 uptake somewhat similar in structure to that employed in water uptake.

Potential NO3 uptake in a layer is given as

Uptake = NO3 kg/ha x (Kln x NO3 ppm x SWFAC)

Where Kln is a parameter constant and SWFAC is a soil water content factor based on relative soil water content between lower limit and drained upper limit.

### Nitrogen demand by vegetative organs

The crop has a defined minimum, critical and maximum N concentration for each plant part. These concentration limits change with phenological stages. The maximum and minimum N concentrations can be found in Wheat.ini. Demand for N in each part attempts to maintain N at the critical (non-stressed) level. N demand on any day is the sum of the demands from the pre-existing biomass of each part required to reach critical N content, plus the N required to maintain critical N concentrations in that day's produced biomass. For each plant part (leaf, stem, root) the N demand is given by:

N_demand = dm_green * (n_conc_critic - n_conc) + dlt_dm_green * n_conc_critic.

Where dm_green and dlt_dm_green are the existing live biomass and biomass growth rate today. N_conc and n_conc_critic are the actual and critical N concentration respectively of this plant part.

Total crop N demand is the sum of the n demand in all vegetative parts.

### Nitrogen partition in the plant

Daily total nitrogen uptake is distributed to the plant parts in proportion to their individual demands.

### Grain N demand

Grain nitrogen demand starts at anthesis and is calculated from grain number, thermal time and a potential grain nitrogen filling rate (g/grain/degree day).

### Nitrogen re-translocation

If there is insufficient nitrogen supplied from senescing material or soil nitrogen uptake, grain nitrogen demand is met by re-translocating nitrogen from other plant parts. Nitrogen is available for re-translocation from leaves and stems until they reach their defined minimum N concentration.

### Nitrogen deficits affecting plant growth

There are four N availability factors (0-1), one each for the photosynthesis, expansion, phenology and tillering. A N concentration ratio is calculated for the stover (stem + leaf) which is used as a measure of N stress, then different constants are used to convert that ratio to a deficit factor for each of the processes. A factor of 1.5 is used to restrict photosynthesis (reduces rue), 1.0 for expansion (reduces leaf area expansion) and 100 to slow phenological development (effectively disabled). For tillering a squared n_conc_ratio is used as the stress factor. As a value of 1 is no stress and 0 complete stress, phenology is least sensitive to nitrogen deficiency and grain N the most.

N_conc_ratio=(N_conc_stover-N_conc_stover_min)/(N_conc_stover_crit-N_conc_stover_min)

## Plant death

All or some of the plants can be killed due to a variety of stresses.

If the crop hasn't germinated within 40 days of sowing, due to lack of germinating moisture, all plants are killed.

If the crop does not emerge with 300 o Cdays of sowing, because it was sown too deep, then all plants are killed.

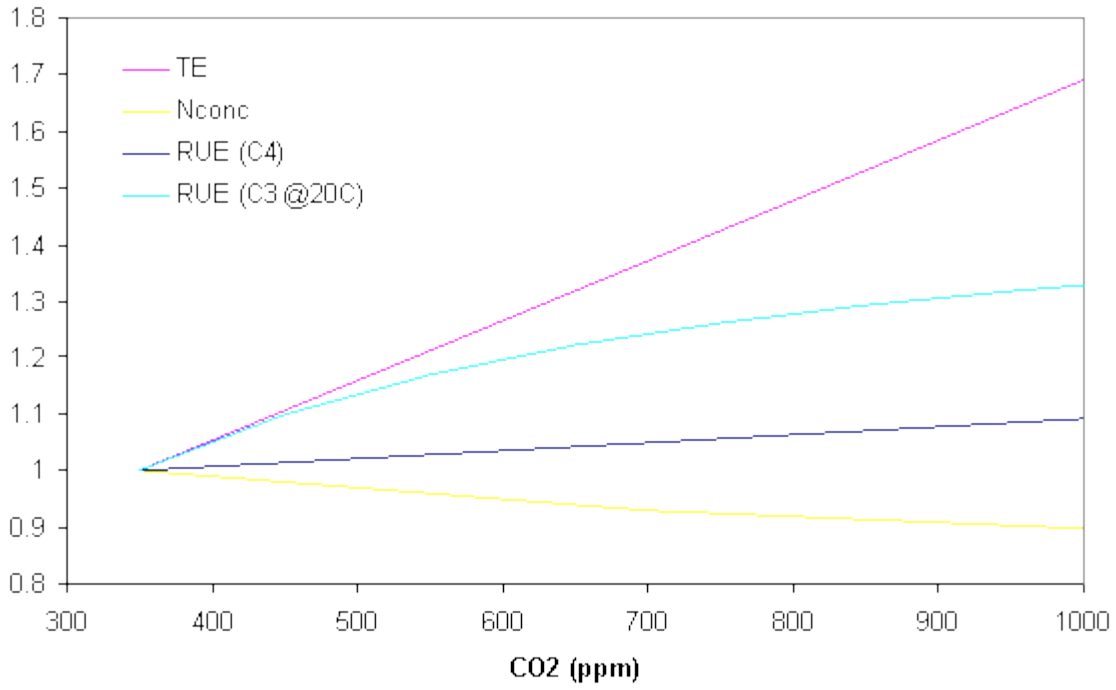
If crop is past floral initiation and LAI = 0, then all plants are killed due to total senescence.

## Detachment

The detachment routines in **wheat** are disabled in the wheat.ini file, except the detachment of senesced roots.

## Effects of elevated atmospheric $CO_2$

Elevated levels of atmospheric $CO_2$ affect plant growth in this module via three mechanisms. Carbon dioxide concentration can affect radiation use efficiency, transpiration efficiency and critical leaf nitrogen concentration. The following graph shows the relative change in RUE for C4 and C3 plants (at 20 o C), TE and critical nitrogen concentration. More information can be found in Reyenga et al (1999).




## Wheat Module Parameterisation

Crop lower limit (LL) and water extraction coefficients (KL) and root exploration factors (XF) values are need for each soil layer. The following example is used in the sample run.

*sample.wheat.parameters*

uptake_source = calc ! calculate own uptakes.

ll = .200 .201 .215 .176 .141 .249 .279 ! Crop lower limit

kl = 0.06 0.06 0.06 0.06 0.06 0.06 0.02 ! Water Extraction parameter (0-1)

xf = 1.00 1.00 1.00 1.00 1.00 1.00 1.00 ! Root Exploration factor (0-1)

## Module Dependencies

The minimum module configuration required to run **wheat** in APSIM is the inclusion of the report, input, manager, soilwat2, soiln2, residue2 and wheat modules.

In the sample folder, within the manager file the following syntax is used for harvest and planting the wheat crop:

*wheat.manager.start_of_day*

if day = 169 and year = 1992 then

wheat sow cultivar = hartog, plants = 121.61, sowing_depth = 30 (mm),

endif

```
if wheat.stage_name = 'harvest_ripe' or wheat.plant_status = 'dead' then
  wheat harvest
  wheat end_crop
endif
```

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