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Water budgeting: Crop factors vs crop coefficients

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Introduction

Periods of water stress are detrimental to tree production and are best avoided by closely monitoring potential tree water use for effective irrigation scheduling.

In Australia many almond growers have been using locally installed standard class A evaporation pans to estimate daily potential tree or crop water use *(ET_c)* which enables them to maintain a water budget that matches tree water requirement to irrigation. The Almond Board of Australia (ABA) provides a spreadsheet based water budgeting tool to facilitate this process. In its current form the spreadsheet requires the user to enter daily estimates of pan evaporation and uses “in-house” crop factors *(C_f)* within the spreadsheet to calculate the crop water requirement for the day (Almond Board of Australia, 2011). The spreadsheet also maintains a tally of the daily and overall irrigation water balance of the current season.

Potential tree water requirement can also be estimated from weather records which are obtained from suitably located automatic weather stations or web based sources (Bureau of Meteorology, 2012). In the Sunraysia and Riverland regions, Lower Murray Water (LMW) and The South Australian Murray Daring Basin Natural Resource Management Board (SA-MDBN-RMB) are providing web access to daily records from a network of automatic weather stations along the lower Murray River (Lower Murray Water, 2014; Natural Resources SA, 2014).

The purpose of this fact sheet is to briefly highlight the differences between direct pan based and indirect weather based methods to estimate potential crop water use and to provide some basic guidance regarding their application.

Class A pan evaporation based estimates

This method relies on daily readings of pan evaporation *(ET_{pan})* from a suitably sited class A evaporation pan together with an appropriate set of crop factors *(C_f)*. The latter is a representation of the tree leaf area at a given stage in the growing season and at a given tree age. Potential crop water use *(ET_c)* results from the product of the measured pan evaporation *(ET_{pan})* and a given crop factor on any particular day during the season (see equation 1).

Equation 1: $$ET_c = C_f \times ET_{pan}$$

The water budgeting spreadsheet made available by the Almond Board of Australia includes a set of crop factors that were developed in-house as part of the almond optimisation trial (Almond Board of Australia, 2011). In its current form the spreadsheet requires the user to enter daily estimates of pan evaporation in order to calculate the crop water requirement for the day according to equation 1. The spreadsheet also maintains a tally of the daily and overall irrigation water balance of the current season. This method has been widely adopted within the almond industry.

A disadvantage of the method is the need for regular readings and frequent maintenance of the evaporation pan. Such work is labour intensive and therefore costly while the possibilities for automating such a system are limited. Many users therefore have looked for alternative methods including weather based estimates of potential crop evapotranspiration to determine tree water use and irrigation requirement.

Weather based estimates

Potential tree water requirements can be accurately estimated from weather records obtained from suitably located automatic weather stations. Some are installed by private producers, while others are in the public domain and a growing number are accessible over the web (Lower Murray Water, 2014; Natural Resources SA, 2014).

The basic calculation is similar to that shown in equation 1, in that it multiplies the potential water demand of the atmosphere, in this case reference crop evapotranspiration *(ET_o)*, with a suitable coefficient *(K_c)* as outlined in equation 2. The crop coefficient *(K_c)* on a given day is representative of leaf area and age of the tree. It is important to note however that matching K_c and C_f values are different and therefore cannot be substituted with each other.

Equation 2: $$ET_c = K_c \times ET_o$$

Unlike ET_{pan}, the reference crop evapotranspiration ET_o is not based on a direct measurement from an evaporation pan but is based on a complex set of calculations using a number of different weather related variables, including daily minimum and maximum air temperature, humidity, sunshine (solar radiation) and wind speed. The calculation routines are well established and have been calibrated for a number of reference crops. The most widely used and recognized method to calculate ET_o is the "FAO-56 Penman-Monteith" method (Allen et al., 1998). The similar "ASCE-standardized Penman-Monteith" method was recently presented as an improvement of the FAO-56 method (ASCE-EWRI, 2005). ASCE have proposed two reference crops, a short crop equivalent to a clipped-grass, 0.12 m high and a tall crop similar to a full cover alfalfa 0.5 m high. The ASCE based methodology is being used in the automatic weather station network made available by SA-MDBN-RMB and LMW (Lower Murray Water, 2014; Natural Resources SA, 2014). It covers a large proportion of the almond growing regions in South Australia and Victoria. Daily readings of ET_o as a tall and a short reference crop are being made available for download over the World Wide Web. For almonds it is recommended to apply the tall reference crop ET_o.

Direct pan evaporation versus weather based crop evapotranspiration

It is important to note that the estimates of ET_{pan} and ET_o are of a different magnitude and therefore are not directly interchangeable without prior conversion. ET_{pan} readings tend to be higher than ET_o readings, particularly on hot and dry days. The current ABA spreadsheet was intended for the use with ET_{pan} and therefore ET_o readings should not be used directly without prior conversion.

Conversion and substitution procedures

There is a simple relationship between ET_{pan} and ET_o determined by a pan coefficient (K_{pan}) as outlined in equation 3. However, the situation is complicated by the fact that each evaporation pan has its own unique pan coefficient which may range from 0.35 - 0.85 (Allen et al., 1998; Aschonitis et al., 2012). K_{pan} is strongly influenced by the location of the pan and associated factors relating to how close and how dense the surrounding vegetation is and how exposed the pan is to the prevailing winds.

Equation 3: $$ET_o = K_{pan} \times ET_{pan}$$

An estimate of the K_{pan} may be obtained by regressing local weather based ET_o records with matching ET_{pan} records. K_{pan} in turn may be used to convert weather based ET_o to ET_{pan} for direct input into the ABA irrigation spreadsheet as outlined in equation 4.

Equation 4: $$ET_{pan} = 1 \div K_{pan} \times ET_o$$

An ongoing irrigation trial being conducted by DEPI and the ABA at Lake Powell determined a K_{pan} of 0.72, using daily readings from a local evaporation pan and corresponding ET_o estimates from historical weather records over a period of two seasons (Bureau of Meteorology, 2012). The coefficient was later used to convert weather based ET_o to ET_{pan} (equation 4) for direct input into the ABA irrigation spreadsheet (Sommer, 2012).

A similar value (0.7) was determined at the same location using 10 years of modelled "SILO data drill" (Bureau of Meteorology, 2012) records of ET_o and ET_{pan}. The value should be a reasonable approximation for the conversion of weather based ET_o to ET_{pan}, the daily input variable required by the current version of the ABA irrigation spreadsheet.

Application of a generic K_{pan} is also applicable for the direct conversion of C_f to Kc or vice versa.

Equation 5: $$K_c = 1 \div K_{pan} \times C_f$$

A table of seasonal C_f recommended by the ABA and their conversion to Kc is presented in Table 1.

Changing to the new Almond Production Spreadsheet

The use of a K_{pan} number to convert C_f to K_c can be site specific i.e. if you have been using evaporation data from the Loxton Research Centre, you may not be able to start using data from an automatic weather station in Waikerie. The simplest way to do this is to enter a full year's data from the evaporation pan you have currently been using and observe the total water use needed in mm. Next enter data from an automatic weather station for the same time period and observe the total water use in mm. The two methods of calculating the total crop water use should be the same. If they aren't the same it means the K_{pan} (relationship between C_f and Kc needs calibrating for your specific location. The new almond production spreadsheet (downloadable from the ABA website) has a default K_{pan} value of 0.7. If the default K_{pan} value does not give you the same total crop water use in mm, then a calibration is needed to correct the error. This can simply be done by altering the K_{pan} value on the spreadsheet until the total crop water use for the automated weather station data equals the total crop water use for the evaporation pan data. Sounds confusing? The staff at the ABA office will be able to help transition from one set of data to another.

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Table 1:

Month	Week	Growth Stage	C_f	K_c
Jul	1		0.0	0.0
	2		0.0	0.0
	3	PE	0.0	0.0
	4	PE	0.0	0.0
Aug	5	PE	0.0	0.0
	6	S1a	0.0	0.0
	7	S1a	0.24	0.34
	8	S1a	0.35	0.50
Sep	9	S1ab	0.36	0.51
	10	S1b	0.37	0.53
	11	S1b	0.39	0.56
	12	S1b	0.45	0.64
Oct	13	S1b	0.57	0.81
	14	S1b	0.62	0.89
	15	S1b	0.67	0.96
	16	S1b S2a	0.71	1.01
Nov	17	S2a	0.75	1.07
	18	S2a	0.77	1.10

Month	Week	Growth Stage	C_f	K_c
	19	S2a	0.77	1.10
	20	S2a	0.77	1.10
	21	S2a	0.75	1.07
Dec	22	S2a	0.75	1.07
	23	S2a	0.75	1.07
	24	S2a	0.75	1.07
	25	S2a	0.76	1.09
Jan	26	S2a	0.76	1.09
	27	S2a	0.76	1.09
	28	S2a S2b	0.74	1.06
	29	S2b	0.74	1.06
	30	S2b	0.72	1.03
Feb	31	S2b	0.67	0.96
	32	S2b	0.61	0.87
	33	S2b	0.58	0.83
	34	S2b	0.56	0.80
Mar	35	S2b	0.56	0.80
	36	S2b	0.56	0.80

Month	Week	Growth Stage	C_f	K_c
	37	S2b	0.56	0.80
	38	S2b	0.54	0.77
	39	S2b S3	0.49	0.70
Apr	40	S3	0.41	0.59
	41	S3	0.35	0.50
	42	S3	0.32	0.46
	43	S3	0.30	0.43
May	44	S3	0.30	0.43
	45	S3	0.29	0.41
	46	S3	0.27	0.39
	47	S3	0.25	0.36
Jun	48	S3	0.23	0.33
	49	S3	0.22	0.31
	50		0.0	0.0
	51		0.0	0.0
	52		0.0	0.0

Further reading

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