Information Sheet

5 IRRIGATION

5.3 Basics of Irrigation Sheduling

*In **Information Sheet 5.1**, the fundamentals of the soil water balance, crop water use, soil water holding characteristics and irrigation scheduling were explained. To recap, irrigation scheduling is the organised process in which water is applied to a crop. For maximum growth, the water supply from the soil to the plant must equal the demand from the atmosphere.*

In this information sheet, more pertinent details and sample calculations are presented in order to deepen the understanding of the principles and dynamics of irrigation scheduling. The principles on which sound irrigation scheduling is based include good knowledge of the soil, the crop and the climate, and the interaction between these factors. Soil matrix properties determine the amount of water in the soil and how much of this is available to the plant. Water requirements of crops are mainly governed by crop age (canopy size) and climatic conditions (atmospheric demand, which varies with season and location) – supply and demand.

Supply

Soil not only acts as a medium for plants to grow in, but also provides nutrients and water vital for plant growth.

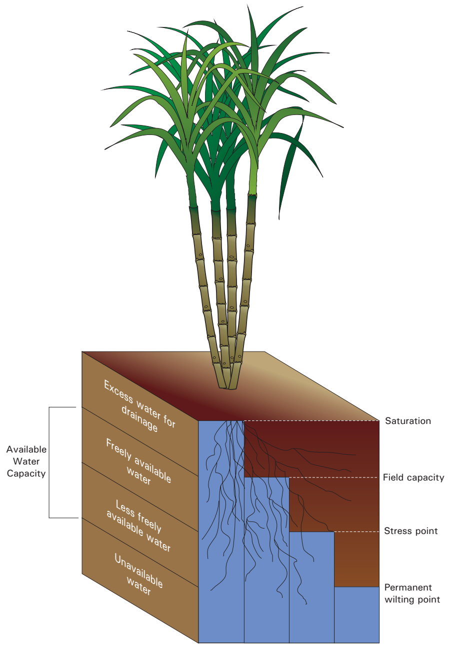

Figure 1 Limits of laboratory-determined soil water content and some relationships between them.
SAT = Saturation, FC = Field Capacity, SP = Stress Point, PWP = Permanent Wilting Point, FAW = Freely Available Water, AWC = Available Water Capacity (see text for details).

Soil consists of small particles with pockets of space in between which mainly contain air and water. The volume of inter-particle space is termed porosity and determines the quantity of water that can be stored. Total porosity and thus soil water retention is governed by the clay content, organic matter content and bulk density.

Water content of soils is defined according to the level to which pores are occupied. Water held in the larger pores is easily accessible by plants but as the soil dries out, water in smaller pores requires more energy for removal and is thus the last to be utilised. The important limits of soil water content are shown in Figure 1 and discussed below.

Saturation (SAT): A soil is said to be at saturation when the total pore volume is filled by water and no air is present. This is undesirable. Plants also need to take up oxygen through the roots. Most crops will die if they are exposed to saturated (waterlogged) conditions for too long. Furthermore, saturated conditions will result in high runoff and deep drainage when any additional water is received.

Field capacity (FC) is the maximum amount of water that a soil can store against the gravitational force of the earth. When a water-saturated profile is allowed to drain freely, water in the pores will move downward under gravity, thus draining the pores and allowing air to enter. Eventually a condition will be reached where the gravitational movement of water will cease. Thus, field capacity has been reached. Water application should not exceed the field capacity of soils.

Stress point (SP): As the soil profile continues to dry, the water content will eventually reach a point where the plant is unable to take up adequate water to satisfy the atmosphere's demand. At this point plants will be exposed to a short period of water stress during the hottest part of the day.

Permanent wilting point (PWP): Further depletion of soil water beyond the stress point will eventually lead to a condition where water is held at a force stronger than the extraction force of the roots. Water is no longer available to the plant and permanent wilting point has been reached. Soil water content at this level is insufficient to sustain growth and plants will die if not replenished. Green plants which remain wilted at dawn are indicative that PWP has been reached.

Available water capacity (AWC) is the amount of water held between field capacity and permanent wilting point. It represents the water storage capacity of the soil reservoir and thus the amount available for crop uptake. The term capacity means that this quantity of soil water is expressed per unit of soil depth (normally per meter depth) (Table 1).

Table 1: Typical available water capacity (AWC) ranges based on clay content.

Clay content (%)	AWC range (mm/m)
< 7	< 80
7 to 15	81 to 100
16 to 35	101 to 140
36 to 55	141 to 180
> 55	< 180

Freely available water (FAW) is the amount of water held between field capacity and stress point. It is the amount of soil water that can be extracted by the plant without experiencing any noticeable degree of water stress. Maximum yield will be obtained if soil water content is kept in the freely available water range. For this reason the allowable depletion level is set before or at the stress point i.e. one aims to trigger irrigation before or at the stress point.

Total available water (TAW): In order to schedule irrigation, total available soil water must be known.This represents the volume of water in a soil profile with a known effective rooting depth (ERD) i.e. TAW = AWC x ERD (see Box 1 for calculation and Table 2 for typical values). The effective rooting depth represents the soil depth in which 85 to 90% of all plant roots are found. If an obstruction occurs within this depth (hard rock, compaction, water table, pH, salinity etc.) then effective rooting depth is reduced to the depth of the obstruction.

Suitability of soils to different irrigation systems are largely determined by the TAW value of the soil. Dragline irrigation systems typically apply large volumes of water and have longer irrigation cycle lengths and are thus more suited

Box 1: Calculating TAW

Example: Soil sample results from FAS:

Field Capacity (FC) = 27.6%
Permanent Wilting Point (PWP) = 14.3%

Step 1: Calculate available water capacity (AWC):
AWC = FC - PWP = 27.6% - 14.3% = 13.3%
Conversion: 13.3 x (1000 mm/m ÷ 100)
= 133 mm/m

Step 2: Calculate total available water (TAW):
Effective Rooting Depth (ERD)
= 0.8 m (field determined)
TAW = AWC x ERD = 133 mm/m x 0.8 m = 106 mm

Table 2: Typical total available water (TAW) values for soil forms commonly found in the South African sugar industry.

Soil forms	Texture	AWC mm/m	ERD mm	TAW mm
Hutton	Sandy clay loam	± 140	1200	± 168
Shortlands	Clay	± 120	1200	± 144
Arcadia	Clay	± 140	900	± 126
Rensburg	Clay	± 140	600	± 84
Bonheim	Clay	± 130	900	± 117
Kroonstad	Sandy loam	± 120	600	± 72
Longlands	Sandy loam	± 120	600	± 72
Fernwood	Sand	± 80	1200	± 96
Glenrosa	Loamy sand	± 100	600	± 60
Estcourt	Sandy loam/clay	± 120	600	± 72

to soils with larger TAWs. Drip and centre pivot irrigation systems are capable of applying small amounts of irrigation more frequently and thus more suited to soils with smaller TAWs. For these reasons allowable depletion levels for dragline irrigation systems are normally set at 50% of AWC, while for centre pivot and drip irrigation the depletion levels are set at 20 to 40% and 10 to 20% respectively. More efficient use of water can be achieved by leaving “room for rain”. This principle can be applied on heavier soils with larger TAWs by not refilling the profile to field capacity.

Demand

Evapotranspiration (ET): Irrigation water applied to a cane field is lost to the atmosphere by two processes, namely, evaporation (E) directly from the soil surface and transpiration (T) from the leaf canopy – the combined effect is commonly referred to as evapotranspiration (ET). Evaporation is regulated by the amount of ground cover exposed to solar radiation as well as the degree of wetness of the soil surface. Transpiration is determined by the size of the canopy, the climate (atmospheric evaporative demand) as well as the crop water status (supply). Early in the crop cycle a large part of the soil surface is exposed to solar radiation which results in E being the major component of water loss. When the crop is mature and has a full canopy, the soil is fairly well covered and at this stage water loss is predominantly due to T. Mulching with plant residues will minimise runoff and erosion, increase infiltration and reduce the evaporation loss directly from the soil surface. Similarly increasing the irrigation cycle length (wet the crop and soil surface less frequently by giving fewer but larger irrigations) will minimise the direct evaporation loss.

Atmospheric evaporative demand (AED): There are four driving forces that determine the strength of the atmospheric evaporative demand:

- **Radiation** is the primary provider of energy which is required to change water from its liquid state, in the leaf or on the soil surface, to its vapour state in the air. This implies that the AED is higher in summer months than in winter months.
- **Temperature** and **humidity** (vapour pressure deficit) control the maximum amount of water vapour the air can hold. The AED is highest on hot days with low humidity.
- **Wind speed** controls the rate at which the air in contact with the leaf is transported away from the surface. The AED is highest on windy days as saturated air can quickly be replaced with unsaturated air.

Calculating sugarcane crop water use (ET): The Penman-Monteith method has become widely accepted as the standard method for calculating crop water use replacing the old class A pan method. Climatic data obtained from automatic weather stations is used to directly calculate ET for sugarcane. Sugarcane reference evapotranspiration (ECref) is defined as the ET of a 3 m tall, fully canopied sugarcane crop adequately supplied with water and nutrients. An adjustment value, namely the crop coefficient (Kc) is required to calculate daily crop water use (ET) for partially canopied sugarcane crops.

ET = Kc x ECref

Daily ECref values for various locations can be obtained from the SASRI Weather Web site: (www.sugar.org.za/sasri) and appropriate Kc values from your local Extension Specialist.

Reference grass evapotranspiration (FAO) can also be obtained from the above Weather Web site for use by growers that have other crops (such as bananas, citrus, mango or vegetables).

The principles of solving a soil water balance are depicted in a simplified manner in the sample calculation in Box 2. From this the reader will gain a better understanding of the underlying calculations typically occurring in a crop model. The procedure can also be followed to calculate your own water budget. The additions or profits (namely rainfall and irrigation) and removal or losses (namely crop water use) to the soil water balance are accounted for on a daily basis. Irrigation is scheduled once the estimated soil water content reaches a predetermined allowable depletion threshold level.

An example for calculating your own basic water balance is provided in Box 2. Daily soil water balances can be updated on a field-by-field basis using soil water budget spread sheets (such as SASched) or by means of irrigation scheduling

Box 2: Profit and loss soil water budget
(Example for a dragline irrigation system)

Step 1: Determine the TAW of the field:

TAW = AWC x ERD

(See Box 1 for details on how to calculate AWC)

= 133 mm/m x 0.8 m

= 106 mm

Step 2: Estimate the amount of crop water use or evapotranspiration (ET):

ET = Kc x ECref (assume Kc = 0.8 for a crop with partial canopy cover and a long-term mean ECref = 6 mm/d)

= 0.8 x 6 mm

= 4.8 mm/day

Step 3: Estimate the allowable depletion level (soil water deficit at which irrigation should commence):

Allowable depletion level = 50% TAW

(Allowable depletion taken as 50% of TAW)

= 106 mm x 0.5

= 53 mm

Step 4: Calculate the irrigation cycle length:

Irrigation cycle length = 53 mm ÷ 6 mm per d (assuming average long-term ECref of 6 mm/d) = 8.8 days

Step5: On daily basis, subtract ET from available water brought forward. Rainfall and irrigation must be added to the available water. Rainfall less than 10 mm is assumed to not be effective and ignored.

Naturally any rainfall that tops-up the profile and exceeds the TAW level, would be lost through runoff or deep percolation and must be ignored.

Available moisture: START		**106 mm**
Minus	daily evapotranspiration	6 mm
Plus	Rainfall	9 mm (not effective, < 10mm)
Plus	Irrigation	0 mm
Available moisture: Day1		**100 mm**
Minus	daily evapotranspiration day 2	6 mm
Plus	Rainfall	0 mm
Plus	Irrigation	0 mm
Available moisture: Day 2		**94 mm**
Available moisture: Day 9		**58 mm**
Minus	daily evapotranspiration day 10	6 mm
Plus	Rainfall	0 mm
Plus	Irrigation	0 mm
Available moisture: Day 10		**52 mm**

Step 6: Apply irrigation to refill the soil profile to field capacity

Apply 54 mm to this field in order to refill the soil profile to FC (106 mm)

software such as Canesim and CanePro. The model will keep track of the water balance and generate irrigation scheduling recommendations based on pre-set depletion levels. A simplified version of the Canesim irrigation scheduling program is available on the SASRI web page (www.sugar.org.za/sasri).

It is recommended that the above irrigation scheduling aids are used in conjunction with various tools available on the market that measure soil water content directly. This topic is covered in Information sheet 5.4 Irrigation scheduling toolbox.

Basic knowledge of the soil, crop and atmospheric conditions and how these factors interact, are required in order for us to better understand the principles and dynamics of irrigation scheduling. For maximum growth, the supply of water to the plant from the soil must equal the demand of water from the atmosphere. Failing to do so could lead to either under-irrigation, resulting in water stress, or over-irrigation, leading to increased pumping cost, waterlogging, leaching of expensive fertilisers and the development of salinity/sodicity problems. The result is a drop in yield and consequent negative return on investment.

Compiled by Francois Olivier (Scientist: Irrigation)
March 2017