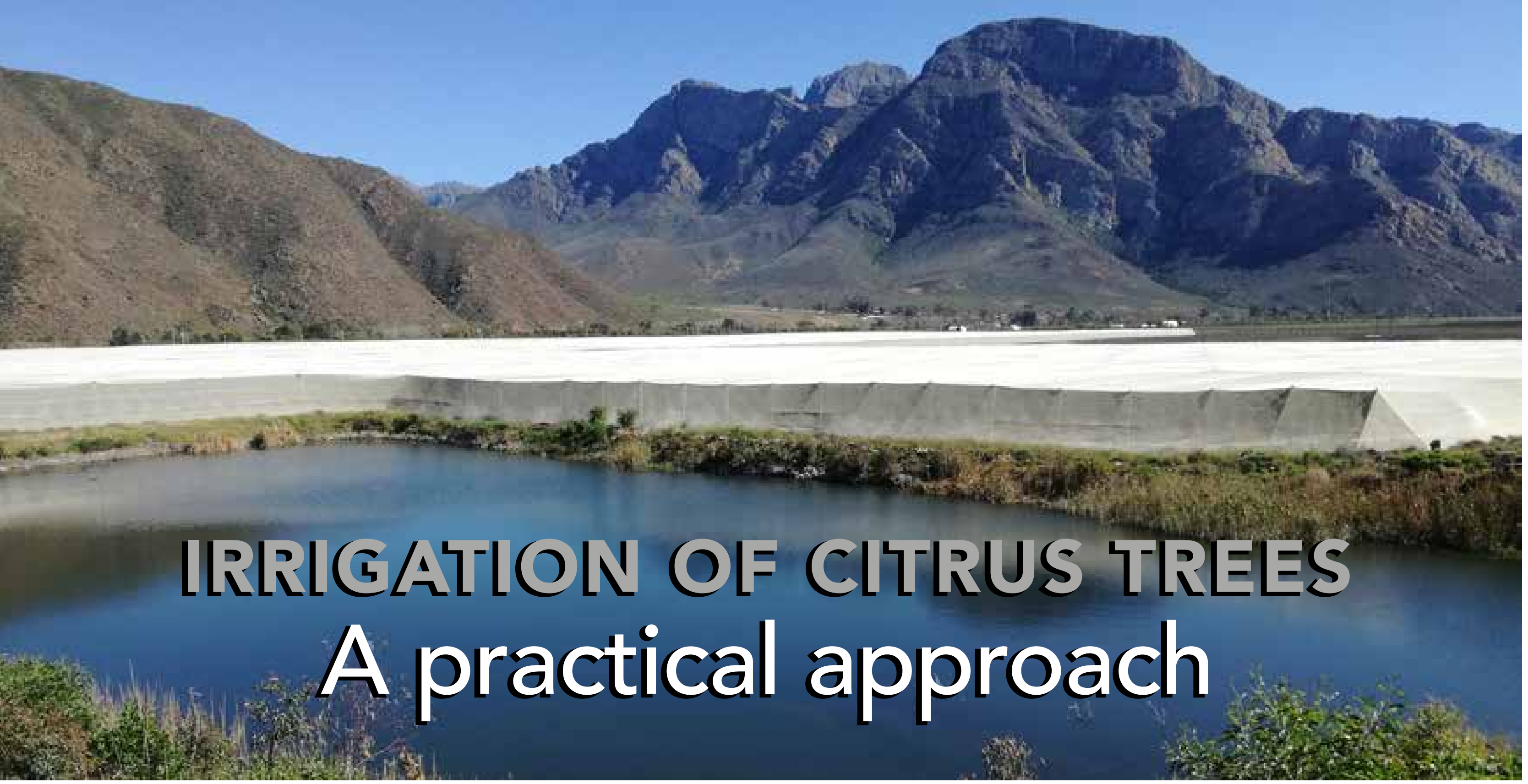

IRRIGATION OF CITRUS TREES
A practical approach

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Effective and accurate irrigation of citrus trees has become critical due to rising electricity costs and an unreliable supply of fresh water.

To secure high yields of good quality fruit, producers sometimes think it is necessary to adjust their irrigation practices in accordance with the availability of water. Although significant changes in irrigation practices might be required in desperate water-limiting situations, accurate irrigation scheduling usually leads to less water being used than is available, even in low rainfall seasons. This is achieved by pursuing some age-old principles to establish when, and how much, one must irrigate. In this paper, we explain the approach to generate accurate irrigation schedules for individual orchards. New research data were incorporated for more accuracy in the calculations.

Tree water requirements can be estimated (i) from soil water measurements, (ii) by studying tree reaction/performance or (iii) by measuring climatic variables. Last mentioned is the simplest and most commonly used method to schedule orchard irrigation.

Irrigation terminology and concepts explained

It is helpful to understand some important concepts to schedule orchard irrigation accurately.

1. Water holding capacity: This is the amount of plant available water (PAW) that a given soil can hold within the plant's root zone, e.g. water that is accessible to the trees. It is expressed as millimetre per meter soil (mm/m) and can be determined in a soil laboratory where the difference between field capacity water content and wilting water content is measured by applying a specific amount of pressure to wet soil. The readily PAW, for example, is the water held by the soil between -10 kPa and -100 kPa. Soil texture class can also be used to estimate it, with Table 1 as guideline.

2. Allowable depletion: This is the maximum amount of readily PAW allowed to be depleted from the soil profile by tree water use (expressed as a percentage of the readily PAW in Table 1) before the next irrigation. Allowable depletion is usually 40% or less for citrus trees; for sandy soils, however, this should be reduced to 30% of readily PAW.

Table 1. Estimated readily plant available water (PAW) of soils with different textures (Myburgh, 1993)

Texture class	Water holding capacity (mm/m)
Very coarse sand	50
Coarse sand, fine sand, loamy sand	80
Sandy loam, fine sandy loam	125
Very fine sand, loam, silty loam	160
Clayey loam, silty clayey loam, sandy clayey loam	180
Sandy clay, silty clay, clay	170

Due to citrus trees' susceptibility to *Phytophthora*, and the growing pressure on fresh-water resources, there is a need to increase the water use efficiency (e.g. less water used per kilogram fruit produced) of citrus. This can be done by increasing the allowable depletion of readily PAW during each phenological stage to the maximum without affecting fruit quality or tree performance (Table 2).

During periods of severe water shortages, controlled stress can be applied from May onwards with little effect on yield and fruit quality. By allowing 50% depletion of readily PAW during this period, irrigation intervals will be longer, resulting in less water being used.

3. Total tree water use or ET (evaporation and transpiration) is the term used to describe water use by the trees. Transpiration (T) refers to the water that moves through the tree/plant and is lost to the atmosphere by evaporation from the surface of the leaves and other

Figure 1: (Opposite) Availability of irrigation water for citrus production is at increasing risk of becoming insufficient to sustain the rate of expansion of the industry

Figure 2 (Above): Drip irrigation is becoming more popular due to more efficient use of water since evaporation from the soil surface is less

Table 2. Maximum depletion of readily plant available water (PAW) allowed without having an impact on fruit quality (adapted from Falivene et al., 2006)

Phenological stage	Max. % depletion of readily PAW	Comments
Flower bud induction and initiation (Apr-May)	40%	Flowering can be increased by short periods of moderate drought.
Flowering & fruit set (Sep-Oct)	30%	Any water stress will impact on fruit set and cause an excessive drop of fruitlets - especially in navels.
Stage 1 of fruit growth: cell division (Oct-Nov)	30%	An important stage to ensure fruit size since the number of cells in the fruit are determined - this directly affects fruit size. Any impact on cell division has an irreversible effect on fruit size.
Stage 2 of fruit growth: cell expansion (Nov-April)	40%	This is the period of maximum growth due to cell enlargement. Any form of stress causes the fruit to stop growing, but the effect is reversible.
Stage 3: Fruit maturation (May onwards)	40%-50%	This is the fruit maturation phase during which the rate of fruit growth levels off. Any further fruit growth can still be reduced due to stress. It however is reversible, and if excessive stress is avoided, a higher extraction of PAW will not affect fruit size.

aerial parts of the plant. The amount of water transpired is determined by light intensity, leaf canopy, wind, temperature and relative humidity. If the water applied is not a limiting factor, the type of irrigation system does not influence the transpiration rate of crops.

Evaporation (E) happens when a liquid turns into gas and is removed from the evaporating surface. As trees grow, the ratio between T and E from the soil surface (Es) changes. The amount of water lost through Es is determined by the size of the wetted soil surface area, irrigation intensity (how often the soil surface is wetted), soil type, mulching practices and energy available to evaporate the water from the soil surface. Water that is lost to the atmosphere through evaporation during the application process, e.g. water released from the micro-sprayer or drip emitter that does not reach the soil, is discussed later since it forms part of the application efficiency of an irrigation system.

Automatic weather stations provide accurate information with regard to radiation, relative humidity, temperature and wind speed. These measured weather elements are used in the modified Penman Monteith equation to calculate the reference evapotranspiration (ET_o). Last mentioned gives an indication of the intensity of the present climatic conditions (atmospheric demand) and is used to calculate total tree water use (ET). Often long-term ET_o values, as indicated in Table 3, are used for planning purposes, such as calculation of the annual water budget for each orchard, water availability for expansion, or for irrigation scheduling (calendar method). These, however, do not take seasonal weather patterns (like sudden heat waves or unexpected rain) into consideration.

4. Crop coefficient (K_c): There is a direct relationship between ET_o for a specified period and the amount of water an orchard needs during the same period. This relationship is described by the K_c. Crop coefficient values also account for tree characteristics, such as canopy size, plant density and effective canopy cover ($f_{c\ eff}$) and will change according to the season and as the phenological stage of the trees progresses. Typical K_c values for citrus trees in the main climatic regions of production in SA are listed in Tables 4 and 5. These values were adapted from transpiration coefficients (K_t), determined by Vahrmeijer & Taylor (2019) for trees of different ages and canopy sizes, and also incorporate Es in micro-irrigated and drip irrigated orchards, respectively.

The impact of canopy cover is evident – from there the suggestion that trees should be heavily pruned under conditions of restricted water availability. These trees usually recover faster than water-stressed trees without any canopy reduction.

5. Application efficiency: This is the percentage of the irrigation water that reaches the soil and roots after it is released from the irrigation system, i.e. that actually replaces the volume of water depleted from the root zone. A decrease in the application efficiency is mainly caused by conditions that favour evaporation and decrease infiltration of irrigation water. Consequently, it is generally accepted that drip irrigation systems are more efficient compared to other irrigation systems, because less water is lost due to evaporation and run-off. The efficiency of the most common irrigation systems is listed in Table 6.

6. Spacing of sprinklers/drippers: This is the distance (in meters) between the sprinklers or drippers in the irrigation line. If the spacing of the sprinklers is uneven, or where double row drip lines are used, it is more practical to use the number of emitters per hectare in the calculations.

7. Delivery rate: This is the volume of water that passes through the opening of the sprinkler or dripper per time unit, at a given pressure. It is expressed in litre per hour, and should be measured in the orchard because pressure variation can affect the delivery rate of micro-sprinklers dramatically.

Table 3. Long-term monthly reference evapotranspiration (ET_o) values (mm/day), generated from SAPWAT, for different citrus producing regions

Region in South Africa	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Messina	2.2	2.8	3.6	4.1	4.6	4.8	4.8	4.5	4.2	3.3	2.5	2.0
Letsitele	2.0	2.5	3.2	3.8	4.0	4.2	4.3	4.1	3.6	2.9	2.3	1.9
Nelspruit	2.6	3.3	4.1	4.3	4.5	4.7	4.9	4.7	4.0	3.3	2.9	2.5
Marble Hall	1.9	2.6	3.5	4.1	4.5	4.7	4.9	4.6	3.9	3.0	2.2	1.8
Rustenburg	2.0	2.7	3.7	4.3	4.7	4.9	4.9	4.6	3.9	3.0	2.4	1.9
Addo	2.3	3.9	3.7	4.5	5.2	5.7	5.7	5.1	4.2	3.2	2.5	2.2
Patensie	2.3	2.7	3.5	4.2	4.8	5.4	5.5	4.9	3.9	3.1	2.4	2.1
Robertson	1.6	2.2	2.6	3.5	4.5	4.7	5.3	5.1	3.7	2.7	1.7	1.8
Citrusdal	1.4	2.2	3.1	4.6	5.9	6.6	7.0	6.3	4.9	3.1	1.8	1.3
Kakamas	3.2	4.2	5.5	7.1	8.5	9.4	9.5	8.3	6.7	5.0	3.6	2.8

Figure 3: Maintenance of drip irrigation systems is crucial - especially in areas where water quality is poor, clogging of drippers must to be prevented

Figure 4: When a proper profile hole is made, the distribution of both the roots and the wetting zone can be established – it also allows one to verify that proper distribution of water by the irrigation system is obtained

Table 4. Crop coefficients (K_c) for citrus trees under micro-irrigation (adapted from Vahrmeijer & Taylor (2019)

Canopy cover	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
[a]70%	1.82	1.50	1.22	1.06	0.97	0.93	0.93	0.95	1.10	1.35	1.54	1.71
[b]50%	0.80	0.70	0.63	0.57	0.51	0.46	0.48	0.48	0.49	0.68	0.87	0.95
[c]30%	0.38	0.36	0.38	0.32	0.27	0.29	0.29	0.30	0.30	0.32	0.40	0.40

Table 5. Crop coefficients (K_c) for citrus trees under drip-irrigation (adapted from Vahrmeijer & Taylor (2019)

Canopy cover	Month											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
[a]70%	1.10	0.91	0.74	0.64	0.59	0.56	0.56	0.58	0.67	0.82	0.93	1.04
[b]50%	0.48	0.43	0.38	0.35	0.31	0.28	0.29	0.29	0.30	0.41	0.53	0.58
[c]30%	0.23	0.22	0.23	0.20	0.16	0.17	0.17	0.18	0.18	0.20	0.24	0.24

[a]Typical of mature trees >15 years old | [b]Typical of mature trees 10-15 years old | [c]Typical of trees <10 years old

Table 6. Application efficiency of different irrigation systems

Irrigation System	Efficiency (%)
Flood irrigation	60
Micro irrigation	80
Drip irrigation	90

8. Width of the wetted area: In the case of micro-irrigation, the wetted zone is clearly identifiable on the soil surface and therefore easily measured. In the case of drip irrigation, a profile pit must preferably be made underneath the dripper-line to accurately establish the wetting zone width. Last mentioned is determined by a combination of the soil texture as well as irrigation cycle lengths.

Steps for irrigation schedule planning, using weather data as well as orchard and soil characteristics (adapted from Myburgh, 1993).

With the above-mentioned information in mind, a few steps can be followed to determine:

- How much water needs to be applied per irrigation cycle;
- How long the cycle must be to apply the correct amount of water; and
- When irrigation is required, in other words, how often must the irrigation cycle be repeated.

To illustrate the process, an example of a micro-sprinkler irrigated mature orchard in Letsitele is used. The following applies to the orchard:

Canopy cover	70%
Soil texture	loamy sand
Tree spacing	7.0 m x 3.0 m
Effective root depth	40 cm
Area of soil surface that is wetted	40% of the surface
Month for which irrigation requirement is calculated	January

From this the ensuing information, required to draw up an irrigation schedule, can be established:

Irrigation of citrus trees	
Soil's water holding capacity (readily PAW)	80 mm/m (from Table 1)
Extraction % of readily PAW in this phenological stage	40% (from Table 2)
Crop coefficient (K_c)	0.93 (from Table 4)
Long-term reference evapotranspiration (ET_o) for January	4.3 mm/day (from Table 3)
Application efficiency	80% (from Table 6)
Delivery rate of micro-sprinklers/drippers	30 L/hour (from the manufacturer)
Micro-sprinkler/dripper spacing	3.0 meters spacing (from orchard)

These values are now used in the steps below

1. Calculate how much water needs to be applied?

Water holding capacity		Root depth (40 cm = 0.4m)		% extraction of PAW (40% = 40/100)		% of wetted area (40% = 40/100)		The amount of water that must be applied per irrigation cycle
80 mm/m	x	0.40 m	x	40/100	x	40/100	=	5.12 mm = 51 m³/ha

2. Calculate the delivery rate of the irrigation system.

Sprinkler/ Dripper delivery rate		Row Spacing		Sprinkler/ Dripper Spacing		% of wetted area (40% = 40/100)		Delivery rate of the irrigation system on the wetted area
30 L/hour	÷	7.0 m	÷	3.0 m	÷	40/100	=	3.57 mm/hour

In case of uneven distribution of emitters, or double row drip lines, use the following calculation for this step:

Sprinkler/ Dripper delivery rate		No of emitters per hectare, divided by 10 000		% of wetted area (40% = 40/100)		Delivery rate of the irrigation system on the wetted area
30 L/hour	x	477/10 000	÷	40/100	=	3.57 mm/hour

3. Calculate the length of the irrigation cycle needed to apply the required amount of water.

Amount of water needed per cycle		Sprinkler/Dripper delivery rate on the wetted area		The length of the irrigation cycle
5.12 mm	÷	3.57 mm/hour	=	1.43 hrs = 1.½ hrs

4. Calculate how regularly (after how many days) an irrigation cycle is required.

Amount of water needed per cycle		Reference evapotranspiration (ET_o)		Crop coefficient (K_c)		System efficiency 90% =.9		Time between cycles
5.12 mm	÷	4.3 mm/day	÷	0.93	÷	0.8	=	1.60 days = 2 days

The above example shows that during January in Letsitele, an irrigation cycle of 5.12 mm is needed every second day to replenish the water in the root zone, to field water capacity. When the delivery rate of the irrigation system is taken into account, the length of the irrigation cycles can be calculated, which is 1.5 hours for our example.

From a practical point of view, these calculations should be done monthly due to variations in ET_o and K_c values. Separate calculations are also required where there are differences between irrigation management zones, e.g. soil type, canopy cover, tree age, or any aspect that might influence ET.

The above-mentioned method for determining the irrigation requirement serves as a theoretical schedule, but makes provision for differences in tree canopy cover, type of irrigation system and soil type. These factors are generally constant for the duration of a season, except for the short-term variation in atmospheric demand (ET_o) and rainfall. The correct amount of water required for irrigation may, however, differ from these calculated values, due to inaccurate estimations of soil water holding capacities and/or diversions in the current weather conditions from the long-term weather patterns. As mentioned, the above calculations are used for setting a theoretical irrigation schedule or irrigation plan and serve as a starting point. Irrigators should then be fine-tuning the proposed irrigation schedule by doing on-farm monitoring of the soil water content with a soil auger or physical profile inspections. In this way, trends of over- and under-irrigation will be avoided. Different technologies are available to measure or estimate the soil water content, but are not discussed in this article.

One of the simplest ways to determine soil water content, or calibrate readings from any apparatus, is still by means of in-situ soil investigations, i.e. feeling the soil water content with one's hand. From an irrigator's perspective, the use of long-term weather data (to develop a basic irrigation schedule), combined with measurements of soil water content (to ensure that they do not tend to over- or under-irrigate over time), facilitates the accuracy of when and how much water to apply.

The value of soil profile examinations

In Table 7 criteria are listed for using the "feel-test", to determine soil water content. This is done after removing soil with a soil auger, or from the side/bottom of a profile pit. Soil profile pits are the preferred choice for farmers or irrigators, because more insights are gained of important elements that may influence the decision making process on when and how much to irrigate, such as: plant root development, soil-root system health and the soil water distribution.

***Table 7.** Criteria used to determine the soil water content*

Soil water content (% of plant available soil water that is left)	Characteristics of soil (a handful of soil pressed in the palm of the hand)
0-25	Soil is too dry to squeeze in a ball – it crumbles
25-50	Soil can be squeezed into a poorly bound ball
50-75	Soil can be squeezed into a well-shaped, stable ball
75-100	Water is left behind on hand, after pressure was applied – no free water
FWC*	Free water is visible – soil flows through fingers when squeezed

**FWC = Field water capacity*

Soil profiles are investigated for various reasons, but when the purpose is for irrigation scheduling, the following need to be considered:

1. Soil water content - as described above (Table 7).

2. Soil water distribution – the presence of soil layers that are water saturated for long periods, or compacted layers/rock that obstruct effective drainage, need consideration in the irrigation plan. The wetting depth of irrigation cycles also needs to line up with root distribution.

3. Soil texture – ensure that the correct soil texture class is used for estimating the soil water holding capacity.

4. Root distribution - the correct soil volume should be used to calculate the soil's water holding capacity.

5. Root health – establish if the root system is healthy and effective in utilising the applied water, or if over-irrigation occurs that negatively affects the roots.

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Choice of irrigation system

Both drip and micro-sprinkler irrigation systems are popular in SA. Traditionally, micro-sprinkler irrigation systems were preferred, due to the ability of these systems to irrigate a larger soil volume. This led to the belief that orchards are better protected against heat waves and a micro-climate is created that benefits the orchard. The emphasis on Integrated Pest Management (IPM) also requires a cover crop between tree rows, which necessitates an irrigation system that can supply water to the work row. Many people also have difficulty managing drip irrigation systems properly, especially in the hot areas, where sudden heat waves often result in yield and quality losses.

A steady increase in the number of orchards established with drip irrigation has occurred over recent years. This is mainly due to improved drip and fertigation technology and products, agronomic support, on-farm managerial skills and increased pressure on water resources. Another factor that contributed to the popularity of drip irrigation is the concept of fertigation, or rather precision farming, where concepts of open hydroponics are utilised to promote more efficient utilisation of water and fertilisers. Growers in SA are world leaders when it comes to the use of low delivery rate drippers, and implementing the concept of a "centralised control continuous irrigation system".

In most respects, the choice of an irrigation system depends on the producer's preference, and to a certain extent, the reliability of fresh water supply. A prerequisite for successful drip irrigation, however, is a well-established deep root system that can only be obtained with proper soil preparation.

Some interesting irrigation facts to bear in mind

Average annual total water use by citrus (Mostert, 1999).	900 -1010 mm 9000 - 10100 m^3/ha
Phenological stage when water stress has an irreversible effect on fruit quality (Mostert, 1999).	Phase 1: cell division
Phenological stage when irrigation can be withdrawn with the least effect on the trees or the crop (Mostert, 1999).	Postharvest (July)
Daily water use of Valencias (Mostert, 1999).	Winter: 2 mm/day Summer: 5.2 mm/day
Cultivar with the highest average daily transpiration (Vahrmeijer & Taylor, 2019).	Nadorcott Mandarin 4.5 mm/day
The percentage that transpiration is reduced when the leaf area index of trees is reduced from 6.9 m^2/m^2 to 4.8 m^2/m^2 (30%), through aggressive pruning (Vahrmeijer & Taylor, 2019).	52%
Percentage of ET that is made up by evaporation from the soil surface (Es) (Vahrmeijer & Taylor, 2019).	Citrusdal: 65-91% Lesitele: 19-45%
Maximum daily atmospheric evaporative demand (ET_o) at which no further increase in transpiration occurs (Vahrmeijer & Taylor, 2019).	5 to 6 mm/day

Summary

In a country where water for irrigation of orchards is becoming less available, producers are forced to invest more financial resources in strategic planning and technology to improve their irrigation practices. The principles set out in this article help to achieve the most efficient use of water, as well as application of accurate irrigation volumes, for optimal tree performance. The four aspects that need to be attended to are:

- Establish the soil's water holding capacity, as well as the optimal percentage extraction of the readily plant available water for each phenological stage, so that the **amount of water that needs to be applied per irrigation cycle** can be established.
- Using the calculated delivery rate in mm/hour, calculate the length of the irrigation cycle.
- Using the ET_o, K_c and amount of water needed per cycle, **calculate how long the period between irrigation cycles must be.**
- Finally, check the soil water content regularly to avoid gradual trends of under- or over-irrigation and make the necessary adjustments if required. ✤

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