SECTION 1: WHAT IS IRRIGATION SCHEDULING?

Irrigation scheduling involves deciding when and how much water to apply to a field. Good scheduling will apply water at the right time and in the right quantity in order to optimize production and minimize adverse environmental impacts. Bad scheduling will mean that either not enough water is applied or it is not applied at the right time, resulting in under-watering, or too much is applied or it is applied too soon resulting in over-watering. Under or overwatering can lead to reduced yields, lower quality and inefficient use of nutrients.

SECTION 2: IRRIGATION SCHEDULING AS A TOOL TO INCREASE WATER EFFICIENCY ON FARMS

The efficiency of water in agricultural production is generally low. Only 40 to 60% of the water is effectively used by the crop, the rest of the water is lost in the system or in the farm either through evaporation, runoff, or by percolation into the groundwater. Irrigation scheduling, if properly managed can offer a good solution to improve water efficiency in the farm.

Various methods and tools have been developed to determine when crops require water and how much irrigation water needs to be applied. These include the various soil and plant monitoring methods as well as the more common soil water balance and scheduling simulation models.

SECTION 3: WHAT ARE THE ADVANTAGES OF IRRIGATION SCHEDULING?

Irrigation scheduling can offer several advantages as it can

- Enable farmers to schedule watering to minimize crop water stress and maximize yields.
- Reduce farmer's costs of water and labour through less irrigation, thereby making maximum use of soil moisture storage.
- Lower fertilizer costs by holding surface runoff and deep percolation (leaching) to a minimum.
- Increase net returns by increasing crop yields and crop quality.
- Minimize water-logging problems by reducing the drainage requirements.

Efficiency will depend on the irrigation system. Micro/irrigation can have higher efficiency (up to 90%). Please see Technical Brief on Irrigation systems for more information.

SECTION 4: WHAT ARE THE DIFFICULTIES ON APPLYING IRRIGATION SCHEDULING AT A FARM LEVEL?

In spite of the variety of methods and tools developed to schedule irrigation, farmer adoption of irrigation scheduling techniques is still limited. Identification of limitations and requirements for use by farmers and managers is important in the selection of the appropriate scheduling methods. Some of the limitations and difficulties on applying irrigation scheduling tools at farm level are listed below.

- Irrigation scheduling becomes particularly sensitive under **conditions of limited water resources**, where water shortages require a refined timing of water applications in order to minimise yield reductions. Similarly, under saline conditions, water scheduling requires appropriate knowledge of salt tolerance levels.
- **Variability of rainfall** is often difficult to adequately accommodate in the planning of irrigation calendars. The options, special requirements and limitations of irrigation scheduling under variable frequency and amount of rainfall need to be considered.
- Deficit irrigation requires suitable and reliable **water stress indicators**, while for the management of saline waters accurate knowledge is needed on yield-salinity relationships.
- The **irrigation efficiency** as measured in terms of adequacy and application efficiency, as well as the design criteria of the irrigation method, needs to be considered in the selection and operation of the irrigation scheduling method.
- **Costs and incentives** for farmers to apply water saving irrigation scheduling include liberalization of cropping, pricing of water, and profitability of irrigation.

  Technology costs in some cases can be higher than the end users can afford.
- **Knowledge transfer** on how to adequately use and mange the tools, does not reach farmers in all cases.
- Some farmers do not fully understand hydrology and water budgets and prefer to irrigate as usual. The farmers can lack the appropriate technical skills to conduct properly a scheduling.

See TB on irrigation systems

SECTION 5: OVERVIEW OF IRRIGATION SCHEDULING METHODS

Several methods are available for estimating crop water use. These are all indirect measurements and require some assumptions. Methods range from the feel of soil, personal calendar scheduling, soil moisture measurement, evotranspiration records, scheduling by water delivery organizations, commercial or government scheduling services and plant moisture sensing device etc. In some cases more than one method are used to schedule irrigation.

There methods for scheduling irrigation can be classified in 3 categories:

- observational (personal experience, plant and soil condition)
- soil moisture
- Calculating evapotranspiration losses.

These methods can vary in complexity and some may require the use of technology. Each method has strengths and weaknesses and it is often recommended that more than one method is used. The following table depicts an overview of different methods of irrigation scheduling, its advantages and disadvantages. Below the table, specific information for each method is described.

Table 1: Different methods of irrigation scheduling.[1]

Method	Measured parameter	Equipment needed	Irrigation criterion	Advantages	Disadvantages
Personal experience and visual observation of the plant and soil	Soil moisture content by feel.	Hand probe.	Soil moisture content.	Easy to use; simple; can improve accuracy with experience.	Low accuracy; field work involved to take samples.
Soil moisture monitoring: Gravimetric soil moisture sample.	Soil moisture content by taking samples.	Auger, caps, oven.	Soil moisture content.	High accuracy.	Labour intensive including field work; time gap between sampling and results.
Soil moisture monitoring: Tensio-metres.	Soil moisture tension.	Tensiometres including vacuum gauge.	Soil moisture tension.	Good accuracy; instantaneous reading of soil moisture tension.	Labour to read; needs maintenance; breaks at tensions above 0.7 atm.

See Technical Brief on soil and water for more detail on soil moisture measurement.

Soil moisture monitoring: Electrical resistance blocks.	Electric resistance of soil moisture.	Resistance blocks AC bridge (meter).	Soil moisture tension.	Instantaneous reading; works over larger range of tensions; can be used for remote reading.	Affected by soil salinity; not sensitive at low tensions; needs some maintenance and field reading.
Water budget approach.	Climatic parameters: temperature, radiation, wind, humidity and expected rainfall, depending on model used to predict ET.	Weather station or available weather information.	Estimation of moisture content.	No field work required; flexible; can forecast irrigation needs in the future; with same equipment can schedule many fields.	Needs calibration and periodic adjustments, since it is only an estimate; calculations cumbersome without computer.
Modified atmometre.	Reference ET.	Atmometre gauge.	Estimate of moisture content.	Easy to use, direct treading of reference ET.	Needs calibration; it is only an estimation.

Source: SOURCE: Colorado State University. Available at http://www.ext.colostate.edu/pubs/crops/04708.html

a. Personal experience and visual observation of the plant and soil methods

One of the most common methods used by farmers to schedule irrigations is by observing the crop and assessing the feel and appearance of the soil and changes in the plant characteristics, such as changes in colour of the plants, curling of the leaves and ultimately plant wilting. The changes can often only be detected by looking at the crop as a whole rather than at the individual plants. When the crop becomes under water stress the appearance changes from vigorous growth (many young leaves which are light green) to slow or even no growth (fewer young leaves, darker in colour, and sometimes greyish and dull).

The advantages of the visual observation as a method to schedule irrigations is that it is a quick and easy method and is popular because it does not need investment in equipment or technical support. However, the drawback of using visual observation is that it may not always be accurate and extensive experience is required to use it effectively. This is mainly due to the limitations of assessing subsoil moisture conditions properly. In addition, by the time the symptoms are evident, the irrigation water has already been withheld too long for most crops and yield losses are already inevitable. This can result in decreases to crop yield and quality. It is not advisable to wait for the symptoms. Especially in the early stages of crop growth (the initial and crop development stages), irrigation water has to be applied before the symptoms are evident.

To determine how deep irrigation water or rainfall has penetrated, the soil needs to be examined using a spade or hand probe. It is recommended that visual observation be used to gain preliminary information to be used in combination with other methods such as using tensiometres or evapotranspiration data to schedule irrigations. With experience, farmers can learn to use visual observations successfully, especially when decisions are supported by other methods. Over or under irrigating is easy to do when not monitoring soil moisture in the subsoil with technical equipment.

b. Soil moisture monitoring methods

Irrigation scheduling can also be conducted by determining the soil moisture. Measuring soil moisture detects if there is a water shortage that can reduce yields or if there is excessive water application that can result in water logging or leaching of nitrates below the root zone.

Monitoring soil moisture levels is required for effective irrigation water management. Many tried and proven methods of estimating or measuring soil moisture are available. Using soil moisture monitoring equipment allows the investigator to gain information about subsoil moisture. Monitoring soil moisture helps to determine to what depth roots are extracting water from, what depth an irrigation or rainfall has penetrated, and when to stop irrigating. For further detail on soil moisture see Technical Brief: Soil and Water.

c. Water budget methods

The water budget methods account for the amount of water that is lost by crop evapotranspiration (ET) and the amount of water that enters the soil reservoir (as effective rain or irrigation).

The logic behind the water budget methods is to apply irrigation with a net amount equivalent to the accumulated ET losses since the last irrigation. The soil profile is thus

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For more information see TB on Water and Soil.

recharged to full capacity, and the crops start to evotranspirate water and the cycle begins again. If full recharge is not desired or not possible, the new balance can be determined from the net irrigation amount or by field observations. This method, however, may not work well at locations where contributions to crop ET from a water table or other source cannot be quantified.

The water budget requires data management. Therefore, farmers need to manage data about the soil and crop, including crop coefficients, field capacity, available water, yield threshold depletion and the starting soil moisture. Once the starting point is determined, farmers need to keep track of outputs (ET) and inputs (precipitation and irrigation) to soil moisture. To prevent a decrease in yield, farmers must irrigate before reaching the previously identified yield threshold depletion level. Typically, a farmer will set a management allowable depletion level (MAD), which is used as a trigger to irrigate and prevents soil from reaching that yield threshold depletion level. This may be based on a percentage of available water.

In many cases, the advantage of using irrigation scheduling is to alert you that a field is getting close to the MAD so that you can begin looking at it closely. It is never recommended that irrigation scheduling be the sole ruler of when to irrigate. However, Some of the data needed to perform water budget irrigation scheduling accurately include - field capacity and available water holding capacity of the soils, the effective root zone of the crops throughout the season, agronomic factors that determine how much stress farmer want the crop under between irrigation, daily reference evapotranspiration (Eto), a crop coefficient curve that relates the actual crop evapotranspiration, ETc, to the reference ET, effective rainfall, that is, rain that is actually used by the crop and is not runoff, infiltrated irrigation depths, how much water delivered to a field infiltrates the soil, and knowledge of high water tables or significant sub-surface water movement.

How dry the soil can get before crop health or yield are affected

Starting soil moisture can be estimated to be approximately equal to field capacity after winter rains, however, if a field is pre-irrigated; using soil moisture measuring devices provides a more accurate starting point. For more information see Technical Brief 5 on Water and Soil.

Management Allowed Depletions (MAD) are a measure of how much stress is to be applied to a crop. MAD's may change with the season. Be aware of the different growth stages of the crops and how they should be manipulated during these stages. Also, if they have fields with high salinity, the MAD is likely to be lower than normal. Many times, MAD's are "backed in to". For example, the farmer is checking a field and finally decides to irrigate. The irrigation scheduling system is checked for the soil moisture level at the time of the irrigation. This is then converted to a MAD for future use.

Readily available water (RAW) is the amount of water that a plant can easily extract from the soil for unrestricted growth. The RAW is calculated for the root zone of the crop. The RAW can be calculated more accurately with some scheduling systems (such as neutron probes and capacitance probes). Irrigation scheduling will always provide an estimate of how much water to put back into the soil.

The limitation of this type of irrigation scheduling is its complexity. Water budget attempts to represent the physical process of water movement into the soil, through the soil, and through the plant. Modeling physical processes can be very complex and may require extensive amounts of data and experience to obtain an accurate budget. An example of this method is conducted in Section 7.

Smart irrigation scheduling refers to technologies that can help farmers determine more precisely when crops need to be watered and how much water they require. With smart irrigation scheduling, farmers can be able to use their water more efficiently, either by reducing or by keeping constant the amount of applied water, while maintaining or improving yields. These technologies make use of local weather stations that measure air temperature, humidity, wind speed, and rainfall; soil probes that measure soil moisture depth, temperature, and salinity; and plant moisture sensing devices that measure the water pressure in plant cells.

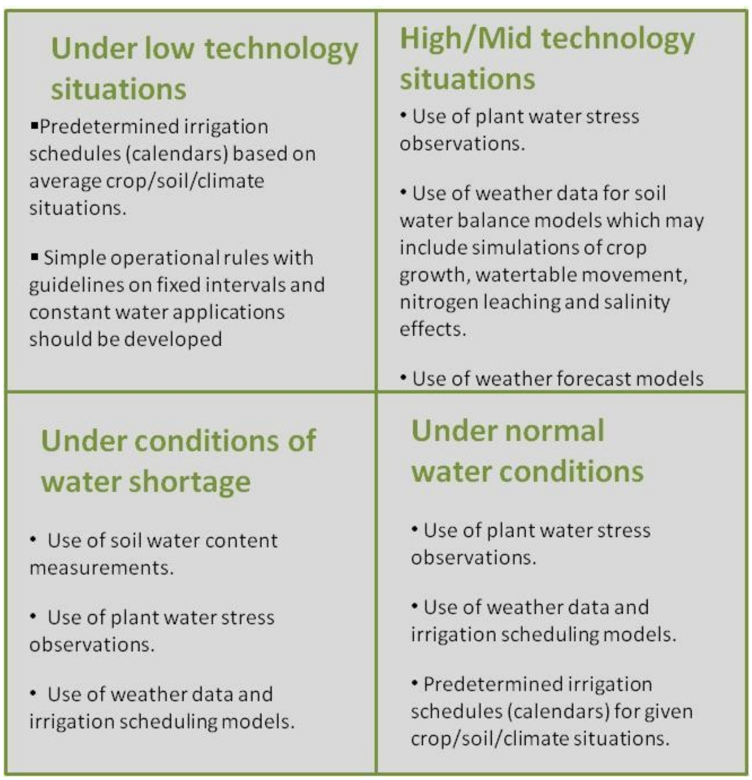
Increasingly, software paired with these technologies allows farmers to easily access real time data on field conditions, receive alerts through email and text messages, and automate or control their irrigation systems remotely.

SECTION 6: HOW TO TAKE IRRIGATION SCHEDULING FORWARD?

The involvement of farmers and irrigation managers is a very important role in the formulation, implementation, monitoring and testing of irrigation scheduling. Most farmers have a good idea of when to irrigate and, in many cases, the refinement offered by scientific scheduling does not provide enough benefits to offset the costs and inputs required for the use of the irrigation scheduling methods.

The following diagram shows some specific recommendations concerning the use and further development of the various irrigation scheduling techniques depending on the conditions of the farm. Four scenarios are highlighted: Low technologies situations, medium or high technology situation, under water shortages or under normal water supply conditions.

Figure 1: Specific recommendation for irrigation scheduling under different scenarios



The support and collaboration of an expert irrigation adviser can improve the rate of success in the adoption of the irrigation scheduling technology. The technology level of the farm will determine the choice of the irrigation scheduling method. Industry farms and farms with high value cash crops are more likely to adopt and invest in sophisticated scheduling methods.

SECTION 7: EXAMPLES OF IRRIGATION SCHEDULING METHODS IN DEPTH

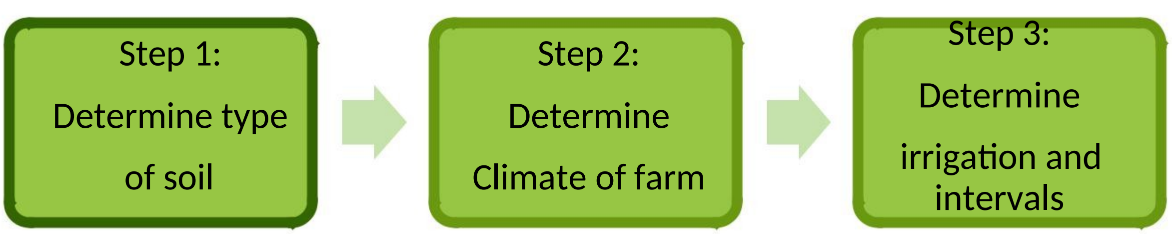
This section provides an explanation of three different methods of scheduling. The intention is to give some examples on how irrigation methods can be conducted from very simple ones to more complex ones. It is strongly recommended to look for location specific data when deciding to carry out a schedule.

a. Simple irrigation schedule method: Irrigation quantity and irrigation intervals.[2]

The simple irrigation schedule method is the most basic approach for scheduling irrigation. By assessing the average temperature in the location of the farm, the crop, the soil texture and the use of some data tables obtained by FAO, the farmer will be able to know how much water to apply during the each irrigation in mm and the periodicity of the irrigation.

This method uses several assumptions. It assumes that crops are grown during the period of peak water demand, little or no rainfall occurs during the growing season and that the maximum possible net application depth is 70 mm. Also it considers only three different soil types (sandy, loam and clay) and three different climates (mean daily temperature <15°C, 15-25°C; >15°C).

This method considers three steps as described as follow.



The information provided in the tables below in this section is not site-specific and is used as an example.

- STEP 1: Determine the type of soil between sand, loam, and clay soil, which have, respectively, low, medium and high available water content.

Table 2: Type of soil and its irrigation characteristics

Type of soil	
Shallow and/or sand	In sandy soil or shallow soil (with a hard pan or impermeable layer close to the soil surface), little water can be stored; irrigation will thus have to take place frequently but little water is given per application.
Loam	In loamy soil more water can be stored than in a sandy or Shallow soil. Irrigation water is applied less frequently and more water is given per application.
Clay	In clay soil even more water can be stored than in a medium Loamy soil. Irrigation water is applied even less frequently and again more water is given per application.

For more detail on soil textures see Technical Brief 5 Soil and Water.

- STEP 2: Determine the climate of the farm location. This method distinguishes between three different climates; climate 1, climate 2 and climate 3 as described in the table below.

Table 3: Types of climate

Type of climate	Reference crop evapotranspiration	Climatic zone and mean daily temperature
Climate 1	4 - 5 mm/day	Desert/arid, semi arid and Sub-humid with low temperatures (less than 15°C)
Climate 2	6 - 7 mm/day	Desert/arid, semi arid and Sub-humid with medium temperatures (15-25°C)
Climate 3	8 - 9 mm/day	Desert/arid, semi arid and Sub-humid with high temperatures (more than 25°C)

See Technical Brief 5 on Water and Soil.

- STEP 3: Determine the recommended interval and irrigation depth.

The table below provides net irrigation depth for each type of soil and climate and also the interval of days to apply irrigation for different type of soil in brackets. The table provides information for some specific crops. Look at the table for the type of soil (Step 1) and climate (Step 2) and obtain the interval and irrigation depth.

Table 4: Interval and net irrigation depths for some crops grow in shallow, loam and clays soil in different types of climates.

	Shallow and/or sand	Loam soil	Clay soil
	Interval (Net Irrigation depth (mm))	Interval-(Net Irrigation depth (mm))	Interval-(Net Irrigation depth (mm))
Type of Climate	**1 2 3**	**1 2 3**	**1 2 3**
Cacao	9 6 5 (40)	13 9 7 (60)	16 11 8 (70)
Carrot	6 4 3 (35)	7 5 4 (35)	22 8 6 (50)
Citrus	8 6 4 (30)	11 8 6 (40)	15 10 8 (55)
Coffee	9 6 5 (40)	13 9 7 (60)	16 11 8 (70)
Potato	6 4 3 (30)	8 6 4 (40)	10 7 5 (50)
Tea	9 6 4 (40)	13 9 7 (60)	16 11 8 (70)

For example, citrus grown in loamy soil, in a semi arid area with low temperatures less than 15°C (Climate 1 according to table above) require 40 mm of net irrigation depth every 11 days. Results for the example are highlighted in the table and below.

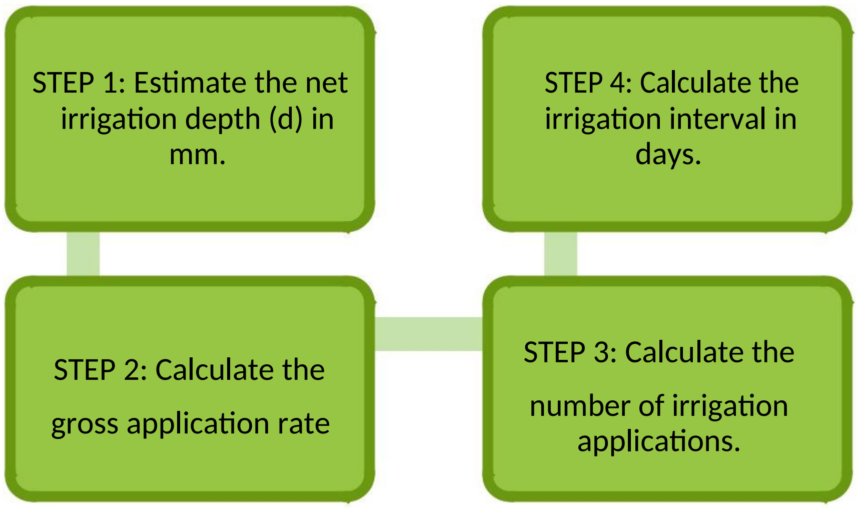
	Loam soil
	Interval-(Net Irrigation depth (mm))
Type of Climate	**1**
Citrus	11 (40)

b. Irrigation schedule method

This calculation method determines an irrigation schedule Which is based on the estimated depth (in mm) of the irrigation applications, and the calculated irrigation water need of the crop over the growing season.

This method is based on calculated irrigation water requirements taking into account climatic factors such as temperature and rainfall. It offers a more accurate schedule than the previous method; nonetheless it is a simple approach to scheduled irrigation.

The simple calculation method involves the following 4 steps that are explained in detail below.



- STEP 1**:** Estimate the net irrigation depth (d) in mm

The net irrigation depth is best determined locally by checking how much water is given per irrigation application taking into consideration the irrigation method and practice in place. In case no local data is easily available the following date provides an estimate of the net irrigation depth (d net) in mm.

Table 5 provides the approximate net irrigation depth required for each type of soil and different lengths of the crop root zone.

Table 5: Approximate net irrigation depths (mm)

	Shallow rooting crops **(30-60 cm)**	Medium rooting crops **(50-100 cm)**	Deep rooting crops **(90-150 cm)**
Shallow and/or sandy soil	15	30	40
Loamy soil	20	40	60
Clayey soil	30	50	70

In case there is no local data about the root depth, the table below provides with an estimate of the length of the crop root zone.

Table 6: Appropriate root depth of some crop

Shallow rooting crops (30-60 cm)	**Crucifers (cabbage, cauliflower, etc.), celery, lettuce, onions, pineapple, potatoes, spinach, other vegetables except beets, carrots, cucumber.**
Medium rooting crops (50-100 cm)	Bananas, beans, beets, carrots, clover, cacao, cucumber, groundnuts, palm trees, peas, pepper, sisal, soybeans, sugar beet, sunflower, tobacco, Tomatoes.
Deep rooting crops (90-150 cm)	Alfalfa, barley, citrus, cotton, dates, deciduous orchards, flax, grapes, maize, melons, oats, olives, safflower, sorghum, sugarcane, sweet potatoes, wheat.

- STEP 2: Estimate the gross irrigation depth (d) in mm

The gross irrigation depth can be calculated using the net irrigation depth and the efficiency of the irrigation. Part of the water applied to the field is lost through deep percolation and runoff. To reflect this water loss, the irrigation efficiency is used. The gross irrigation depth, in mm, takes into account the water loss during the irrigation application and is determined using the following formula:

$$\text{gross irrigation depth (mm)} = 100 * \text{net irrigation depth(mm) irrigation efficiency}$$

If irrigation efficiency data is available and reliable at a local level, these should be used. If such data is not available, See Technical Brief on Irrigation for further detail on efficiency.

- STEP 3: Calculate the number of irrigation applications over the total growing Season

The number of irrigation applications over the total growing season can be obtained by dividing the irrigation water need over the growing season by the net irrigation depth per application. If no data on irrigation water needs is available, the estimation simple method should be used.

Water consumption per crop can be calculated and compared with a theoretical standard value. In practice, the requirement for irrigation water depends on crop species, soil type, evaporation, and water conservation practices. FAO provides guidance on water management and how to calculate appropriate irrigation. CROPWAT is a practical tool for the personal computer that can complete standard calculations for evapotranspiration and crop water requirements and crop irrigation requirements and, more specifically, design and manage irrigation schemes.

It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain-fed conditions or deficit irrigation.

Calculations of crop water requirements and irrigation requirements are carried out with inputs of climatic and crop data. Standard crop data is included in the program and climatic data can be obtained for 144 countries through the CLIMWAT database. Examples of the water requirements of individual crops and typical yields and efficiencies are presented in the following table.

Crop	Crop water need (mm in total growing period)[6]	Typical yield and efficiency[7]
Coffee	Water requirements 1500–2500 mm/ yr	Average of 1 100 kg/ha with varieties producing 2 400 kg/ha under good growing conditions
Sugar cane	Water requirements vary between 1500 to 2500 mm/ yr	Good yields in the humid tropics of a totally rain fed crop can be in the range of 70 to 100 ton/ha cane, and in the dry tropical and subtropics with irrigation, 110 to 150 ton/ha cane. Sugar content at harvest is usually between 10 and 12 percent of the cane fresh weight.
Citrus	Water requirements vary between 900 and 1200 mm/ yr	Good yields of citrus are: Orange 25 to 40 tons per ha per year; grapefruit 40 to 60 tons per ha; lemons 30 to 45 tons per ha per year; mandarin - 20 to 30 tons per ha per year.

- Step 4: Calculate the irrigation interval (INT) in days

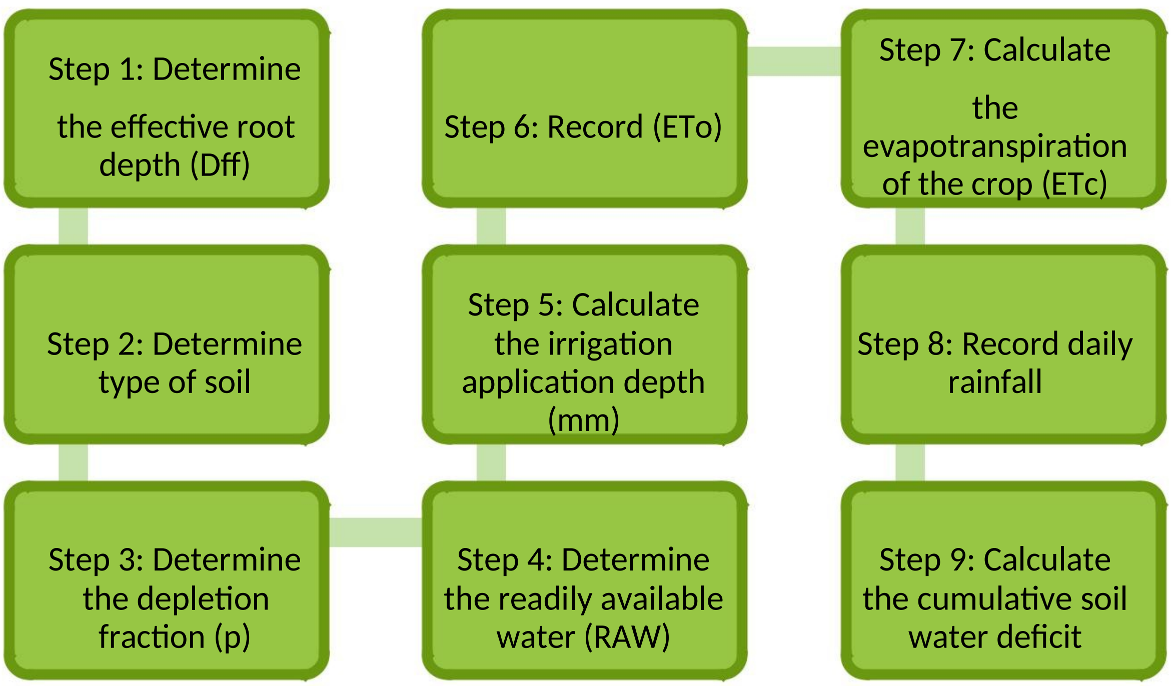
Note that are not site-specific

The irrigation interval in days is calculated by dividing the total growing season in days by the number of irrigation applications over the total growing season.

c. Using the moisture accounting method

The moisture accounting method can provides with a more comprehensive irrigation scheduling, taking into consideration climate, soil and crop properties. Some inputs to take into consideration include the crop characteristics, its root depth, the depletion factor, the crop coefficient value Kc, the soil characteristics (Soil type and texture, total available water), the irrigation requirements (efficiency and evotranspiration (Eto) calculated from climate data and evaporation).

This moisture accounting method involves the following steps that are explained in detail below. In addition, an example for tomatoes is conducted further down.



For adjustments the Simple Calculation Method for the Peak Period see: http://www.fao.org/docrep/t7202e/t7202e06.htm#3.3 simple calculation method

- STEP1: Determine the root depth of the crop

Rooting depth can be determined by digging out the whole plant, shaking the soil off or digging a soil pit and then measuring the depth of the root system. Table 6 above provides an estimate of the root depth by type of crop.

- STEP 2: Find out the type of soil and determine the Total Available Water (TAW) for the type of soil.

Table 7 provides an estimate of the TAW for different textures of soil.

Table 7: Total available water in mm per metre of soil depth (TAW)

Soil Texture	Range	Average
Sand	30-65	49
Sandy Loam	90-123	106
Loam	155-172	164
Light Clay Loam	172-180	172
Clay Loam	155-172	164
Heavy Clay Loam	137-155	147

- STEP 3: Determine an appropriate depletion fraction (p)

Each crop has an estimated depletion factor. In the case of vegetables the depletion fraction (p) is roughly 0.3-0.5.

- STEP 4: Determine the readily available water (RAW)

Total available water, readily available water and depletion fraction are critical to planning an appropriate irrigation schedule. To maintain soil moisture at optimum levels, it is important to understand that not all of the total available water (Table 7) is used before the next irrigation is applied. Readily available water (RAW) is the amount of water that a plant can easily extract from the soil for unrestricted growth. The RAW is calculated for the root zone of the crop. The RAW can be calculated more accurately with some scheduling systems (such as neutron probes and capacitance probes).

The readily available water is obtained by multiplying the depletion factor (Step 3) by the total available water estimated in Step 2.

- STEP 5: Calculate the net irrigation application depth (mm)

The net irrigation application depth **i**s obtained by multiplying the root depth (Step 1) by the total readily available water calculated in Step 4.

- STEP 6: Record reference evapotranspiration (ETo) from climate data or calculate it from pan evaporation.

The reference evapotranspiration ETo is the water use of a lush, well-watered grass pasture. ETo expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. Eto depends on climatic parameters. Consequently, ETo is a climatic parameter and can be computed from weather data.

The Penman-Monteith equation is used for determining ETo. See Crop evapotranspiration Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56 for more detail.

- STEP 7: Calculate the evapotranspiration of the crop (ETc)

The actual evapotranspiration of the crop (ETc) depends on the following: the type of plant (some plants use more water than others), stage of growth (a mature plant uses more than a seedling), condition of plant (stress from whatever cause, insects, fertilizer, excess salinity, or lack of soil water, decreases ETc) and climate (higher temperature, lower humidity, and higher wind will increase ETc).

The length of the total growing season and each growth stage of the crop are important when estimating crop water needs. The growth of an annual crop can be divided into four stages:

- Initial (establishment): from sowing to 10% ground cover
- Crop development: from 10 to 70% ground cover
- Mid-season (fruit formation): including flowering and fruit set or yield formation
- Late-season: including ripening and harvest.

To estimate Etc multiply ETo in mm/day (Step 4) by the appropriate crop coefficient (Kc) value to obtain crop water needs. Kc can be obtained from FAO.[9]

- STEP 8: Record daily rainfall and estimate effective rainfall (mm)

Effective rainfall is defined by USDA as effective rainfall received during the growing period of a crop and is available to meet consumptive water requirements. It does not include surface runoff or deep percolation losses.

- STEP 9: Calculate the cumulative soil water deficit

The cumulative soil water deficit is obtained by adding all water deficits since the last irrigation. It is calculated by adding up the all of the water deficits since the last irrigation and subtracts the effective rainfall. (After an irrigation event the soil is saturated and crop water use is assumed to be zero).

Example

The following example illustrates the moisture accounting method for tomatoes grown in January, in clay soil. For the sake of this exercise the Eto, Kc and rainfall were used. It is recommended to use a moisture balance sheet to keep a sound record for irrigation as shown in the table below.

Step 1: Effective root depth (Dff)=0.55 metre (Table 6)

Step 2: For Clay loam, the total available water (TAW) is 180 mm/m.
Step 3: For tomatoes the depletion fraction (p) is 0.4.

Step 4: The readily available water. RAW= 0.4 * 180 =72

Step 5: The irrigation application depth (mm) = Dff * RAW = 0.55*72=39.6 (rounded 40 mm)

Step 6: The (ETo) was given in column A

Step 7: The evapotranspiration of the crop (ETc) is Eto *Kc. Calculated on column C

Step 8: Daily rainfall was given in column D. The effective rainfall (mm) was calculated in column E. In this example, the effective rainfall, during spring, summer and autumn periods calculated by subtract 5 mm from each of the daily rainfall totals. The main assumption is that rainfall of 5 mm or less to be non-significant (zero). In winter, all the rainfall is assumed to be effective.

Step 9: The cumulative soil water deficit was calculated by H=E+F-C on an accumulative basis.

Table 8: Example of irrigation Scheduling

	A	**B**	**C=A*B**	**D**	**E=D-5mm**	**F**	**H=E+F-C**
Day	ETo (mm/day)	Crop coefficient (Kc)	Crop water use (Etc) (mm/day)	Rainfall (mm)	Effective rain (mm)	Net Irrigation application (mm)	Cumulative soil water deficit
1	7.6	0.85	6.5	0	0	0	-6.5
2	8.6	0.85	7.3	3.8	0	0	-13.8

3	8.6	0.85	7.3	0.4	0	0	-21.1
4	8.8	0.85	7.5	0	0	0	-28.8
5	7.1	0.85	6.0	0	0	0	-34.6
6	9.1	0.85	7.7	0	0	40	IRRIGATION
7	6.4	0.85	5.4	0	0	0	0
8	3.4	0.85	2.9	0	0	0	-2.9
9	6.2	0.85	5.3	6	1	0	-8.2
10	6.3	0.85	5.4	3.2	0	0	-13.6
11	4.3	0.85	3.7	4.6	0	0	-17.3
12	7.7	0.85	6.5	1.4	0	0	-23.8
13	8.7	0.85	7.4	17.8	12.8	0	-11.0
14	7.2	0.85	6.1	0	0	0	-17.1

Section 8: Case Studies

Case Study 1: How are farmers from California scheduling irrigation?

Farmers from California are using and different methods to schedule irrigation. According the USDA's Farm and Ranch Irrigation Survey, the most commonly methods used to schedule irrigation in California are the condition of the crop, the feel of the soil, and a personal calendar schedule as shown in the table below[10]. In some irrigation districts, farmers are restricted by scheduled water deliveries and must irrigate when their water arrives.

Picture 1: California Farmer

Table 9: Methods used by California farmers to decide when to irrigate, 2008[11]

Method	Percent of farmers[o]
Condition of crop	66
Feel of soil	45
Personal calendar schedule	32
Soil moisture sensing device	14
Daily ET reports	12.3
Scheduled by water delivery organization	10
Commercial or government scheduling service	9.7
When neighbors irrigate	6.1
Other	5.5
Plant moisture sensing device	3.1

Source: Pacific Institute

Many farmers use more than one method when deciding when to irrigate, thus the total of all methods exceeds 100 percent.

The California Irrigation Management Information System (CIMIS), a network of more than 130 automated weather systems across California provides farmers with localized weather data online, such as temperature, wind speed and Eto.

A survey by the University of California evaluated the water use and yield of all major crop types for 55 farmers across California who used evotranspiration data to determine water application. The study found that on average, the use of CIMIS increased yields by 8% and reduced water use by 13%.

Case study 2: Introduction of water-saving irrigation scheduling to farmers in China[12,13]

The Chinese irrigation agency started an irrigation scheduling program in the arid area of Gansu province, in the north-west part of China. The aim of the proram was to increase awareness among farmers about water saving irrigation and popularize the water-saving irrigation schedule through involving farmers more in the process of water-saving irrigation scheduling.

Picture 2: Gansu farmer.

The approach applied in this program consisted of demonstrating the new water-saving irrigation schedule and training farmers. The training of farmers was based around field activities with a number of classroom presentations. The field activities, organized on a village basis, were appreciated by the farmers and provided opportunities for lively discussion. The training of farmers was conducted in conjunction with the implementation of the demonstration.

The results of the program were positive; water savings were achieved in the area, the period elapsed for every rotation of irrigation was reduced and on farm irrigation management and the irrigation service have improved. A key learning from this program was that the farmer involvement in irrigation management is key to the appropriate implementation and success of irrigation scheduling.

Case study 3: Difficulties in introducing new technology to

Picture 3: Sugar Cane farmers at Pongola

Schedule irrigation for small sugar cane farmers in Pongola, South

Africa

The aim of the programme was to conduct the pilot implementation of a high-technology system to provide practical, real-time irrigation advice to small sugar cane farmers in South Africa. The system consists of a web-based simulation model that estimates the recent, current and future water balance, crop status and yield from field information and real-time weather data. The system automatically generates and distributes simple irrigation advice by SMS to farmers' cellular phones.

Unfortunately, the adoption of irrigation scheduling techniques in South African sugarcane production has been disappointing. The main challenge has been to convince farmers of the benefits of irrigation scheduling by on-farm demonstration. Nonetheless, farmers who adopted the technology obtained large reductions in irrigation applied (33%), deep drainage (64%) and irrigation costs. Yields were not affected significantly and profitability was enhanced considerably. The main impact is to reduce irrigation during winter and when the crop is young.

Case study 4: Using forecasting and scheduling systems to save water[16,17]

Unilever reduced water use in tomato crops in Brazil by using online weather system technologies.

The online system allows farmers to assess the quantity of irrigation water needed. The system provides guidance based on temperature, rainfall, moisture, dew and solar radiation data, collected from weather stations across the cropping area every 15 minutes.

Tomato farmers managed to halve their water use (from 800mm/ha to 400mm/ha) by making irrigation and chemical applications more efficient, largely using information from online weather data systems.