Information Sheet

5.18 Evapotranspiration (ET) Calendars

Introduction

In this information sheet, Evapotranspiration (ET), factors that affect ET and calendars of simulated daily ET are introduced. The information sheet also demonstrates how the ET calendars can be used for irrigation planning and irrigation management.

Evapotranspiration (ET) is the total crop water use, and consists of water loss through transpiration by leaf stomata and evaporation from the soil surface according to the function:

EVAPOTRANSPIRATION (ET) = TRANSPIRATION (T) + SOIL EVAPORATION (E_{soil}*)*

ET is an essential component of crop growth and is responsible for moving water and nutrients from the roots to the leaves. The loss of water from the green leaves is unavoidable and occurs during the uptake of carbon dioxide (CO_2) from the atmosphere into the leaves. CO_2 is essential for photosynthesis and crop growth. Hence, a crop that is actively using water (i.e. transpiring), is also actively growing and accumulating yield.

ET is critical to establish the rate of soil water depletion by the crop and is important for many aspects of irrigation decision-making to avoid water stress (see Information Sheet 5.1 - Irrigation Fundamentals). This information sheet highlights key factors affecting ET and provides sugarcane ET calendars for the irrigated areas in the South African sugar industry.

Factors affecting Evapotranspiration rate

Climate (weather) has a substantial influence on ET rates. Increased sunshine duration (solar radiation), air temperature and wind speed as well as low relative humidity increase atmospheric evaporative demand which promotes high ET. Therefore, ET is generally higher in summer than in winter and similarly is higher in the sunnier and hotter northern parts of the industry than in the southern Coastal and Midlands regions.

Crop growth stage also has an influence on ET rates. Four growth stages are recognised for sugarcane (Figure 1). In the germination stage, a newly planted (or harvested) crop has no or small leaves. ET is therefore very low. Most of the water lost from the crop area would be due to evaporation from bare soil surface. During the tillering stage, there is an increase in the number and size of leaves and the root system resulting in increasing ET. The ET is highest during the grand growth stage when the crop canopy and root systems are fully developed. The peak ET rate typically occurs when the grand growth stage coincides with hot summer months. Towards harvest (maturation stage), growth rate may decrease resulting in a slight drop in ET.

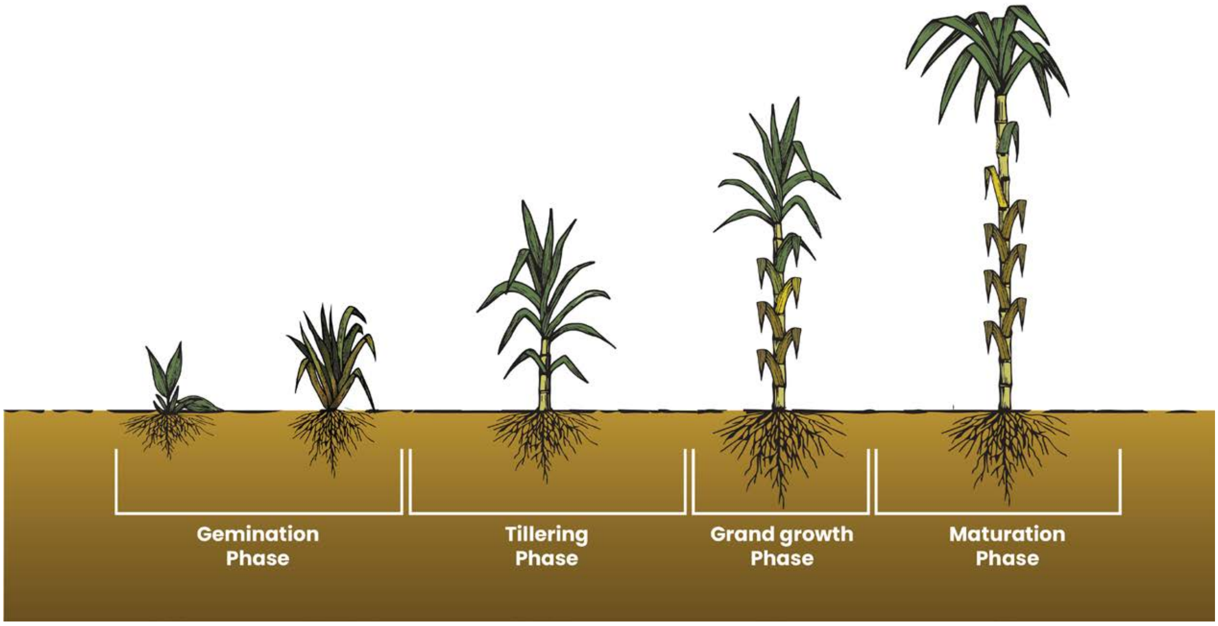

Figure 1: The growth stages of a sugarcane crop.

Soil and crop management factors also influence ET rates. The soil needs to hold adequate water in the root zone for crop uptake, otherwise, the crop suffers water stress which reduces ET. Waterlogged soils cause a lack of oxygen, slowing down respiration in the root system and, consequently, poor root development and reduced water uptake. During any crop growth stage, stressed crops will use less water than stress-free crops. Water stress, pests and diseases, poor nutrition, soil salinity or sodicity and other related soil and crop management factors that stress the crop may all result in reduced ET. In the early growth stages before full leaf canopy, mulched (covered) soils lose less water through evaporation than bare soils.

The ET calendars

The Canesim model, https://sasri.org.za/decision-support-tools/, together with weather data from representative weather stations for each irrigated region, was used to simulate crop water use for 12-month crops for different start dates ranging from April to December. Irrigation was optimised in the model to minimise water-related stress on the crop throughout the growth period. The simulated crops were neither dried off nor mulched. The average daily ET rate, by growth month, for at least 20 seasons, ending in December 2020, is shown in the calendars (Tables 1, 2 and 3). Calendars for regions with similar atmospheric evaporative demand, particularly in the peak months, were combined into one calendar; this was the case for Northern Zululand (Table 1). The simulated ET values are applicable for both plant and ratoon crops.

Reading the ET calendars

The rows contain simulated ET rates pertaining to a plant or ratoon crop starting in the specified month while the columns show simulated ET rates for the given growth month, from start to harvest (12 months). The table shows simulated ET rates for each month of growth from start to harvest (12 months), for crop cycles that start in each of the months from April - December. The letters at the top of each column represent the growth months (A – April, M – May, J - June .... D - December) in their order. For example, the average daily ET for a crop starting in April (Apr) during the first growth month, April (A) is 1.0 mm for Northern Zululand (Table 1), 1.2 mm for Komatipoort (Table 2) and 1.1 mm for Malelane (Table 3). Similarly, a crop which starts in October (Oct) will, in the third growth month, December (D), have a daily average ET of 5.3 mm, 5.9 mm and 5.2 mm for Northern Zululand, Komatipoort and Malelane, respectively.

Table 1: Simulated average daily sugarcane ET rate (mm/day) in each calendar month for different harvest cycles (start month) for Pongola, Makhathini, Mkuze, Umfolozi and Heatonville [Weather data from 1998 to 2020]. The annual total crop water use per crop start month is also provided.

Crop start month	Growth Month																				Annual Total (mm)
	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	
Apr	1.0	1.5	2.2	2.6	3.5	4.3	4.7	5.1	5.6	5.7	5.3	4.5									1396
May		0.6	0.8	1.5	2.6	3.9	4.5	5.1	5.6	5.6	5.3	4.5	3.6								1324
Jun			0.6	0.5	1.5	3.3	4.4	5.0	5.5	5.6	5.3	4.5	3.6	3.2							1302
Jul				0.5	0.8	2.7	4.2	4.9	5.5	5.6	5.3	4.5	3.6	3.2	3.1						1330
Aug					0.6	1.7	3.9	4.9	5.5	5.6	5.3	4.5	3.6	3.2	3.1	3.3					1371
Sep						1.0	2.6	4.6	5.4	5.6	5.3	4.5	3.6	3.2	3.1	3.3	4.0				1405
Oct							1.5	3.5	5.3	5.6	5.2	4.5	3.6	3.2	3.1	3.3	4.1	4.6			1439
Nov								2.0	4.2	5.5	5.2	4.5	3.5	3.2	3.1	3.3	4.1	4.6	4.8		1457
Dec									2.2	4.6	5.1	4.5	3.5	3.2	3.1	3.3	4.1	4.6	4.8	5.2	1458

Table 2: Simulated average daily sugarcane ET rate (mm/day) in each calendar month for different harvest cycles (start month) for the Komatipoort mill supply area [Weather data from 2001 to 2020]. The annual total crop water use per crop start month is also provided.

Crop start month	Growth Month																				Annual Total (mm)
	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	
Apr	1.2	1.7	2.1	2.6	3.9	5.3	5.7	5.9	6.1	5.8	5.7	4.7									1546
May		0.6	0.6	1.3	2.8	4.9	5.6	5.9	6.1	5.8	5.7	4.7	3.6								1444
Jun			0.5	0.2	1.2	4.1	5.4	5.9	6.1	5.8	5.7	4.7	3.6	3.1							1401
Jul				0.4	0.5	3.3	5.3	5.8	6.1	5.8	5.7	4.7	3.6	3.1	2.8						1435
Aug					0.5	2.2	5.1	5.8	6.0	5.8	5.7	4.7	3.6	3.1	2.8	3.2					1476
Sep						0.8	3.8	5.7	6.0	5.8	5.7	4.7	3.6	3.1	2.8	3.2	4.4				1510
Oct							1.5	4.7	5.9	5.8	5.7	4.7	3.6	3.1	2.8	3.2	4.4	5.4			1543
Nov								2.2	5.3	5.7	5.7	4.7	3.6	3.1	2.8	3.2	4.4	5.4	5.6		1572
Dec									2.4	5.2	5.6	4.7	3.6	3.1	2.8	3.2	4.4	5.4	5.6	5.9	1574

Table 3: Simulated average daily sugarcane ET rate (mm/day) in each calendar month for different harvest cycles (start month) for the Malelane mill supply area [Weather data from 1998 to 2020]. The annual total crop water use per crop start month is also provided.

Crop start month	Growth Month																				Annual Total (mm)
	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	
Apr	1.1	1.4	1.8	2.2	3.0	4.2	4.6	5.1	5.4	5.3	5.1	4.1									1314
May		0.5	0.6	1.2	2.2	3.9	4.6	5.0	5.4	5.3	5.1	4.1	3.1								1246
Jun			0.4	0.3	1.1	3.3	4.4	5.0	5.3	5.3	5.1	4.1	3.1	2.7							1220
Jul				0.4	0.5	2.7	4.3	5.0	5.3	5.3	5.1	4.1	3.1	2.7	2.4						1242
Aug					0.4	1.7	4.1	4.9	5.3	5.3	5.1	4.1	3.1	2.7	2.4	2.6					1270
Sep						0.6	3.1	4.8	5.3	5.3	5.1	4.1	3.1	2.7	2.4	2.6	3.3				1292
Oct							1.3	4.0	5.2	5.3	5.1	4.1	3.1	2.6	2.4	2.6	3.3	4.3			1317
Nov								2.1	4.5	5.2	5.1	4.1	3.1	2.6	2.4	2.6	3.3	4.4	4.7		1340
Dec									2.3	4.6	5.0	4.1	3.1	2.6	2.4	2.6	3.3	4.4	4.7	5.1	1344

Associated concepts and theory

Before demonstrating how ET calendars can be used, we first introduce relevant concepts and equations, which are used in conjunction with the data in the ET calendars.

a. Effective Rainfall (Re)

Not all rainfall is available to the crop. Some of the rainfall is intercepted by the canopy, runs off the soil surface or drains beyond the root zone. Hence, only the portion of rain that is stored within the crop root zone is considered to be effective. Effective rainfall is calculated using equation 1:

$$Re = \frac{\text{Monthly Rain (LTM)} - 20}{2} \qquad \text{Eqn 1}$$

Where, Re = effective rainfall (mm/month)

Monthly rain (LTM) = monthly Long Term Mean (LTM) rainfall value (mm/month) obtainable from SASRI's weather web or calculated with data from an automatic weather station

b. Nett Irrigation Requirement (NIR)

The NIR is the depth of water required to meet the plants' ET in its specific growth phase and during the specific period. The NIR is different for full irrigation and supplementary irrigation.

Full Irrigation: When the irrigation system is designed to meet the crop water requirements, ignoring rainfall.

$$NIR = ET \qquad \text{Eqn 2}$$

Where, NIR = Nett irrigation requirement (mm/unit time)

ET = Monthly ET (mm/unit time, e.g. mm/day or mm/month)

Supplementary irrigation: The irrigation system is designed to meet the fraction of the crop water requirements that rainfall cannot supply.

$$NIR = ET_{month} - Re \qquad \text{Eqn 3}$$

Where, NIR = Nett irrigation requirement (mm/month)

ET_{month} = Monthly ET (mm/month)

Re = effective rainfall (mm/month)

c. Gross Irrigation Requirement (GIR)

The GIR is the net irrigation requirement (NIR) of the crop plus the unavoidable water losses of the irrigation system. The unavoidable water losses of irrigation systems is expressed as an efficiency *(η)*.

$$GIR = \frac{NIR}{\eta} \qquad \text{Eqn 4}$$

Where, GIR = Gross irrigation requirement (mm/month)

NIR = Nett irrigation requirement (mm/month)

η = irrigation system efficiency (fraction between 0 and 1, see information sheet 5.1 for efficiency values for different irrigation systems)

In the next section, we demonstrate how the data from the ET calendars can be used, in conjunction with weather data and equations 1, 2, 3 or 4.

Uses of ET calendars

ET calendars can be used in many ways. In the irrigation planning and design stage, ET calendars can be used to inform the irrigation system capacity, farm level water planning or economic forecasting and cash flow budgeting. ET calendars can also provide a simplified and robust approach to scheduling irrigation.

1. **Irrigation system capacity:** Since the ET calendars are robustly developed from weather data spanning over 20 years, an irrigation designer can use the peak ET values from the calendar (mm/day) to appropriately size the irrigation system capacity.

In Table 1: the peak ET = 5.7 mm/day for the Pongola, Makhatini, Mkuze, Umfolozi and Heatonville regions.

In Table 2: the peak ET = 6.1 mm/day for Komatipoort.

In Table 3: the peak ET = 5.4 mm/day for Malelane.

2. **Farm level water planning:** The crop water requirements (water demand) from ET calendars can be compared to anticipated effective rainfall, available water resources and/or available water quotas (water supply).

Table 4 presents a sample calculation for a September cut crop in Pongola. Data from the ET calendar in Table 1 is used as input in Table 4. In this example, we assume a semi-permanent sprinkler irrigation system, with a system efficiency (η) of 83%.

Table 4: Sample calculation for a September cut crop in Pongola (Northern KwaZulu-Natal).

Parameter	Unit	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Totals
Days per month		30	31	30	31	31	28	31	30	31	30	31	31	
ET [a]	mm/d	1	2.6	4.6	5.4	5.6	5.3	4.5	3.6	3.2	3.1	3.3	4	
ET [b]	mm/m	30	81	138	167	174	148	140	108	99	93	102	124	1404
Rain (LTM)[c]	mm/m	30	75	105	116	112	91	82	38	12	10	9	15	694
Re (LTM)[d]	mm/m	5	27	43	48	46	36	31	9	0	0	0	0	244
NIR[e]	mm/m	25	53	96	120	128	113	108	99	99	93	102	124	1160
GIR[f]	mm/m	30	64	115	144	154	136	131	119	120	112	123	149	1397

Notes:

[a] ET from Table 1 (mm/day), for a September cut crop in Pongola

[b] Monthly ET = ET per day x number of days in the corresponding month (mm/month)

[c] Long term mean (LTM) rain obtained from SASRI's Weather Web for Pongola (mm/month)

[d] Effective Rain (Re), calculated using Eqn 1

[e] Net Irrigation Requirement (NIR), calculated using Eqn 3

[f] Gross Irrigation Requirement (GIR), calculated using Eqn 4

The annual gross irrigation requirement (GIR) can be compared to the annual irrigation quota or availability of water resources.

Using ET calendars to explore water supply and demand scenarios can inform the area to be cultivated, irrigation system choice (relating to efficiency and associated water losses), planting and harvesting dates, length of fallows and/or choice of rotation/fallow crops, amongst many other possibilities.

3. **Economic forecasting and cashflow budgeting:** Based on inputs from the ET calendars, Table 4 can also provide a basis for forecasting crop yields, expected revenue, as well as monthly irrigation costs, such as water & electricity.

4. **Irrigation Scheduling:** In addition, ET calendars can be used as an approach to schedule irrigation. Irrigation scheduling must aim to make maximum use of rain, while simultaneously meeting crop demand with irrigation when rainfall is insufficient. Hence, we can apply a paradigm where one aims to schedule irrigation to meet crop demand with irrigation only, and stop or adjust irrigation when rainfall occurs.

Table 5 presents a sample calculation to indicate how much irrigation is required when there is no rain. In this example, we continue with the scenario of a September cut crop in Pongola. Hence, the daily ET values for a September cut crop from Table 1 is used again as an input in Table 5. Since we are ignoring rain (as a starting point), the NIR in Table 5 are equal to ET (Eqn 2). In this example, we continue with the assumption of a semi-permanent sprinkler irrigation system, with a system efficiency (η) of 83%. Furthermore, the system was assumed to be capable of applying 35 mm every 5 days (i.e. peak capacity of 7 mm per day). The notes at the bottom of Table 5 explain how each row was determined. In practice, Table 5 will be drawn up at the start of the season for the specific field.

Table 5: Example of how ET calendars can be used to schedule irrigation.

Parameter	Unit	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Days per month		30	31	30	31	31	28	31	30	31	30	31	31
ET [a]	mm/d	1	2.6	4.6	5.4	5.6	5.3	4.5	3.6	3.2	3.1	3.3	4
ET [b]	mm/m	30	81	138	167	174	148	140	108	99	93	102	124
NIR[c]	mm/m	30	81	138	167	174	148	140	108	99	93	102	124
GIR[d]	mm/m	36	97	166	202	209	179	168	130	120	112	123	149
Irrig. Events[e]	No./m	2	3	5	6	6	6	5	4	4	4	4	5

Notes:

[a] ET from Table 1 (mm/day), for a September cut crop in Pongola

[b] Monthly ET = ET per day x number of days in the corresponding month (mm/month)

[c] Net Irrigation Requirement (NIR) = Monthly ET (Eqn 2)

[d] Gross Irrigation Requirement (GIR), calculated using Eqn 4

[e] Number of Irrigation events = GIR / target application depth of the irrigation system (35mm)

Irrigation can be scheduled according to the number of irrigation events per month as shown in Table 5. If it rains, irrigation should cease for a period of time, dependent on the amount of rain and the month in which the rain falls.

Estimates for the delay period for different months of the year and amounts of rain are shown in Table 6.

Table 6: Estimated rain delay period for different months and rainfall amounts.

	Rain delay period for which irrigation applications should cease following rain (days)											
Rain (mm)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
<6mm	0	0	0	1	1	2	1	1	0	0	0	0
6-10mm	1	1	1-2	2-3	2-3	4	2-3	2	1-2	1-2	1	1
11-15mm	2	2	2-3	4	4	6	4	3-4	2-3	2-3	2	2
16-21mm	2-3	3	4	6	6	8	6	5	4	4	3	2-3
22-27mm	3-4	4-5	5	8	8	8	8	6-7	5	5	4	3-4
28-34mm	4-5	5-6	6	8	8	8	8	8	7	6-7	5-6	4-5
>34mm	6	6	7	8	8	8	8	8	7	7	6	6

The information shown in Table 6 has been used to develop a "Rain Delay Calculator" made from laminated cardboard as illustrated in Figure 2. These are available from an Extension Specialist or the SASRI librarian. To account for effective rainfall during a particular month, the outer dial is rotated so that the window of the inner dial aligns with the correct month. In Figure 2, the window is aligned appropriately for rain falling in the month of January. The number of days for which irrigation applications should cease following rain is simply read as the number in the window adjacent to the given amount of rain.

For example, if 20 mm of rain was recorded in January, irrigation water applications should cease for a period of 2-3 days (refer to Figure 2 or Table 6) before continuing with the remainder of an irrigation cycle. If 20 mm of rain fell in June, the delay period would be 8 days (refer Table 6). In effect, the irrigation cycle is extended by the time given in the Rain delay calculator or Table 6. If rain falls on consecutive days, the daily amounts should be totalled and the result used with the 'Rain delay calculator'. For example, if the following amounts of rain were recorded for 10 days in January: 0 mm, 20 mm, 8 mm, 3 mm, 0 mm, 0 mm, 0 mm, 16 mm, 0 mm and 0 mm, there would be two rain delay periods: one based on 20+8+3=31 mm, the second based on 16 mm. Start of irrigation would have initially been delayed by 4 days for the 31 mm rainfall event. Following the second rainfall event (16 mm) the start of irrigation is postponed a further 2 days. Thus, total delay time before irrigation applications resume would be: 4 + 2 = 6 days.

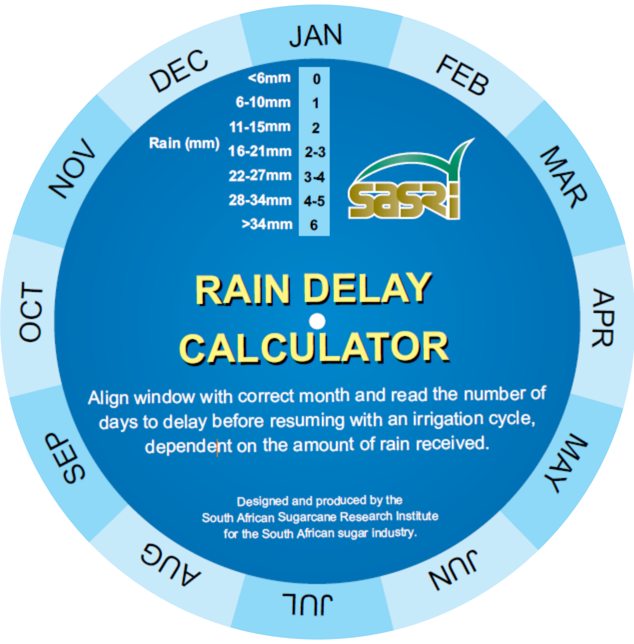

Figure 2: Rain delay calculator.

Scheduling irrigation with ET calendars is based on long-term average climatic data. One should monitor to see if the prevailing conditions deviate from the average. In addition, the farmer can monitor soil water content in the field to confirm if the ET calendars and rainfall delay rules are working. Using ET calendars to schedule irrigation is a rudimentary, but robust, cost-effective and easy to use approach and can be used as a stepping-stone towards more sophisticated tools. To learn about more sophisticated irrigation scheduling tools and methods, please consult Information Sheet 5.4 (Irrigation Scheduling Toolbox).

In summary, climate plays a critical role in determining the atmospheric evaporative demand and accounts for the spatial and seasonal variation in ET. Crop start date and growth phase is another important factor of ET. The ET calendars account for these two factors and are very useful for irrigation planning and water management in the irrigated parts of the South African sugar industry. The calendars are robust enough for use on both plant and ratoon crops. The ET values in the calendar represent unstressed crops under optimal growing conditions. The ET calendars can be used for sizing irrigation system capacity, comparing crop demand to water supply, informing economic forecasts or cash flow budgets, and as a guideline for irrigation scheduling. Since the calendars are based on long term averages, adjustments will be required when climatic factors deviate from the long-term average or when crop conditions are less than optimal.

Phillemon Sithole (Agrometeorologist) and Ashiel Jumman (Agricultural Engineer)

October 2022