# Changes implemented for APSIM sugarcane

**Report on progress by Geoff Bamber (26/6/2014)**

Shaun Verrall implemented the requested changes incrementally and each change has its own APSIM setup and sugar.dll and sugar.xml files. In this report I checked each change as it was made in its own folder but I used the latest .dll file unless I was having difficulty in getting the change to work properly and had doubts that the latest .dll file was appropriate. When all the steps are working correctly we will have to test if they all work together from the same xml and dll files. My feeling is that they will work well together. The numbering of the change steps are the same as in the change request document.

## Transpiration efficiency

### Step 1. Intrinsic water use efficiency (k) = transpiration efficiency (TE)= ‘transp\_eff\_cf’

This is defined for each growth stage as ‘transp\_eff\_cf’ in APSIM at present. We want *k* to depend on water stress (*S*) defined as the ratio of water supply to water demand *(D)* rather than on the growth stage (as is the case presently in APSIM):

*S* = root water supply/ sw\_demand = W/D (1)

Daily transpirational demand (D) is derived thus:

*D = R(1-exp(-E.LAI)) \* RUE \* VPD / k* (2)

Where:

*R* = Daily radiation (MJ/m2)

*E* = extinction\_coef

*k* = y\_transp\_eff\_cf (g kPa/Kg)

*RUE* = radiation use efficiency (g/MJ)

*LAI* = leaf area index

*VPD* = Mean daily vapour pressure deficit

I am not sure what the APSIM name is for root water supply (sw\_supply I think) but it is assigned to ‘RWU’ in WATBAL in CERES-Maize.

*W = RWU = Σ(KLn \* ESWn) for n = 1 to nlayr* (3)

The user must be able to set the response to water stress as in this example where k = 8.7 g KPa/kg when demand is fully met by root water supply and *k* increases proportionally to 10.0 g KPa/kg when water supply is zero.

x\_stress\_photo = 0 1

y\_transp\_eff\_cf = 0.0100 0.0087

Please use the typical APSIM extrapolation system so we can have a more complex relation to *S* if we want. Data below obtained by Jaya and Phil suggest a response to stress something like:

x\_stress\_photo = 0 0.2 0.8 1

y\_transp\_eff\_cf = 0.004 0.0150 0.0087 0.0087 (Kg KPa/Kg)

|  |
| --- |
| IF ep>0.1 then let te = DLT\_DM/ep  let vpsat\_max = 0.1 \* 6.1078 \* exp(17.269\*Tmax/(Tmax+237.30))  let vpsat\_min = 0.1 \* 6.1078 \* exp(17.269\*Tmin/(Tmin+237.30))  LET vpd = 0.75\*(vpsat\_max-vpsat\_min)  let TEc = te \* vpd  LET prevswdef=LAG(swdef1)  DSAVE te1  SCALE 120 80  plot tec\*PREVSWDEF / XLABEL = 'Water Demsnd/Supply (swdef\_photo) ' YLABEL = 'Transpiration efficiency coefficient g kPa/ kg' |
|  |
| <x\_swdef\_photo> 0 0.2 0.8 1</x\_swdef\_photo>  <y\_transp\_eff\_cf units="g kPa/Kg">0.004 0.0150 0.0087 0.0087</y\_transp\_eff\_cf> |

Fig 1. 'Transpiration efficiency coefficient (k or TEC) in relation to Water Demand/Supply (swdef\_photo) '. TEC is not an output variable in APSIM and was derived as in the code in the top box. The lower box has the sugar.xml line for the relationship shown in the graph

**Conclusion: Step 1 is working as expected on a daily time step basis.**

### Step 2: Develop hourly temperature, radiation and VPD values from daily data

This initial check was done with a data set from Kalamia here we use data sets from Kalamia and the Ord so covering a very wide range of conditions. In the figures below automatic weather station (AWS) data is compared to hourly data generated in the new version of APSM. The rainfall data are daily totals from the AWS and APSIM just to confirm that the same data source was used. In the case of Kalamia , temperature was estimated very well with r2>90% as we required in the agreement. In the Ord R2 was 87%, close to the required level of agreement. Regression coefficients were close to unity and constants were close to zero so we can regard these estimates as reliable. Radiation was estimated with the required degree of precision at both sites (R2>90%) but regression coefficients were a bit low (0.917 and 0.892 for Kalamia and the Ord respectively). Hourly VPD was not estimated very well with R2 = 77 and 80 % respectively). APSIM generally under-estimated VPD by about 25% probably because the assumption that minimum and dew point temperatures are equal, is not always true. An improvement to the VPD estimate would be to allow the user to select some function of the other daily climate variables as the dew point. This could be a simple deduction from the minimum temperature or something more complex requiring some thought and modelling on the part of the user.

Shaun has developed some of the procedure for determining hourly from daily values in a folder labelled Script(C#). The user can modify the way VPD is determined for example by changing the estimate of dew point temperature. The use can also supply VP as from the SILO data base. This option was not tested because I used AWS not SILO data which is on a daily not an hourly basis.

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|  | | Dependent Variable | TEMPAPS | | --- | --- | | N | 21888 | | Multiple R | 0.961 | | Squared Multiple R | 0.923 | | Adjusted Squared Multiple R | 0.923 | | Standard Error of Estimate | 1.444 |  | **Regression Coefficients B = (X'X)-1X'Y** | | | | | | | | --- | --- | --- | --- | --- | --- | --- | | **Effect** | **Coefficient** | **Standard Error** | **Std. Coefficient** | **Tolerance** | **t** | **p-Value** | | CONSTANT | -0.008 | 0.049 | 0.000 | . | -0.168 | 0.866 | | TEMPERATURE | 0.997 | 0.002 | 0.961 | 1.000 | 513.620 | 0.000 | |
|  | | Dependent Variable | RADNAPS | | --- | --- | | N | 21888 | | Multiple R | 0.979 | | Squared Multiple R | 0.958 | | Adjusted Squared Multiple R | 0.958 | | Standard Error of Estimate | 0.218 |  | **Regression Coefficients B = (X'X)-1X'Y** | | | | | | | | --- | --- | --- | --- | --- | --- | --- | | **Effect** | **Coefficient** | **Standard Error** | **Std. Coefficient** | **Tolerance** | **t** | **p-Value** | | CONSTANT | 0.070 | 0.002 | 0.000 | . | 38.011 | 0.000 | | RADNMJ\_AWS1 | 0.917 | 0.001 | 0.979 | 1.000 | 708.456 | 0.000 | |
|  | | Dependent Variable | VPDAPS | | --- | --- | | N | 21888 | | Multiple R | 0.777 | | Squared Multiple R | 0.604 | | Adjusted Squared Multiple R | 0.604 | | Standard Error of Estimate | 0.400 |  | **Regression Coefficients B = (X'X)-1X'Y** | | | | | | | | --- | --- | --- | --- | --- | --- | --- | | **Effect** | **Coefficient** | **Standard Error** | **Std. Coefficient** | **Tolerance** | **t** | **p-Value** | | CONSTANT | 0.297 | 0.004 | 0.000 | . | 81.477 | 0.000 | | VPD | 0.743 | 0.004 | 0.777 | 1.000 | 182.792 | 0.000 | |
|  | | Dependent Variable | VPDAPS | | --- | --- | | N | 18288 | | Multiple R | 0.805 | | Squared Multiple R | 0.648 | | Adjusted Squared Multiple R | 0.648 | | Standard Error of Estimate | 0.383 |  | **Regression Coefficients B = (X'X)-1X'Y** | | | | | | | | --- | --- | --- | --- | --- | --- | --- | | **Effect** | **Coefficient** | **Standard Error** | **Std. Coefficient** | **Tolerance** | **t** | **p-Value** | | CONSTANT | 0.290 | 0.004 | 0.000 | . | 75.893 | 0.000 | | VPD | 0.795 | 0.004 | 0.805 | 1.000 | 183.338 | 0.000 | |

Fig 2. Daily rainfall and hourly temperature, radiation and VPD derived from Shauns new APSIM version compared to values measured hourly at the automatic weather station in Kalamia (2003-2005). The second VPD plot was done after correcting errors in the C# script.

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| --- | --- |
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|  | | Dependent Variable | TEMPAPS | | --- | --- | | N | 10896 | | Multiple R | 0.933 | | Squared Multiple R | 0.871 | | Adjusted Squared Multiple R | 0.871 | | Standard Error of Estimate | 2.127 |  | **Regression Coefficients B = (X'X)-1X'Y** | | | | | | | | --- | --- | --- | --- | --- | --- | --- | | **Effect** | **Coefficient** | **Standard Error** | **Std. Coefficient** | **Tolerance** | **t** | **p-Value** | | CONSTANT | 1.379 | 0.099 | 0.000 | . | 13.877 | 0.000 | | TEMPERATURE | 0.956 | 0.004 | 0.933 | 1.000 | 271.261 | 0.000 | |
|  | | Dependent Variable | RADNAPS | | --- | --- | | N | 10896 | | Multiple R | 0.955 | | Squared Multiple R | 0.913 | | Adjusted Squared Multiple R | 0.913 | | Standard Error of Estimate | 0.316 |  | **Regression Coefficients B = (X'X)-1X'Y** | | | | | | | | --- | --- | --- | --- | --- | --- | --- | | **Effect** | **Coefficient** | **Standard Error** | **Std. Coefficient** | **Tolerance** | **t** | **p-Value** | | CONSTANT | 0.093 | 0.004 | 0.000 | . | 24.548 | 0.000 | | RADNMJ\_AWS1 | 0.892 | 0.003 | 0.955 | 1.000 | 337.735 | 0.000 | |
|  | | Dependent Variable | VPDAPS | | --- | --- | | N | 10896 | | Multiple R | 0.896 | | Squared Multiple R | 0.803 | | Adjusted Squared Multiple R | 0.803 | | Standard Error of Estimate | 0.499 |  | **Regression Coefficients B = (X'X)-1X'Y** | | | | | | | | --- | --- | --- | --- | --- | --- | --- | | **Effect** | **Coefficient** | **Standard Error** | **Std. Coefficient** | **Tolerance** | **t** | **p-Value** | | CONSTANT | 0.031 | 0.008 | 0.000 | . | 4.148 | 0.000 | | VPD | 0.724 | 0.003 | 0.896 | 1.000 | 210.505 | 0.000 | |

Fig 3. Daily rainfall and hourly temperature, radiation and VPD derived from Shauns new APSIM version compared to values measured hourly at the automatic weather station in the Ord (2005-2007)

### Step 3: Derive maximum hourly transpiration rate from hourly radiation, and VPD estimates.

#### When root water supply is limiting

['E:\sug\s12dat\MCPD\APSIMupgrade\GeoffTest\1\Stage3 - part 1']

[using sugar.dll made for this step]

Vapour pressure is derived in units of hPa in Shauns C# script. This led to estimates of crop water demand (sw\_demand) that were 10 x greater than were possible. After discussion with Shaun I changed the units to kPa. My estimate of hourly VPD and Shaun’s estimates now agree (Fig 4) when we are both using the daily max and min temperature data rather than actual hourly data from the AWS as in step 2 above.

|  |  |
| --- | --- |
| A | B |

Fig 4. Hourly VPD derived from Shauns new APSIM version compared Geoffs derivation of hourly VPD as requested in the change request document, using A) daily values of max and min temperature from the automatic weather station in Kalamia (2003-2005), B) daily values of vapour pressure, max and min temperature from SILO (Ingham) 1998-2000.

I was expecting hourly transpiration to be derived as:

Potential hourly transpiration (TOi) for the ith hour

*TOi = Ri(1-exp(-E.LAI)) \* RUE \* VPDi / ka (4)*

Where:

*Ri* = hourly radiation (MJ/m2) = 1.8 for plant and 1.65 for ratoon crops

*VPDi* = hourly vapour pressure deficit

*ka =* as derived in step 1, set at a constant *=* 8.7 g kPa/kg in this example

Shauns values are sort of in line with what was expected when demand was <2 mm/hr but there were some very high values in Shauns data up to 7 mm/h which is impossible in nature (Fig 5). Shauns values are on average 50% greater than expected (Fig 5). This I think leads to some very highly daily demand values (Fig 6) which should not really exceed 10 mm/d but do so some times in APSIM normally because of the strong influence of VPD in the demand equation. Examples of hourly values are shown in Fig 7 where there may be some clue to what the problem is. Geoffs hourly values were obtained as *Tai = Ri(1-exp(-E.LAI)) \* RUE \* VPDi \* S / ka,* from eqns 1 and 4 while Shaun has worked out the max supply for each hour and capped *Ta* (actual transpiration) at that value as was requested (Geoff has not done that). Geoffs and Shauns values were similar when demand was low and S=1 (no stress) but Shauns midday values were much higher when demand was high, also with S=1. Shauns capped values were applied throughout the day when we were expecting them to be applied only during the period of high water demand as in the example in the change request document. Transpiration cannot exceed demand but does so in the example in Fig 7c.

|  |  |
| --- | --- |
|  |  |
| <nh4\_min\_lb units="kg/ha">0</nh4\_min\_lb>  <x\_swdef\_photo> 0 0.2 0.8 1</x\_swdef\_photo>  <y\_transp\_eff\_cf units="kg kPa/kg">0.0087 0.0087 0.0087 0.0087</y\_transp\_eff\_cf>  <plant\_crop> | |

Fig 5. Hourly potential transpiration derived from APSIM VPD, direct from APSIM (ie Shaun) and from Geoffs equations above. VP calculations were done after correcting for apparent unit errors in the C# script.

The xml settings are shown in the box in Fig x were such that transpiration efficiency coefficient (TEC) was set not to change with water stress.



Fig 6.

|  |  |  |
| --- | --- | --- |
|  |  |  |
| a: High demand, no stress | B: Low demand, no stress | C: High demand, stress (S~0.4) |

Fig 7. Examples of three days in December of hourly transpiration (o = Shauns, X = Geoffs) and evaporative demand (△ = Shauns, ▽ = Geoffs) and the supply / demand ratio (+ = swdef\_photo).

Table 1

|  |  |  |
| --- | --- | --- |
| Hour | T0i | TAi |
| 6 | 0.05 | 0.050 |
| 7 | 0.1 | 0.100 |
| 8 | 0.3 | 0.300 |
| 9 | 0.5 | 0.500 |
| 10 | 0.7 | 0.558 |
| 11 | 0.8 | 0.558 |
| 12 | 0.9 | 0.558 |
| 13 | 0.9 | 0.558 |
| 14 | 0.8 | 0.558 |
| 15 | 0.7 | 0.558 |
| 16 | 0.5 | 0.500 |
| 17 | 0.2 | 0.200 |
| Total | 6.45 | 5.000 |

#### Where stomatal conductance is limiting

['E:\sug\s12dat\MCPD\APSIMupgrade\GeoffTest\1\Stage3 - part 2']

[using sugar.dll made for this step]

For this, the user can set a maximum hourly transpiration rate and in so doing allow the crop to avoid the effects of water stress on leaf expansion.

The examples below show how transpiration was set at a max of 0.8 mm/h regardless of the degree of water stress (Fig 8) and then how the max value was reduced to 0.6 mm/h with max water stress (Fig 9). The demand values are correct but not the transpiration values. There should be no transpiration at night and transpiration cannot exceed demand.

In Figs 10 biomass accumulation is not affected much by capping transpiration demand because when it is capped, biomass accumulation is reduced about the same extent that water stress reduced biomass accumulation with no capping. Transpiration efficiency is increased with capping because of reduced effective VPD and transpiration is reduced (Fig 11) and the conservation of water could then lead to yield increases but did not do so in this case at Ingham during the wet years of 1998 to 2000 (Fig 10). The results may be different when the hourly transpiration code is corrected.

|  |  |  |
| --- | --- | --- |
| <x\_swdef\_photo2>0 1</x\_swdef\_photo2>  <y\_sw\_demand\_hourly\_max units="mm"> 0.8 0.8</y\_sw\_demand\_hourly\_max> | | |
|  |  |  |

Fig 8. Examples of three days in of Shauns hourly transpiration (X), evaporative demand (O) and the supply / demand ratio (+ = swdef\_photo). Transpiration capped at 0.8 mm/h independent of stress.

|  |  |
| --- | --- |
| <x\_swdef\_photo2>0 1</x\_swdef\_photo2>  <y\_sw\_demand\_hourly\_max units="mm"> 0.6 0.8</y\_sw\_demand\_hourly\_max> | |
|  |  | |

Fig 9. Examples of two days in of Shauns hourly transpiration (X), evaporative demand (O) and the supply / demand ratio (+ = swdef\_photo). Transpiration capped at 0.6 to 0.8 mm/h dependent on stress.



Fig 10. Biomass yield when transpiration demand is not capped or is capped at 0.8 mm/h

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Fig 11. Cumulative demand transpiration demand is not capped or is capped at 0.8 mm/h

## 2) Root water supply to be derived from root length density

Phil Jackson is concerned that traits for vigour (leaf area and RUE) do not link with root water uptake (RWU) capability in the APSIM sugarcane model even though this link appears to be described in the Keating et al (1999) paper. After the January review it was decided to investigate the possibility of getting this link to work in APSIM as an alternative to the current kl based approach. The user should be able to select one or the other method. This step should take precedence over following steps which have been renumbered below.

Shaun and Geoff discussed this point at length and Shaun is now aware of what variable in the code (representing root length per layer) to use in the derivation of potential root water supply. Based on the excerpts below from Monteith and Greenwood (1986) and Robertson et al (1993) and separating *k* and *l*, root water uptake for layer n is:

RWU(n) = RLV(n) \* 100 \* KL(n) \* ESW(n) mm/d

RLV is reported in mm/mm3 in APSIM so the 100 multiplier converts RLV to cm/cm3

Change in soil water content (theta) in eqn 2 of Robertson is in cm3/cm3/d and theta is in cm3/cm3 .

ESW is in mm per layer rather than cm3/cm3 so RWU is also in mm/layer/d which is what we want to determine potential or actual water uptake per day.

Currently RWU derived as:

RWU(n) = KL(n) \* ESW(n) mm/d

Data in thi Fig 12A confirms that APSIM is now determining root water supply from root length volume. My ‘rwunew’ is my estimate of this variable and sw\_supply comes from the new version of APSIM. Root water supply depends on water available in each layer and RLV which increases with time at depth but cane also decrease as roots die back (Fig 12B).

|  |  |
| --- | --- |
|  |  |

Fig 12

## 3) TE and CO2

CO2 has a dominant effect on k (transp\_eff\_cf) or TE so please allow for the kind of response below and also allow CO2 levels to be set in the manager file or to be read in from the climate (met) file.

y\_transp\_eff\_cf is a multiplier for modifying *k* as in step 1

transp\_eff\_cf\_fact = 1.0 1.25

x\_CO2 = 375 720 ppm

**Checking in step 3 which has CO2 effects on TEC and RUE without any other changes [using sugar.dll created on 14/2/2014 – latest]**

There were some errors in the way CO2 levels are chosen by the user which I fixed in the script for yearly changes in climatic factors. The user is prompted to select a change coefficient which is then multiplied by the difference between the selected base year and the year in the met record. The equation for CO2 was the same as for the other variables so the default change coefficient (~390) was added for each year from the selected base year, ending up with some very large CO2 levels. The code now simply uses the CO2 entry (left of Table 2) as the selected CO2 level for the run.

The code is working correctly in this example where TEC = 8.72 for 390 ppm and 10.44 for 720 ppm, a 20% increase resulting reduced transpiration (EP). TEC was a bit unstable when EP was very small (Fig 13).

**Table 2**

|  |  |
| --- | --- |
| <x\_co2 units="ppm">375 720</x\_co2>  <y\_transp\_eff\_cf\_fact>1.0 1.2</y\_transp\_eff\_cf\_fact>  <x2\_co2 units="ppm">380 720</x2\_co2>  <y\_rue\_co2\_fact>1.0 1.01</y\_rue\_co2\_fact> |  |



**Fig 13. Transpiration efficiency coefficient (TEC g kPa/kg) and daily transpiration (EP mm) for two CO2 levels**

**Checking with y\_transp\_eff\_cf (TEC) constant in relation to water stress**

|  |
| --- |
| <x\_co2 units="ppm">360 720</x\_co2>  <y\_transp\_eff\_cf\_fact>1.0 1.2</y\_transp\_eff\_cf\_fact> |
|  |

Fig 14. Intrinsic TE for two CO2 levels

Intrinsic TE (TEC) derived from daily biomass gain divided by transpiration (dlt\_dm/ep) was 8.7 and 10.44 g kPa/kg for 360 and 720 ppm CO2 as expected (Fig 14).

## 4) RUE and CO2 [using sugar.dll created on 14/2/2014 – latest]

|  |
| --- |
| <x2\_co2 units="ppm">360 720</x2\_co2>  <y\_rue\_co2\_fact>1.0 1.1</y\_rue\_co2\_fact> |
|  |

Fig 15. RUE derived as dlt\_dm/radn\_int for SELECT SWDEF\_PHOTO =1 AND RADINT >2 and nfact\_photo=1, for two CO2 levels and a plant and ratoon crop.

Max RUE increased with CO2 as expected (by 10%)(Fig 15).. I am not sure why RUE was lower than the values set in the xml file. This may have something to do with biomass losses due to detachment

## 5) Radiation use efficiency and RESPIRATION [using sugar.dll created on 14/2/2014 – latest]

The fraction of sucrose lost to respiration each day was related to daily mean temperature as expected (Fig 16A) and biomass and CCS were reduced by respiration as anticipated (Fig 16B and 16C). The inclusion of respiration increased the impact of seasonal temperatures on ripening which is interesting.

|  |  |
| --- | --- |
| <x\_tmean units="oC"> 10 15 20 25 30 35</x\_tmean>  <y\_suc\_resp\_fr units="0-1">0 0.001 0.002 0.005 0.009 0.015</y\_suc\_resp\_fr> | |
| **A** | **B** |
| **C** | |

**Fig 16. A)** Sucrose respiration fraction in relation to daily mean temperature and B) biomass accumulation with time, with (blue) and without respiration.

## 6) Radiation use efficiency and leaf no.

In this example RUE was set to decrease to 80% of the starting value (1.8 g/MJ for plant crops and 1.65 g/MJ for ratoon crops when leaf number increased from 30 to 50. The model performed exactly as expected apart from reduced values of RUE in the early stages, probably because of leaf senescence after tillering (Fig 17)..

|  |  |
| --- | --- |
| <x\_leaf\_no> 1 30 50</x\_leaf\_no <y\_rue\_leaf\_no\_fact>1.0 1.0 0.8</y\_rue\_leaf\_no\_fact> |  |

Fig 17. RUE derived as dlt\_dm/radn\_int for SELECT SWDEF\_PHOTO =1 AND RADINT >2 and nfact\_photo=1, for a plant and ratoon crop in relation crop phenology (leaf number)