CHAPTER 6: Irrigation scheduling

Irrigation scheduling is one of the factors that influence the agronomic and economic viability of small farms. It is important for both water savings and improved crop yields. The irrigation water is applied to the cultivation according to predetermined schedules based upon the monitoring of:

- the soil water status;
- the crop water requirements.

The type of soil and climatic conditions have a significant effect on the main practical aspects of irrigation, which are the determination of how much water should be applied and when it should be applied to a given crop.

In addition to the basic factors relevant to the preparation of irrigation schedules examined below, other important elements should also be considered, such as crop tolerance and sensitivity to water deficit at various growth stages, and optimum water use.

SOIL-WATER RELATIONSHIP

Table 6.1 presents a summary table of soil physical properties.

TABLE 6.1 - Soil physical properties (average values)

Type of soil	Light (coarse) texture	Medium texture	Heavy (fine) texture
Saturation capacity (SC) % weight	25–35%	35–45%	55–65%
Field capacity (FC) % weight	8–10%	18–26%	32–42%
Wilting point (WP) % weight	4–5%	10–14%	20–24%
SC/FC	2/1	2/1	2/1
FC/WP	2/1	1.85/1	1.75/1
Bulk density(volume weight)	1.4–1.6 g/cm^3	1.2–1.4 g/cm^3	1.0–1.2 g/cm^3
Soil available water (moisture) by volume (FC-WP *x* bulk density)	6%	12%	16–20%
Available moisture (Sa) in mm per metre soil depth (FC-WP *x* bulk density *x* 10)	60 mm	120 mm	160–200 mm
Soil water tension in bars:			
• at field capacity	0.1	0.2	0.3
• at wilting point	15.0	15.0	15.0
Time required from saturation to field capacity	18–24 h	24–36 h	36–89 h
Infiltration rate	25–75 mm/h	8–16 mm/h	2–6 mm/h

Example:

The field capacity (FC) of a 45-cm layer of soil is 18 percent. How much water in cubic metres per hectare does this layer hold?

Answer:

FC = 18 %, WP = FC ÷ 1.85 = 9.7 %, Sa = 18-9.7 = 8.3 %;

Bulk density = 1.2 g/cm^3; Sa mm/m = 8.3 *x* 1.2 *x* 10 = 99.6, Sa mm/45 cm = 8.3 *x* 1.2 *x* 10 *x* 0.45 = 44.8 mm; m^3/ha = 0.0996 ÷ 1 *x* 0.45 *x* 10 000 (1 ha) = 448.2, or m^3/ha = Sa (mm/m) *x* depth of layer (m) *x* 10.

Therefore, the answer is 448.2 m^3/ha.

EFFECTIVE ROOT DEPTH

This is the soil depth from which the plants take nearly 80 percent of their water needs, mostly from the upper part where the root system is denser. The rooting depths depend on the plant physiology, the type of soil, and the water availability (kind of irrigation). Indicative figures are presented in FAO Irrigation and Drainage Paper No. 24, Table 39.

In general, vegetables (beans, tomatoes, potatoes, onions, peanuts, cucumbers, etc.) are shallow rooted, about 50–60 cm; fruit trees, cotton and some other plants have medium root depths, 80–120 cm. Alfalfa, sorghum, and maize have deeper roots (Table 6.2). Moreover, rooting depths vary according to age.

TABLE 6.2 - Example of rooting depth (metres) during the growing season

	August	September	October	November	December	January
Maize	-	0.4	0.9	1.2	1.2	-
Cotton	0.4	0.8	1.0	1.0	1.0	-
Tomato	-	-	0.3	0.7	0.9	0.9

PERMISSIBLE DEFICIT OR DEPLETION OF SOIL AVAILABLE WATER

The fraction of moisture in the soil which amounts to 20–70 percent of the total available moisture (Sa) and is easily absorbed by the plants (without any stress that results in yield reduction) is called readily available moisture. It is a product of Sa multiplied by p, which represents the maximum permissible depletion of available water (moisture). The p value differs according to the kind of plant, the root depth, the climatic conditions and the irrigation techniques. Values for p are given in FAO Irrigation and Drainage Paper No. 33, Tables 19 and 20, and vary from

0.25 in shallow rooted sensitive crops to 0.70 in deep rooted tolerant crops. Table 23 of the same paper provides information on the sensitive growth periods of different crops.

Field observations have shown that the lower the soil moisture depletion (p), the better the crop development and yield. Hence, the recommended p values are:

- 0.20–0.30 for shallow rooted seasonal crops;
- 0.40–0.60 for deep rooted field crops and mature trees.

NET IRRIGATION APPLICATION DEPTH

Irrigation takes place when the permissible percentage (p) of available water (Sa) is depleted from the root depth, i.e. to replenish the depleted water. Therefore:

$$\textit{Net depth of irrigation dose (d) (mm)} = (Sa \times p)\, D$$

where **Sa** is the available water in millimetres per metre, **p** is the permissible depletion (fraction), and **D** is the root depth (m).

Example:
Where Sa = 99 mm/m, p = 0.5, D = 0.4 m, what is the net irrigation dose (d) in millimetres to replenish the moisture deficit?

$$d = 99 \times 0.5 \times 0.4 = 19.8 \text{ mm}$$

CROP WATER REQUIREMENTS

The amount of water which evaporates from wet soils and plant surfaces together with the plant transpiration is called evapotranspiration (ET). Its value is largely determined by climate factors, such as solar radiation, temperature, humidity and wind, and by the environment. Out of the total evapotranspiration, evaporation accounts for about 10 percent and plant transpiration for the remaining 90 percent. Crop water requirements encompass the total amount of water used in evapotranspiration.

Alternative approaches for estimating the evapotranspiration, such as the radiation, Penman and pan methods, are presented in FAO Irrigation and Drainage Papers Nos. 24 and 33. Reference evapotranspiration (ETo) represents the rate of evapotranspiration of green grass under ideal conditions, 8–15 cm tall, with extensive vegetative cover completely shading the ground. It is expressed as a mean value in millimetres per day over a period of 10–30 d.

The most practical method for determining ETo is the pan evaporation method. This approach combines the effects of temperature, humidity, wind speed and sunshine. The best known pans are the Class A evaporation pan (circular) and the Colorado sunken pan (square).

The evaporation from the pan is very near to the evapotranspiration ofgrass that is taken as an index of ETo for calculation purposes. The pan direct readings (Epan) are related to the ETo with the aid of the pan coefficient (kpan), which depends on the type of pan, its location (surroundings with or without ground cover vegetation) and the climate (humidity and wind speed) (Table 6.3). Hence, ETo = Epan *x* kpan.

The kpan values for both types of pans are given in FAO Irrigation and Drainage Paper No. 24, Tables 18 and 19. For the Class A pan the average kpan is 0.70 and for the Colorado sunken pan it is 0.80.

Example:

TABLE 6.3 - Estimate of ETo in millimetres per day in the Wadi Tuban Delta

Month	June	July	August	September	October	November	December
Epan	9.0	8.8	8.8	8.2	8.0	6.5	5.7
kpan			average	0.70			
ETo	6.3	6.2	6.2	5.7	5.6	4.5	4.0

In order to relate ETo to crop water requirements (ETc), the specific crop coefficient (kc) must be determined: ETc = ETo *x* kc.

The crop coefficient (kc) depends on the crop leaf area and its roughness, the stage of growth, the growing season and the prevailing weather conditions (Table 6.4). Tables 6.5 and 6.6 list the kc values for different crops at various growth stages.

Example:

TABLE 6.4 - Cotton, growing season August-December

	August	September	October	November	December
ETo mm/d	6.2	5.7	5.6	4.5	4.0
Cotton kc	0.4	0.7	1.1	1.0	0.8
Cotton ET cmm/d	2.5	4.0	6.2	4.5	3.2
Cotton ET cmm/month	78	120	192	135	99

Total net water requirement approximately 580 mm
(December taken as half)

TABLE 6.5 - Crop factor (kc) for seasonal crops (average figures)

Crop	Initial	Crop development	Mid-season	Late and harvest
Bean (green)	0.35	0.70	1.0	0.9
Bean (dry)	0.35	0.75	1.1	0.5
Cabbage	0.45	0.75	1.05	0.9
Carrot	0.45	0.75	1.05	0.9
Cotton	0.45	0.75	1.15	0.75
Cucumber	0.45	0.70	0.90	0.75
Eggplant	0.45	0.75	1.15	0.80
Groundnut	0.45	0.75	1.0	0.75
Lettuce	0.45	0.60	1.0	0.90
Maize (sweet)	0.40	0.80	1.15	1.0
Maize (grain)	0.40	0.75	1.15	0.70
Melon	0.45	0.75	1.0	0.75
Onion (green)	0.50	0.70	1.0	1.0
Onion (dry)	0.50	0.75	1.05	0.85
Pea (fresh)	0.45	0.80	1.15	1.05
Pepper	0.35	0.75	1.05	0.90
Potato	0.45	0.75	1.15	0.75
Spinach	0.45	0.60	1.0	0.90
Squash	0.45	0.70	0.90	0.75
Sorghum	0.35	0.75	1.10	0.65
Sugar beet	0.45	0.80	1.15	0.80
Sugar cane	0.45	0.85	1.15	0.65
Sunflower	0.35	0.75	1.15	0.55
Tomato	0.45	0.75	1.15	0.80

TABLE 6.6 - Crop factor (kc) for permanent crops

Crop	Young	Mature
Banana	0.50	1.10
Citrus	0.30	0.65
Apple, cherry, walnut	0.45	0.85
Almond, apricot, pear, peach, pecan, plum	0.40	0.75
Grape, palm tree	0.70	0.70
Kiwi	0.90	0.90
Olive	0.55	0.55
Alfalfa	0.35	1.1

EFFECTIVE RAINFALL

In many areas, seasonal rain precipitation (P) might provide part of the water requirements during the irrigation season. The amount of rainwater retained in the root zone is called effective rainfall (Pe) and should be deducted from the total irrigation water requirements calculated. It can be roughly estimated as:

Pe = 0.8 P where P > 75 mm/month;
Pe = 0.6 P where P < 75 mm/month.

GROUND COVER

Another element to consider when estimating crop water requirements is the percentage of the field area (ground) covered by the cultivation. A reduction factor, expressed as kr, is applied to the conventional ET crop calculations. This factor is slightly higher, by about 15 percent, than the actual ground covered by the crop. For example, if the actual ground cover is 70 percent, kr = 0.70 *x* 1.15 = 0.80.

IRRIGATION INTERVAL OR FREQUENCY

This is the number of days between two consecutive irrigations, i = d ÷ ETc, where d is the net depth of irrigation application (dose) in millimeters and ETc is the daily crop evapotranspiration in millimetres per day.

Example:
Where d is 19.8 mm, and ETc is 2.5 mm/d, then i = 19.8 ÷ 2.5 = 8 days.

IRRIGATION APPLICATION EFFICIENCY

The amount of water to be stored in the root zone is estimated as the net irrigation dose (d). However, during the irrigation process, considerable water loss occurs through evaporation, seepage, deep percolation, etc. The amount lost depends on the efficiency of the system (Table 6.7). Irrigation field application efficiency is expressed as:

$$Ea = \frac{d}{Water\ Applied\ (gross)} \times 100$$

where, **d** is water stored in the rootzone and **Water Applied (gross)** is the irrigation water.

Example:
The net irrigation dose (d) for an area of 1 ha is 19.8 mm, i.e. 198 m^3. The water delivered during irrigation is 280 m^3. What is the application efficiency?

Answer:
Ea = 198 *x* 100 ÷ 280 = 70.7 percent, or expressed as a fraction, 0.70. The remaining 30 percent of water applied is lost.

TABLE 6.7 - Approximate application efficiency of various on-farm irrigation systems and methods

System/method	Ea %
Earth canal network surface methods	40–50
Lined canal network surface methods	50–60
Pressure piped network surface methods	65–75
Hose irrigation systems	70–80
Low-medium pressure sprinkler systems	75
Microsprinklers, micro-jets, minisprinklers	75–85
Drip irrigation	80–90

GROSS IRRIGATION APPLICATION DEPTH

Given the irrigation efficiency as a fraction, i.e. Ea = 0.60 (60 percent), the gross depth of irrigation application or gross irrigation dose (dg) is calculated as follows:

$$dg = \frac{d}{Ea\ (fraction)}$$

LEACHING REQUIREMENTS

The salinity level in the root zone is related directly to the water quality, the amount of fertilizers and the irrigation application depth. A high salt content in the soil is controlled by leaching (see Chapter 7 Water Quality). An excess amount of water, 10–15 percent, is applied during the irrigation where necessary for leaching purposes. In this way a portion of the water percolates through and below the root zone carrying with it a portion of the accumulated soluble salts. The leaching requirements (LR) are considered for the calculation of the gross irrigation application (d).

SYSTEM FLOW (SYSTEM CAPACITY)

The minimum flow capacity of any irrigation system should be the one that can meet the water requirements of the area under irrigation at peak demand:

$$minimum Q = 10\ A\ \frac{dg}{it}$$

where ***Q*** is the system flow in cubic metres per hour, ***A*** is the area in hectares, ***dg*** is the gross irrigation application depth (irrigation dose) in millimetres, ***i*** is the interval in days between two irrigations at peak demand, ***t*** is the operating hours per day, and 10 is a constant for hectares. However, the minimum flow of the system should be the one that enables the completion of irrigation at least two days before the next irrigation. This allows time to repair any damage to the system or pumping unit. Therefore, the value of i in the above formula should be reduced by two days.

The duration of application per irrigation is determined as:

$$T = 10\,A\,\frac{dg}{Q}$$

where ***T*** is the total operating hours of the system.

GENERAL EXAMPLE

In the following example (Table 6.8) the effective rainfall (Pe), the ground cover (kr) and the leaching requirements (LR) are not considered. However, these elements are important in localized micro-irrigation systems.

- Crop: Cotton
- Area: 1.5 ha.
- Location: Tuban Delta.
- Growing season: August-December.
- Irrigation method: Pressure piped surface method.
- Irrigation efficiency: 70 percent.
- Soil of medium texture, Sa = 99 mm/m.

TABLE 6.8 - Cotton example

	August	September	October	November	December
Soil available water Sa mm/m	99	99	99	99	99
Depletion of available water p	0.5	0.6	0.6	0.6	0.6
Cotton root depth D m	0.4	0.7	1.0	1.0	1.0
Net irrigation application d mm	19.8	41.6	59.4	59.4	59.4
Epan mm/d	8.8	8.2	8.0	6.5	5.7
kpan	0.7	0.7	0.7	0.7	0.7
ETo mm/d	6.2	5.7	5.6	4.5	4.0
Cotton kc	0.4	0.7	1.1	1.0	0.8
Cotton ETc mm/d	2.5	4.0	6.2	4.5	3.2
Irrigation interval i days	8	10.5	9.6	13	18.5
Gross irrigation dose dg mm	28.3	59.4	85.0	85.0	85.0
Gross irrigation dose dg m^3/h	425	891	1 275	1 275	1 275

The peak demand is in October when ETc is 6.2 mm/d and the irrigation frequency (interval) is 8 days. If the number of operating hours per day is seven, the system flow should be:

$$minimumQ = 10\ \frac{1.5ha \times 85mm}{(9days - 2days) \times 7hrs/day} = 26m^3/\text{hr}$$

The duration of application per irrigation would be as follows (Table 6.9):

- August: T = 10 *x* 1.5 *x* 28.3 ÷ 26 = 16.3 hours, i.e. 2 days;
- September: T = 10 *x* 1.5 *x* 59.4 ÷ 26 = 34.3 hours, i.e. 5 days;
- October: T = 10 *x* 1.5 *x* 85.0 ÷ 26 = 49.0 hours, i.e. 7 days;
- November: T = 10 *x* 1.5 *x* 85.0 ÷ 26 = 49.0 hours, i.e. 7 days;
- December: T = 10 *x* 1.5 *x* 85.0 ÷ 26 = 49.0 hours, i.e. 7 days.

TABLE 6.9 - Irrigation programme

End of July	**pre-sowing irrigation to wet 0.6 m soil depth**	**1 273 m³**
Beginning of August	crop establishment	
8 August	irrigation	425 m³
16 August	irrigation	425 m³
24 August	irrigation	425 m³
1 September	irrigation	891 m³
11 September	irrigation	891 m³
22 September	irrigation	891 m³
2 October	irrigation	1 275 m³
11 October	irrigation	1 275 m³
21 October	irrigation	1 275 m³
31 October	irrigation	1 275 m³
13 November	irrigation	1 275 m³
26 November	irrigation	1 275 m³

The last irrigation on 26 November can last up to 9 December, i.e. until harvest. The total amount of water that must be applied to this crop on an area of 1.5 ha is: 11 598 m^3 plus 1 273 m^3 as the minimum amount for pre-irrigation, for a total of 12 871 m^3.