

Weed Modelling in APSIM

Introduction

When weeds are simulated in APSIM it is done using procedures that were developed for intercropping (ie growing two crops intermingled, for example maize and cow pea in African small holder farms). For this reason, in APSIM weeds are considered a crop, they need to be sown at a depth with a row spacing and a density. Crops have been bred to be uniform; they have synchronous germination and phenological development. Alternatively, natural selection favours diversity in most weed species, germination, emergence and phenological development can occur over a range of times within one population and individual populations can vary between ecological regions. This makes it impossible to represent a weed species with a single model. However, this is exactly what APSIM does by trying to treat the weed as a crop and model the average plant for one specific genotype.

APSIM is a point scale model and when trying to model weed populations or weeds in a paddock it is important to remind yourself that weeds do not occur in uniform stands, evenly distributed throughout the crop and across the paddock, but APSIM thinks they do. Low weed densities, patchiness and access to soil resources must all be considered, especially if your weed simulation does not look like two sown crops growing side by side.

Many crops exist in APSIM and weeds are included, and appear in a similar way to crops. There is also a generic weed model that can be reconfigured to look like different weeds. In most competition studies the question revolves around how one plant affects another plant. In field studies when researchers want to ensure a uniform stand of weeds with synchronous emergence they will use pseudo weeds (other crops with a weed like appearance). This same approach can be used in APSIM, canola can be used to represent Turnip or radish weeds, wheat can be used to represent wild oats or other winter grasses, and millet or sorghum can be used to model tropical summer grasses. In these cases the seed yield of the weed is not important, but its use of resources and impact on the crop are. If this is the type of simulation being considered don't be discouraged because the specific weed you wish to study is not available. Think laterally, if there is a crop that has a similar appearance to the weed being studied, using it may get you well on the way to answering your question.

The remainder of this document will describe how to set up weed simulations and methods to model complex situations. This is not an exhaustive list and it is hoped many of the limitations identified will be addressed in future releases of APSIM. Some of the limitations will not be addressed because a model is only a tool that partially represents the processes interacting within the system and will never be exact.

Simulating weeds in APSIM

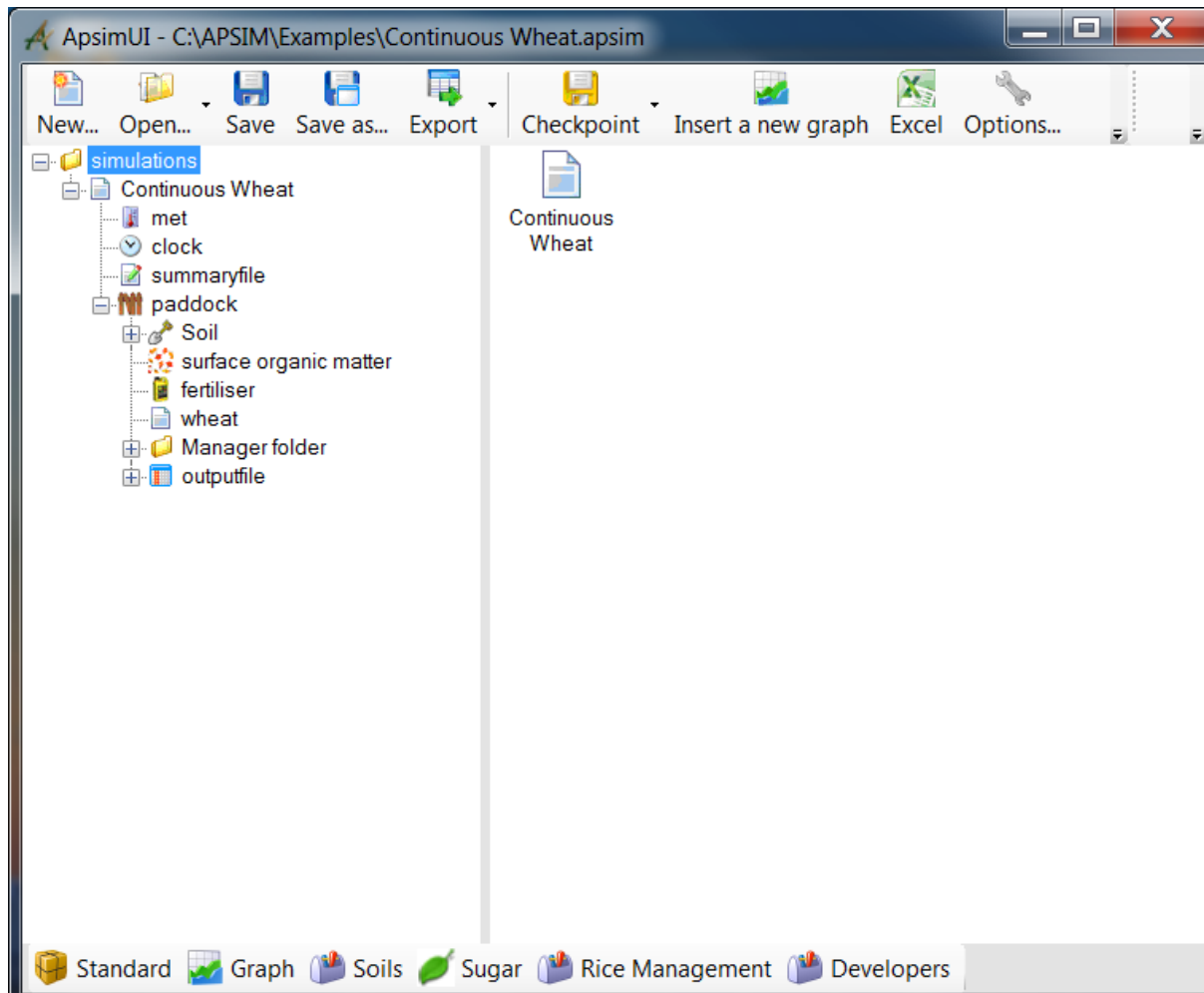
NB. APSIM has many plant models. These are generally called crops within the model, but include weeds, pastures and trees. To look for a plant model you look in the crop folder, overtime this naming may change, but for now when you read crop think plants.

Carrying on from this thought, planting weeds in APSIM is no different to planting a crop and the same GUI objects can be used. Some weed specific tools have been created to help, but if you look at the underlying manager code you will see it is the same as that used for the sowing of all APSIM plant models. When sowing two plants at once it is important to use a gui object that is suitable in the current versions of APSIM 7.3 -7.4 the sow on a variable date object is not suitable for sowing two crops. This is because it looks to see if the paddock is in fallow before sowing. When you try to use this rule only the first crop will be sown. To sow multiple crops use the sow on a date rule or the intercrop sowing rule (weed management tool box).

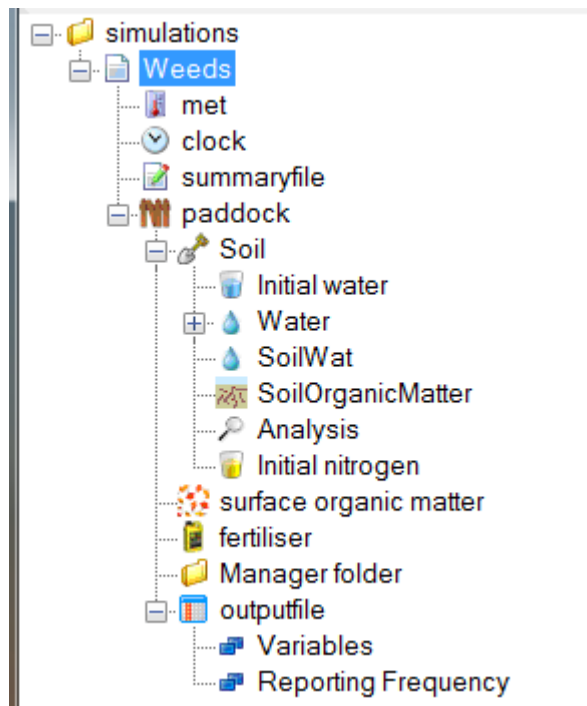
To run two crops in the one simulation APSIM needs to know how to differentiate between the two, it does this by using the canopy model. There are some concerns about the canopy model and alternative approaches are available but these also have limitations. For the purposes of this documentation I will confine my comments to the use and limitations of the canopy model. To simulate competition in APSIM your simulations need to have two crops, (both have to have different names wheat and wheat1 if using a pseudo weed), crop lower limits in the soil model for each crop, the canopy model listing both crops, sowing rules for each crop, and harvest rules for each crop in the manager model.

Building a Basic Weed Model in APSIM

We'll begin by building a simple simulation that uses one weed cohort in a fallow situation. When building a new model in APSIM it is always best to start from an existing simulation, rather than building one from scratch. We'll start by using the Continuous Wheat example simulation which will you find in the Examples folder of your installation directory.



Remove everything in the Manager folder (leave the folder itself though) and the wheat crop. Rename the simulation to “Weeds”.




Open the Standard toolbox and drop an instance of the weed *Raphanus Raphanistrum* (wild radish) on to your paddock. **[Pre-release... weed is currently in Developers toolbox]**

Open the node Soil > Water. You’ll notice a number of crops are listed here with soil water parameters. Copy one of the crops (by dragging to the water node then rename to the weed eg. “*raphanus_raphanistrum*” (no quotes) then change the water values to represent the weed in your soil. Every crop/weed in your simulation must have an entry here.

Now we have the simulation set up with our weed, we add the manager components required to use them. In the Standard toolbox, go to the Management > Weed management node. A number of scripts are here that allow you to manage the weeds in your simulation. Drag a weed sowing script to the empty manager folder in the simulation. You will get a Properties pane that looks like this:

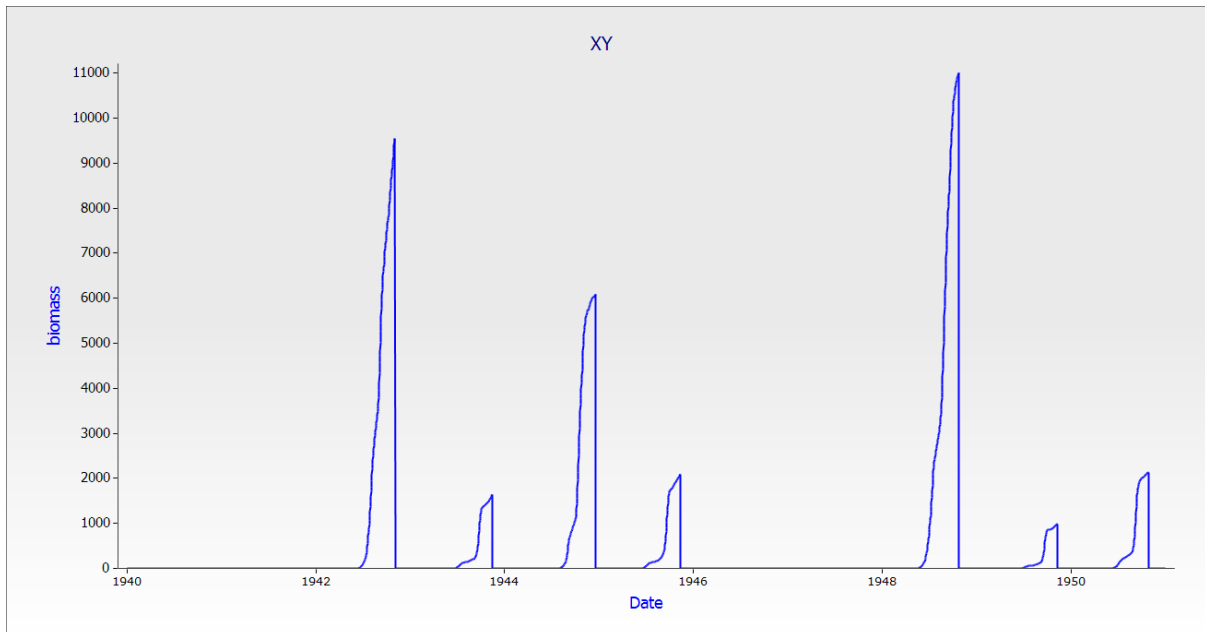
Properties	start_of_day	init	end_of_day
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	Description	Value
	Sowing criteria	
	Enter sowing window START date (dd-mmm) :	1-may
	Enter sowing window END date (dd-mmm) :	15-jul
	Amount of rainfall :	30
	Number of days of rainfall :	3
	Days since last cohort:	0
	Sowing parameters	
	Enter name of weed to sow :	raphanus_raphanistrum
	Enter sowing density (plants/m2) :	50
	Enter sowing depth (mm) :	30
	Enter cultivar :	PacN145
	Enter crop growth class :	plant
	Enter row spacing (mm) :	250
	Enter cohort number	1

Sowing window START date	Weeds will not germinate before this date.
Sowing window END date	Weeds will not germinate after this date.
Amount of rainfall	Minimum amount of rainfall for weed to germinate.
Number of days of rainfall	The rainfall must occur of this many consecutive days.
Days since last cohort	Only used for multi cohort simulations. If you are only simulation one cohort, leave this at 0.
Name of weed to sow	Select the weed to manage (APSIM does not distinguish between crops and weeds).
Sowing density	Weed density.
Sowing depth	Seed depth.
Cultivar	Choose weed cultivar.
Crop growth class	This should generally be plant unless sorghum or maize are being used as weeds.
Row spacing	This can be left at default unless you have a need to change.
Cohort number	For multi cohort simulations. This is the order in which they will germinate; must be unique. For a single cohort leave at 1.

The script already contains code to handle removing the weed on maturity so a separate harvesting rule is not needed.

Adding a graph and plotting Biomass should give you something similar to the following:



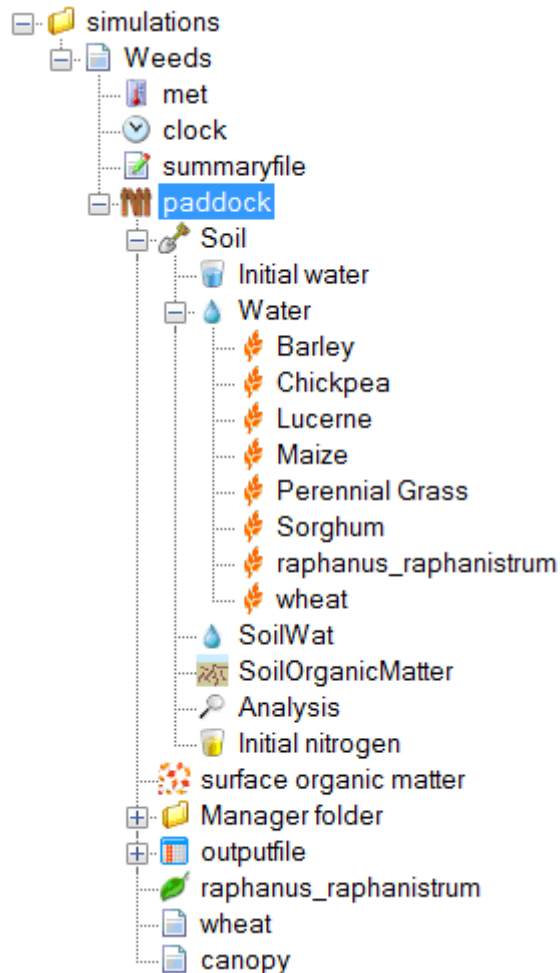
Weed Control

To simulate the effect of herbicide on weeds two scripts have been provided in the weed management folder. One controls by killing a fraction of a weed on a given date, the other by killing a given number of days after germination. It is possible to use both on a single weed which would result in two controls. It is also possible to use multiple controls on a single weed. To use, simply drag the control you want to use from the toolbox to your manager folder. The scripts are detailed in the weed control by date section.

Crop-Weed Competition

To run a competition model three main components are required; a crop, a weed and a module to control the interactions. The canopy module will be used for this.

Starting from the previous example, drag a wheat crop onto the paddock. In Soil > Water, copy the raphanus_raphanistrum node and rename it wheat. Also drop a canopy module into the paddock. You'll find it at the bottom of the crops tree in the standard toolbox.



We need to tell canopy what crops/weeds should interact. Click on the canopy module, remove the defaults and add our two modules:

Description	Value
Enter crop names to intercrop	raphanus_raphanistrum wheat

Finally, add sowing and harvesting rules for wheat in your manger folder.

Multiple Weed Cohorts

It is possible to sow multiple weed cohorts and have them interact with crops in the same season. You will need one weed node for each cohort and at least one management rule for each as well. Have a look at the simulation tree below:

This simulation models a scenario where there is the possibility of up to three cohorts appearing in a wheat crop.

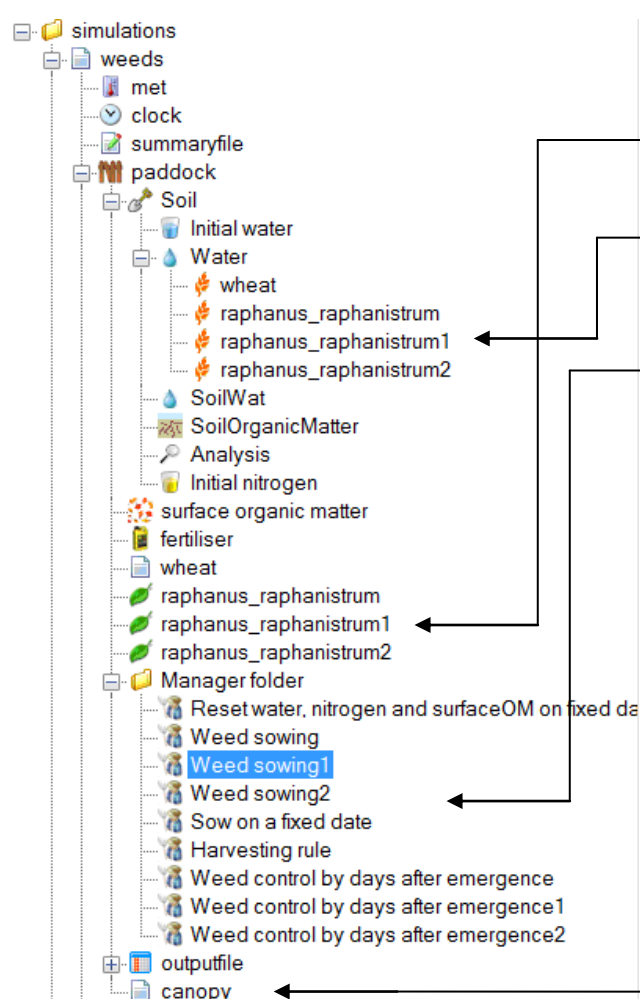
In order to run multiple weed cohorts, each cohort needs a separate entry and each entry needs a unique name.

They also each need an entry in Soil > Water as well.

Each weed is managed separately, so we will need a sowing rule for each weed and as many controls for each weed as you require (here we're using one control for each cohort, see below).

Finally, we need to add all cohorts and the crop to canopy to do the interaction effects.

Description	Value
Enter crop names to intercrop	raphanus_raphanistrum raphanus_raphanistrum1 raphanus_raphanistrum2 wheat



We've already looked at the weed sowing manager, but now we'll look at the options specific to cohort management.

Description	Value
Sowing criteria	
Enter sowing window START date (dd-mmm) :	1-may
Enter sowing window END date (dd-mmm) :	15-jul
Amount of rainfall :	30
Number of days of rainfall :	3
Days since last cohort:	0
Sowing parameters	
Enter name of weed to sow :	raphanus_raphanistrum
Enter sowing density (plants/m2) :	6
Enter sowing depth (mm) :	30
Enter cultivar :	PacN145
Enter crop growth class :	plant
Enter row spacing (mm) :	250
Enter cohort number	1

The sowing pane uses an extra criterion to determine if a cohort should germinate. 'Days since last cohort' allows you to specify the minimum number of days that need to pass before another cohort is considered for germination. If you leave this at 0 it will germinate alongside the previous cohort which is probably not what you want. Sowing dates and rainfall criteria still need to be met for a germination to occur.

'Cohort number' in sowing parameters specifies the order in which the cohorts will germinate. This number needs to be unique, contiguous and start at 1. The number of cohorts in your simulation specifies the maximum number that can germinate. If any of the sowing criteria are not met, you will have fewer than the maximum, or even no cohorts germinating some years.

Reference - Weed Sowing Manager Component

This control is found in the Standard Toolbox under Management > Weed Management

Description	Value
Sowing criteria	
Enter sowing window START date (dd-mmm) :	1-may
Enter sowing window END date (dd-mmm) :	15-jul
Amount of rainfall :	30
Number of days of rainfall :	3
Days since last cohort:	0
Sowing parameters	
Enter name of weed to sow :	raphanus_raphanistrum
Enter sowing density (plants/m2) :	6
Enter sowing depth (mm) :	30
Enter cultivar :	PacN145
Enter crop growth class :	plant
Enter row spacing (mm) :	250
Enter cohort number	1

Sowing window START date	Weeds will not germinate before this date.
Sowing window END date	Weeds will not germinate after this date.
Amount of rainfall	Minimum amount of rainfall for weed to germinate.
Number of days of rainfall	The rainfall must occur of this many consecutive days.
Days since last cohort	The number of days that must pass before another cohort is eligible for germination
Name of weed to sow	Select the weed to manage (APSIM does not distinguish between crops and weeds).
Sowing density	Weed density.
Sowing depth	Seed depth.
Cultivar	Choose weed cultivar.
Crop growth class	This should generally be plant unless sorghum or maize are being used as weeds.
Row spacing	This can be left at default unless you have a need to change.
Cohort number	For multi cohort simulations. This is the order in which they will germinate; must be unique. For a single cohort leave at 1.

Reference - Weed Control By Date or Days After Emergence

These controls are found in the Standard Toolbox under Management > Weed Management

Description	Value
Control parameters	
Enter date to apply control	
Enter fraction to kill (0 - 1)	0
Choose weed to kill	

Description	Value
Control parameters	
Enter number of days after emergence to apply	10
Enter fraction to kill (between 0 and 1)	0
Choose weed to kill	

Date to apply control (dd-mmm)	Weeds will be killed on this date (e.g. 01-jun).
Number of days after emergence	Kill weeds this many days after emergence.
Fraction to kill	The proportion of weeds to kill.
Choose weed to kill	Select the weed to apply the control to.

Each weed you want to control will need at least one of these controls. An individual weed can have multiple controls assigned to it and you can use both controls at the same time.

Science issues and limitations of simulating competition using the APSIM canopy model

There are a number of potential error sources when using canopy. These occur because all the models are built as monocultures and the parameters set within the model are specific to a monoculture at a set density. When plants are grown in competition the density changes, which can affect plant height and growth. I will use the results from a simple experiment to demonstrate the size of these errors. The experiment was constructed using wheat. The control is a single wheat crop planted on the 1st of June every year in Goondiwindi with a plant population of 100 plants/m², 150kg/ha of Urea is added at sowing. Water Nitrogen and residue are reset each year to 100mm filled from the surface, 100kg as No3 and 1000kg/ha.

Treatment 1

The competition experiment planted two wheat crops at the same time with a plant population of 50 plants/m² (combined total 100 plants/m²) each experiment was run for 100 years and the results compared to the control.

Treatment 2

Treatment 2 was the same as treatment 1 in all aspects apart from the kl values. Each of the competing wheat crops kl values was reduced by 50% so the combined total was the same as the control.

Results and Discussion

Figure 1 shows the comparison of a 100 year simulation with a sowing density of 100 plants/m² with the sum of a competition experiment with two 50 plants/m² wheat densities. The green line shows the 50 + 50 wheat densities and the black line is the control. There are some differences but generally over the 100 years the performance is similar. This is when the kl value has not changed. The second figure (Fig. 2) has the kl value changed by 50% for each of the lower density plantings.

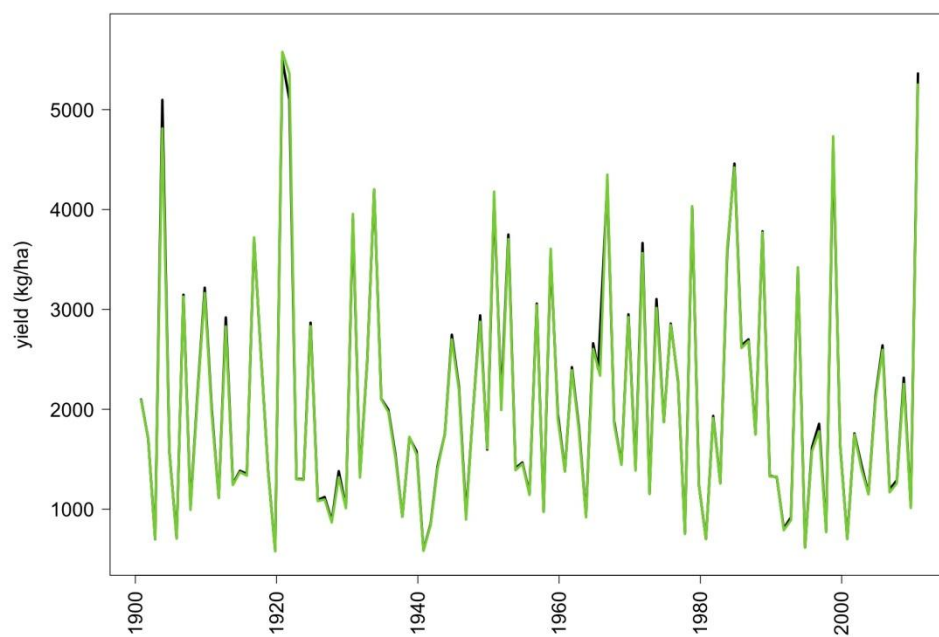


Figure 1 - Unchanged kl values

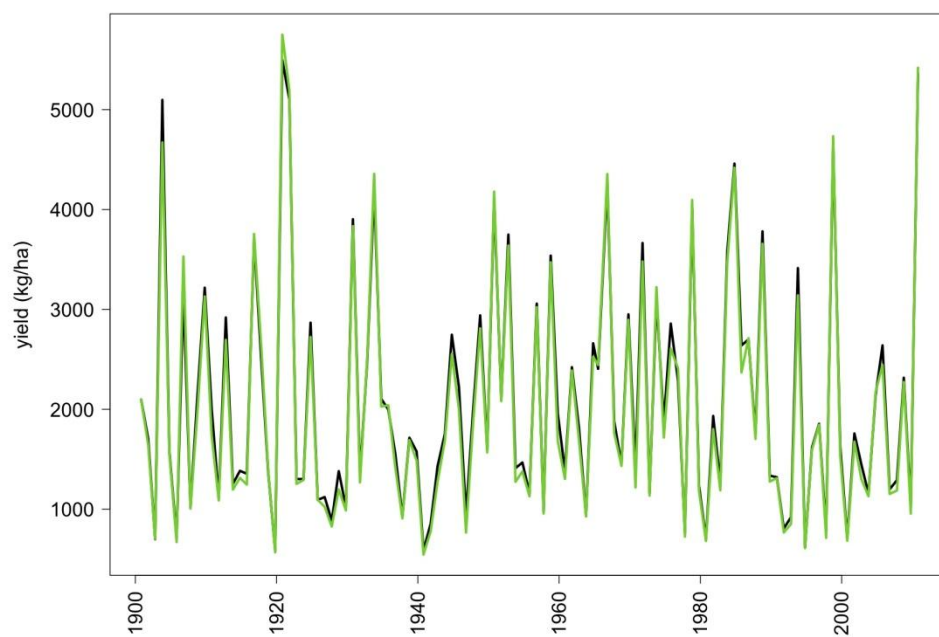


Figure 2 - Changing the kl values appeared to marginally change the yields.

Treatment 2 kl values

The second treatment looked at the kl values. The kl value is used to determine the 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 0.06 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)
```

Thinking through this problem one can assume that if you halve the plant population then you should halve the kl value because the root length density will be halved. If the density remains set as it is for the mono crop then the halved densities will have a higher than usual uptake potential. That said changing the kl values has very little impact on our test set (figure 1 and 2). Three simulations were completed, the first looked at an average year where the soil water was reset to 100 mm at sowing each year. The second was reset to 320mm each year and the third reset to 20mm this gave an average, a non stressed and stressed scenarios. In all cases the black line is when kl has been halved and the green line is when kl was unchanged. From the results the only time when changing kl made a significant impact (reducing final grain yield) was when there was high water availability in the non stressed situation.

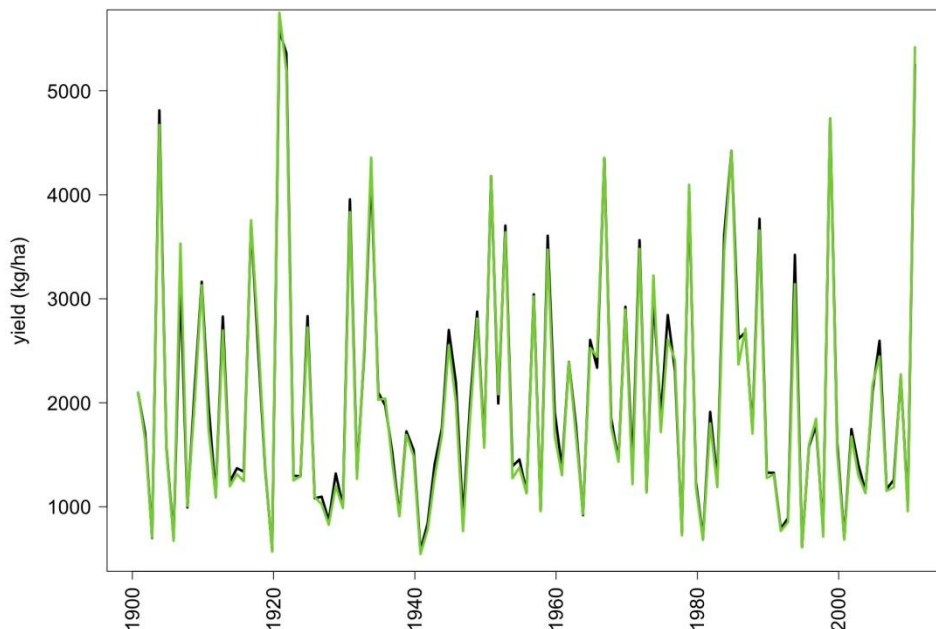


Figure 3 - Average conditions 100mm of water in profile at sowing

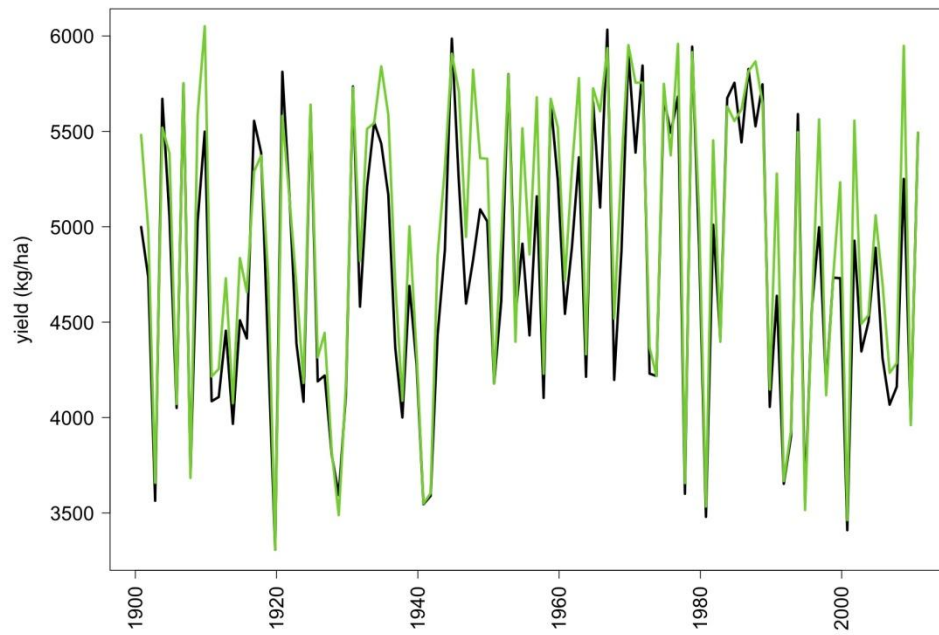


Figure 4 - Low stress soil set to full profile, 320mm at sowing

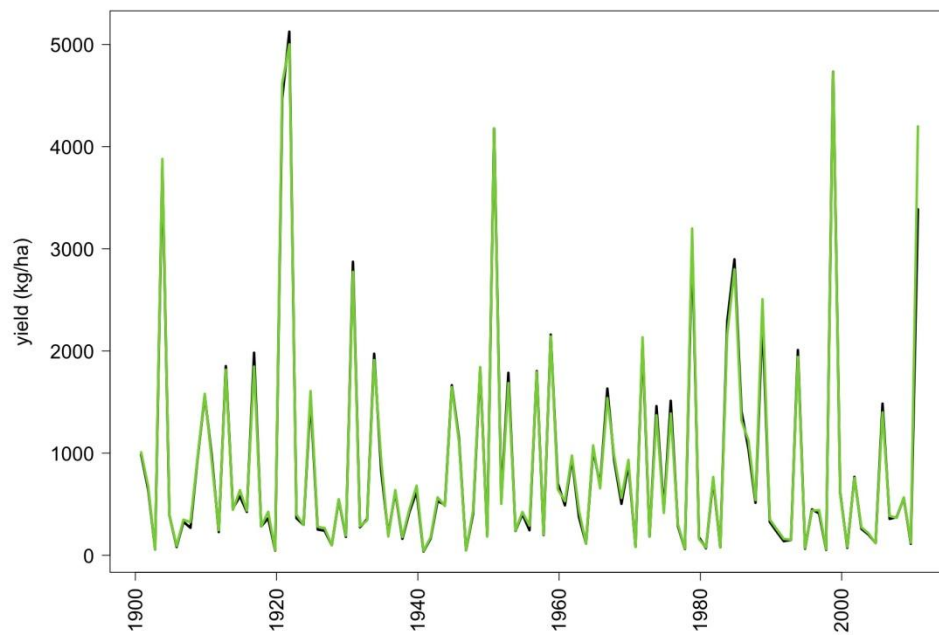


Figure 5 - High stress soil reset to 20mm PAWC at sowing

To understand why this is occurring an understanding of how the canopy model works is needed.

Understanding the flip flop approach in the canopy model.

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 $\text{extinct_coeff} \times \text{lai}$ 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 $\text{extinct_coeff} \times \text{LAI}$ 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.

Generally Canopy is a simple substitute for the complex arbitration that is occurring when two plant species compete, but at times strange things happen. In our demonstration of the wheat at half the density, things look good when the kl values are left unchanged (fig 6), but when the kl values are halved (fig 7) strange things happen on specific years. These strange responses are often called runaways and result from one crop becoming dominant over the other.

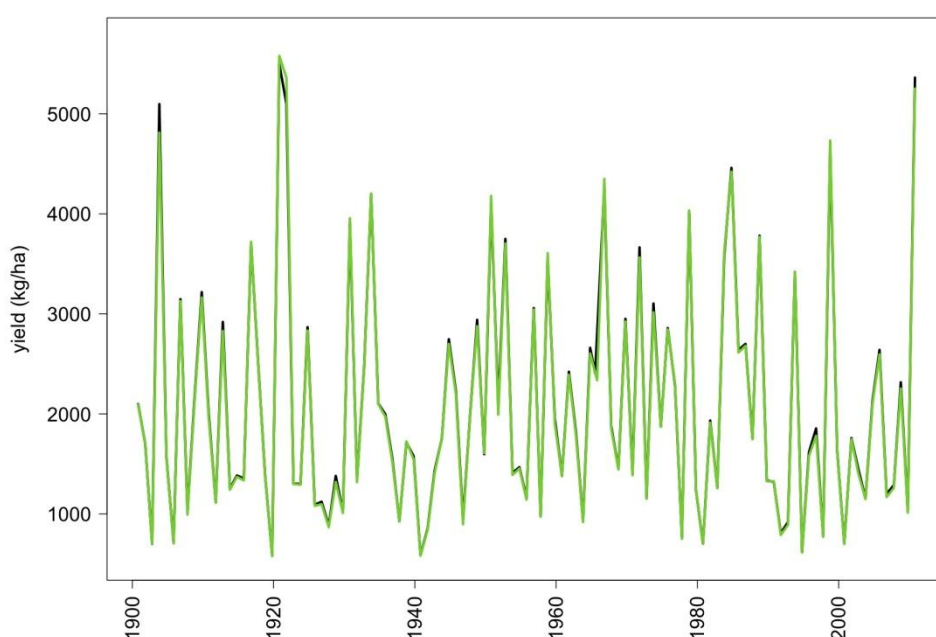


Figure 6 – kl values unchanged

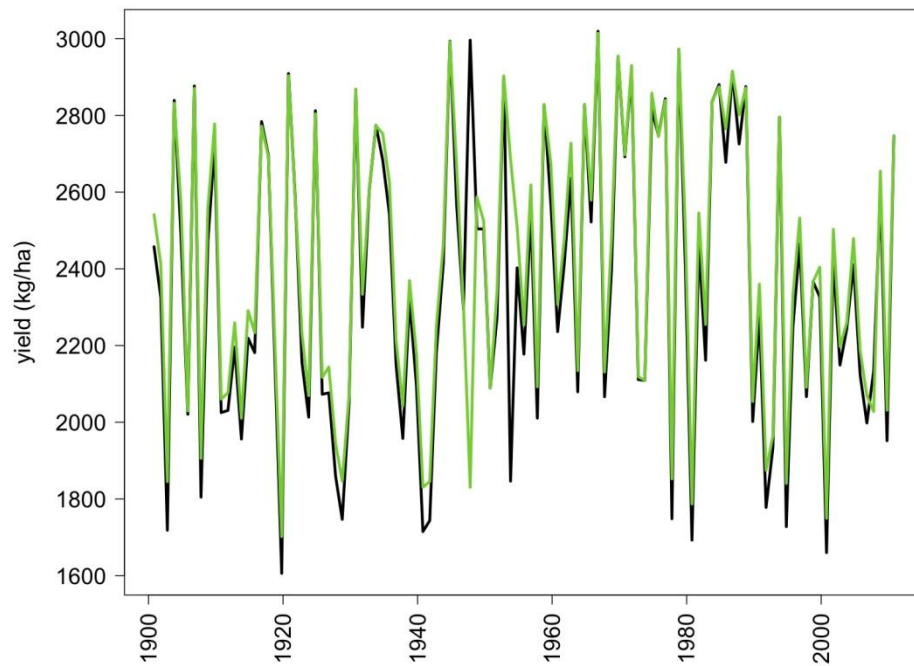


Figure 7 - kl values halved

When Figure 7 is examined a runaway occurs in 1947, we will zoom into this date to further understand the process that is occurring.

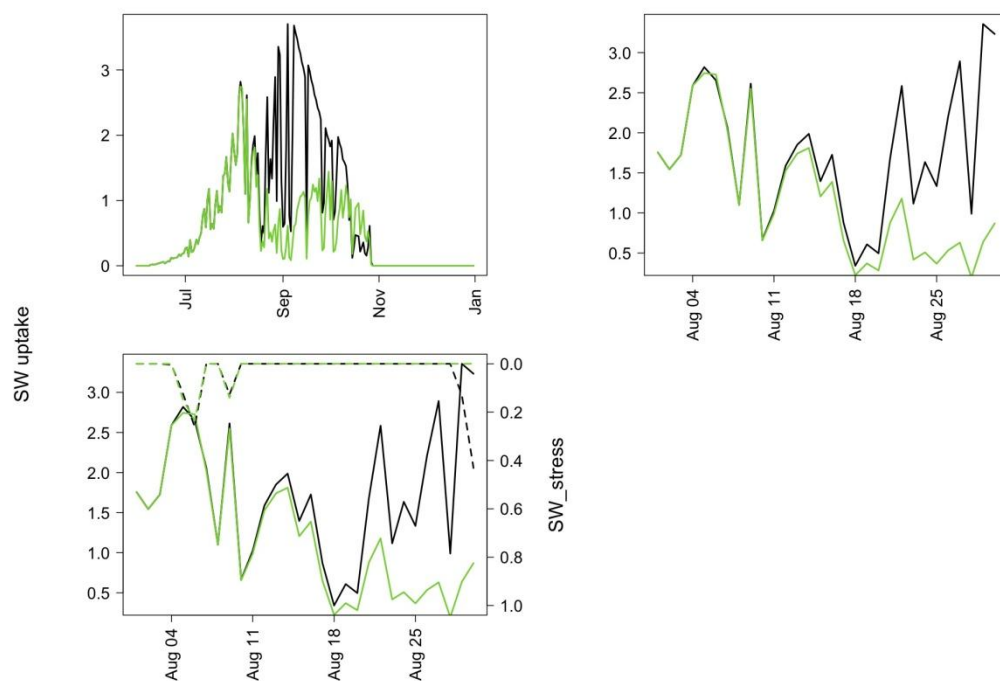


Figure 8 - Daily examination of 1947 wheat crop

The first figure top left shows the soil water uptake by the two competing wheat crops tracking together and then separating in August. Zooming in closer the separation started on Aug 11 (fig 8b, top left). The bottom figure includes APSIM's stress indices (dotted lines right hand axis) and shows

no significant stress occurred on this day but previously some stress had occurred. Breaking down the simulation it is interesting to see how all the different components of the simulation behave (fig. 9)

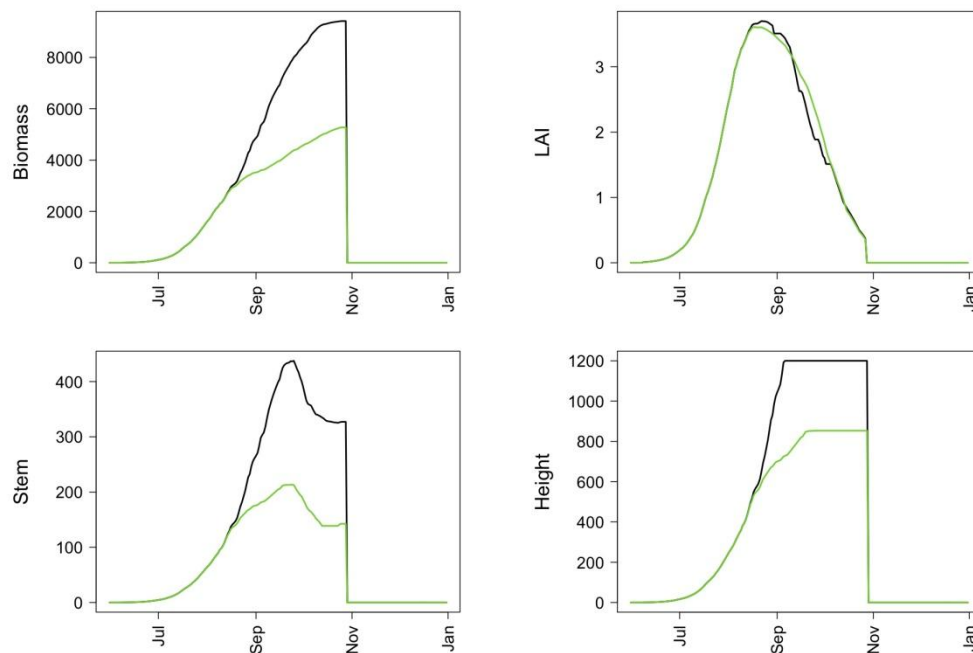


Figure 9 - Break down of process responses in daily 1947 simulations.

The point where the two simulations differ (Aug 11) comes about because the stem biomass changes. However, the LAI and the green leaf biomass (not shown) do not differ substantially. When APSIM partitions resources, a fraction is taken by the leaves, a fraction is taken by the pod/grain and the remainder is shared between the roots and the stem. If resources become limiting the crop which has the second bite may get enough resources to supply the leaves but not the stem. This then causes a circular problem, because height is driven off stem mass. The plant that had the first bite on the limiting day (plant A) will grow taller producing more resources and depositing more biomass in the stem. The crop that had the second bite (plant B) gets first bite the next day, but this only gives it enough resources to catch up to the height of plant A. Thus, plant B is always second and in time, because its height is less than plant B and canopy supplies the largest proportion of intercepted radiation to the top of the canopy, even more resources are withheld and plant A has a runaway response.

Table 1 shows the daily values for this simulation and how one stress day can cause a runaway.

ApsimVersion = 7.3								
	plant A	plant B	plant A	plant B	plant A	plant B	plant A	plant B
Date	stem wt	stem wt	height	height	uptake	uptake	sw_stress	sw_stress
(d/m/y)	(g/m ²)	(g/m ²)	(mm)	(mm)	(mm)	(mm)	()	()
4/08/1947	74.4	74.4	281.909	281.909	2.588	2.588	0.004	0
5/08/1947	78.61	78.5	297.606	297.606	2.819	2.745	0.124	0.149
6/08/1947	82.61	82.61	314.428	313.988	2.655	2.727	0.261	0.235
7/08/1947	86.43	86.36	330.452	330.446	2.06	2.023	0	0
8/08/1947	89.65	89.58	345.726	345.446	1.101	1.1	0	0
9/08/1947	95.38	95.17	358.594	358.305	2.613	2.549	0.127	0.14
10/08/1947	98.25	97.99	381.524	380.671	0.666	0.657	0	0
11/08/1947	102.71	102.31	392.986	391.974	1.027	0.991	0	0
12/08/1947	108.81	108.16	410.85	409.227	1.588	1.526	0	0
13/08/1947	116.24	115.15	435.228	432.645	1.851	1.741	0	0
14/08/1947	123.87	122.1	464.946	460.589	1.987	1.811	0	0
15/08/1947	129.28	126.78	495.483	488.412	1.396	1.206	0	0
16/08/1947	137.09	133.06	517.13	507.114	1.726	1.388	0	0
17/08/1947	141.15	136.09	548.35	532.226	0.87	0.65	0	0
18/08/1947	144.02	137.98	564.6	544.361	0.342	0.225	0	0
19/08/1947	147.5	140.1	576.092	551.915	0.609	0.371	0	0
20/08/1947	153.12	143.3	589.991	560.386	0.497	0.283	0	0

The stress event on the 4th of August was minor it did not affect uptake, height or stem weight, the next day plant A was under stress, but plant B had a greater stress and this reduced stem growth that in turn reduced plant height the next day. Stress was relieved the following day, but the influence of height continued with plant B almost catching back up to plant A. This minor difference may have corrected itself, but the next stress day was 2 days later and caused a further reduction in stem mass and consequently plant B height. Once plant A is higher the canopy model allocates more light and the runaway process occurs. To prove this a simple change was made to the model. Maximum plant height was set at day one of the simulation removing the growth response related to stem mass (fig 10) .

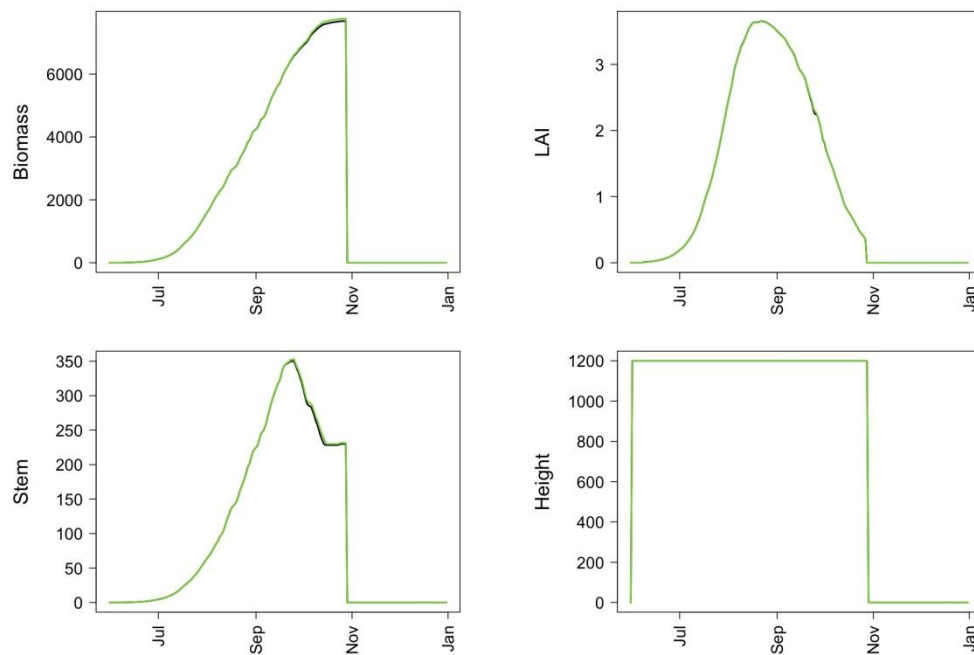


Figure 10 - Simulation with maximum height set on day 1 of the simulation

This result suggests that the linking of height to stem weight is a problem, owing to stem uptake not being a fixed proportion. The key to solving this problem is a better method to derive height. One suggestion is to derive height from LAI. The reason this problem does not occur when kl is not reduced, is because the initiating water stress does not happen. In fact no stress occurs until after maximum height is reached. An alternative solution is to use a different radiation-proportioning model such as micromet. Micromet proportions radiation throughout the canopy unlike canopy that has a higher weighting to the taller plant. Current work is getting micromet working with canopy without conflict.

Eo

Soil water demand is calculated in the 'biomass accumulation' 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 efficiency 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. $eo_crop_factor * eo * cover_green$.

The concern for competition experiments is soil water demand is calculated by multiplying the crop factor * eo and $cover_green$, in a mixed canopy $cover_green$ represents the mixture not the individual plant so soil water demand is going to be greater than it should be. An easy fix for this is to derive uptake by relating to the green cover of the individual plant i.e. LAI.

Accounting for discontinuous canopies and patchiness

The underlying design of APSIM, and most cropping models assumes a continuous canopy. When row crops are simulated or skip rows are modelled the canopy is divided up to limit the amount of light that a crop receives. Similar approaches have been proposed for low weed densities. However this approach only considers light interception, the availability of below ground resources are not considered, resulting in an unrealistically large volume of soil for the plants roots to explore. Generally modelling low densities of weeds in APSIM is dangerous. However, the patchy nature of weeds means in general weed populations are at least a few plants per m². There may be a few patches in a paddock resulting in a low paddock weed density. Simulating the yield for the weed patch and then the weed free area will provide more reliable information. However it will require more post simulation processing to estimate the proportion of each ha that was weedy and weed free.

Setting plant height

From the discussion on canopy, above, it can be seen that height is an important parameter in competition modelling. Unfortunately, crop models that have been built to simulate monoculture crops, do not need it. For this reason model builders do not always check the values entered into this parameter and some of APSIMS models may have unrealistic height parameters. Some will hit maximum height at emergence while others will have detailed descriptions of height. Currently the height response is fixed and the affect of density is not considered so plants growing in a competitive environment will not elongate.

Conclusion

The issues identified in this document exist at the time of writing. The purpose of writing this document is to challenge the existing methods with which competition is modelled. The hope is that through this approach the modelling of crop competition in APSIM will improve. Some alternative are close to release, but the simplest method of looking at competition between species using APSIM uses canopy.

References

Carberry, P.S., Adiku, S.G.K., McCown, R.L. and Keating, BA. Application of the APSIM Cropping Systems Model to Intercropping Systems. In Dynamics of Roots and Nitrogen in Cropping systems of the semi-Arid Tropics. Japan International Research Centre for Agricultural sciences.