Irrigation Water Management: Irrigation Water Needs

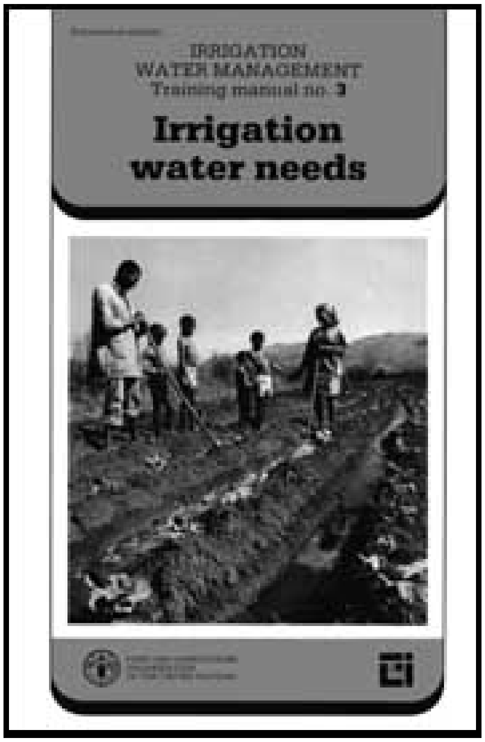

Table of Contents

IRRIGATION WATER MANAGEMENT
Training manual no. 3

Part I Principles of irrigation water needs
Part II Determination of irrigation water needs

a manual prepared jointly

by

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PREFACE

This is one in a series of training manuals on subjects related to Irrigation that will be issued in 1985, 1986 and 1987.

The papers are intended for use by field assistants in agricultural extension services and irrigation technicians at the village and district levels who want to increase their ability to deal with farm-level irrigation issues.

The papers contain material that is intended to provide support for irrigation training courses and to facilitate their conduct. Thus, taken together, they do not present a complete course in themselves, but instructors may find it helpful to use those papers or sections that are relevant to the specific irrigation conditions under discussion. The material may also be useful Co individual students who want to review a particular subject without a teacher.

Following an introductory discussion of various aspects of irrigation in the first paper, subsequent subjects discussed will be:

- topographic surveying
- crop water needs
- irrigation scheduling
- irrigation methods
- irrigation system design
- land grading and levelling
- canals and structures
- drainage
- salinity
- irrigation management

At this stage, all the papers will be marked provisional because experience with the preparation of irrigation training material for use at the village level is limited. After a trial period of a few years, when there has been time to evaluate the information and the use of methods outlined in the draft papers, a definitive version can then be issued.

For further information and any comments you may wish to make please write to:

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ABOUT THIS PAPER

Irrigation water needs is the third in a series of training manuals on irrigation. Unlike Volumes 1 and 2, Volume 3 has been divided into two parts.

Part I Principles of Irrigation Water Needs

> Part I of this manual describes in general terms the principles to determine the water need of standard grass; how the water need of grass relates to the water needs of the crops actually grown on an irrigation scheme. Lastly it indicates how the irrigation water needs can be estimated for the various crops, taking into account the effective rainfall.
>
> Part I is intended for use by village level extension workers who will not be involved - on a project basis - with the determination of the irrigation water needs, but who need to understand the principles behind and the factors involved in their determination.
>
> Part I uses only very elementary arithmetic, provides tables indicating approximate values or orders of magnitude only, but does not elaborate on their more accurate determination.

PART II Determination of Irrigation Water Needs

> Part II covers in principle the same topics as Part I: reference crop evapotranspiration, crop evapotranspiration or crop water needs and irrigation water needs. It provides - be it still in a fairly simple manner - methods to calculate these.
>
> Part II is intended for use by irrigation technicians at the village and district levels who will be involved in the determination of irrigation water needs for small projects and who are not in a position to obtain these data easily from the Extension Service, Irrigation Department or Ministry of Agriculture.

Although the calculations do not go beyond multiplication and division, the whole calculation procedure to arrive, for the various crops, at irrigation water needs on a monthly basis is rather time-consuming and requires background knowledge. It is advisable that those intending to use Part II first take notice of the content of Part I.

For those technicians who are not involved in the actual determination of irrigation water needs and who can obtain these data locally. Part I may serve as general background to the subject.

Table of Contents

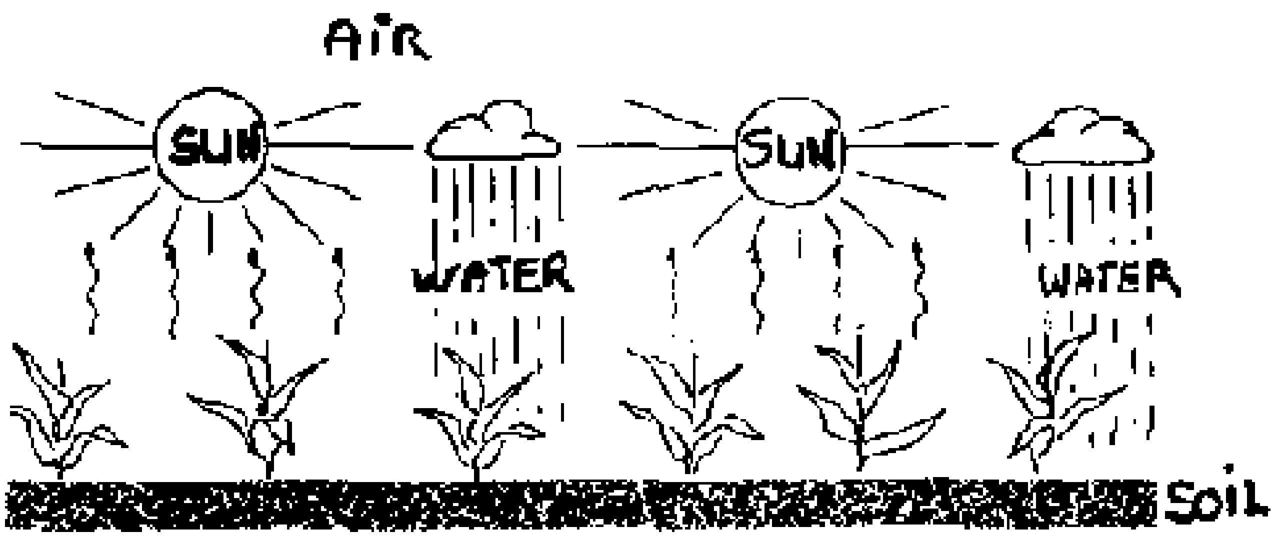
PART I - PRINCIPLES OF IRRIGATION WATER NEEDS

PART II - DETERMINATION OF IRRIGATION WATER NEEDS

CHAPTER 1: INTRODUCTION

All field crops need soil, water, air and light (sunshine) to grow. The soil gives stability to the plants; it also stores the water and nutrients which the plants can take up through their roots. The sunlight provides the energy which is necessary for plant growth (Fig. 1). The air allows the plants to "breath".

Fig. 1 Plants need soil, water, air and sunlight ......



Without water crops cannot grow. Too much water is not good for many crops either. Apart from paddy rice, there are only very few crops which like to grow "with their feet in the water". The most well-known source of water for plant growth is rain water. There are two important questions which come to mind: What to do if there is too much rain water? What to do if there is too little rain water?

If there is too much rain, the soil will be full of water and there will not be enough air. Excess water must be removed. The removal of excess water - either from the ground surface or from the root zone - is called **drainage** (see Volume 1, Chapter 6).

If there is too little rain, water must be supplied from other sources; **irrigation** is needed (Fig. 2). The amount of irrigation water which is needed depends not only on the amount of water already available from rainfall, but also on the total amount of water needed by the various crops.

Fig. 2 If there is only a little rain water, irrigation is needed .....

With respect to the need for irrigation water, a distinction can be made among three climatic situations:

1. Humid climates: more than 1200 mm of rain per year. The amount of rainfall is sufficient to cover the water needs of the various crops. Excess water may cause problems for plant growth and thus **drainage** is required.

2. Sub-humid and semi-arid climates: between 400 and 1200 mm of rain per year. The amount of rainfall is important but often not sufficient to cover the water needs of the crops. Crop production in the dry season is only possible with irrigation, while crop production in the rainy season may be possible but unreliable: yields will be less than optimal.

3. Semi-arid, arid and desert climates: less than 400 mm of rain per year. Reliable crop production based on rainfall is not possible; irrigation is thus essential.

The two major factors which determine the amount of irrigation water which is needed are:

the total water need of the various crops
the amount of rain water which is available to the crops

In other words: the irrigation water need is the difference between the total water need of the crops and the amount of rainfall which is available to the crops.

In Chapter 2 the crop water needs are discussed; Chapter 3 discusses the contribution from the rainfall while in Chapter 4 the determination of the irrigation water needs is explained (Fig. 3).

Fig. 3 Irrigation water need

In many countries it is already well known what the crop water needs and irrigation water needs are of the most commonly grown crops. Such data can usually be obtained from the Extension Service, the Irrigation Department or Ministry of Agriculture. It is then not necessary to determine the crop and irrigation water need. However, there may be situations where it is not possible to obtain these data and it would thus be necessary to determine them on the spot.

Part I of this manual allows the reader to make a rough estimation of the crop and irrigation water needs - without using any complicated calculations.

Part II of this manual allows the reader actually to calculate - be it in a fairly simple manner - the crop and irrigation water needs. These calculations obviously lead to a greater accuracy, but they also require more time and background knowledge.

CHAPTER 2: CROP WATER NEEDS

Crops need water for transpiration and evaporation (see Volume 1, Section 4.2).

The plant roots suck or extract water from the soil to live and grow. The main part of this water does not remain in the plant, but escapes to the atmosphere as vapour through the plant's leaves and stem. This process is called **transpiration.** Transpiration happens mainly during the day time.

Water from an open water surface escapes as vapour to the atmosphere during the day. The same happens to water on the soil surface and to water on the leaves and stem of a plant. This process is called **evaporation** (Fig. 4).

The water need of a crop thus consists of transpiration plus evaporation. Therefore, the crop water need is also called **"evapotranspiration".**

The water need of a crop is usually expressed in mm/day, mm/month or mm/season.

Suppose the water need of a certain crop in a very hot, dry climate is 10 mm/day. This means that each day the crop needs a water layer of 10 mm over the whole area on which the crop is grown (Fig. 5). It does **not** mean that this 10 mm has to indeed be supplied by rain or irrigation every day.

It is, of course, still possible to supply, for example, 50 mm of irrigation water every 5 days. The irrigation water will then be stored in the root zone and gradually be used by the plants: every day 10 mm.

Fig. 4 Evapotranspiration

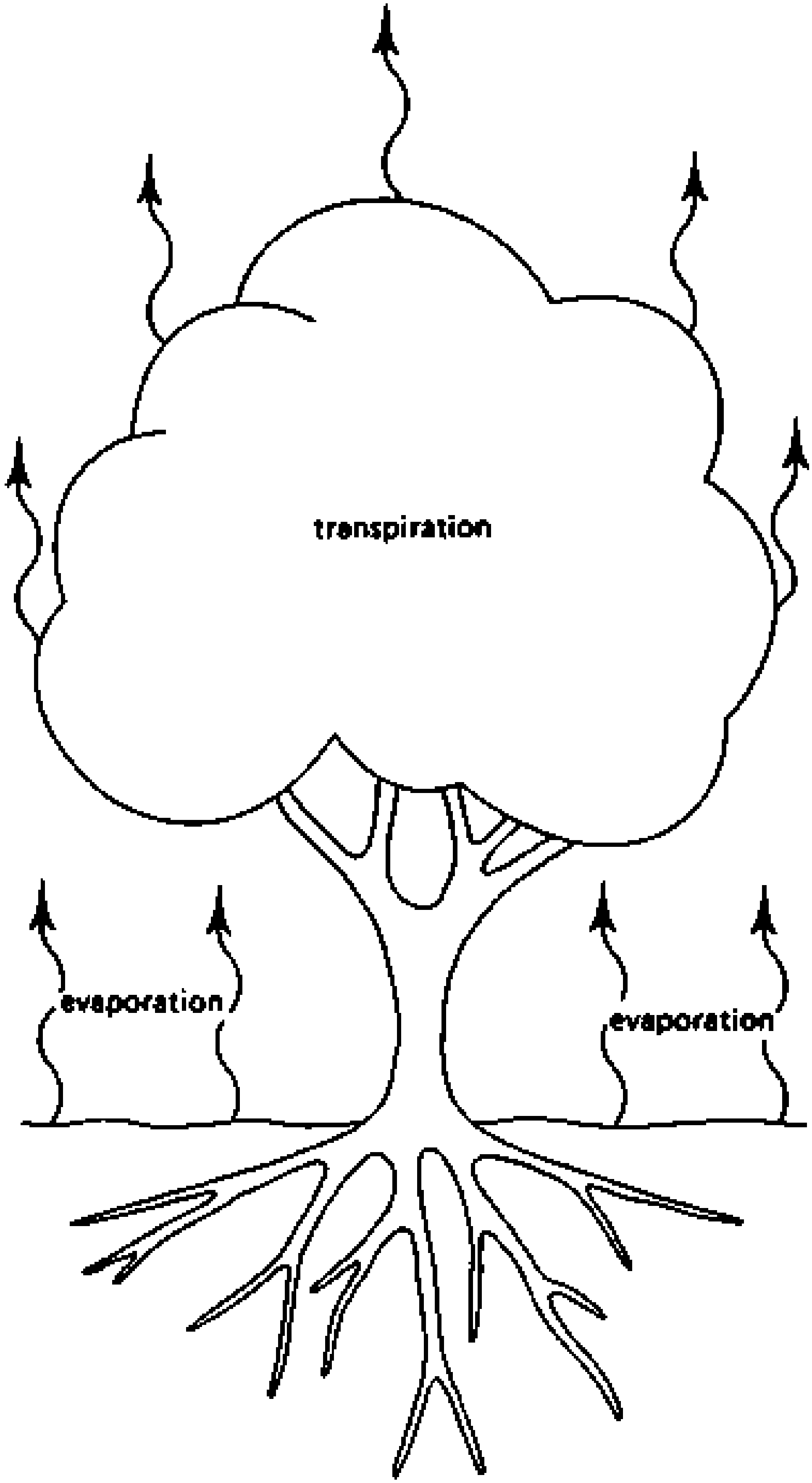
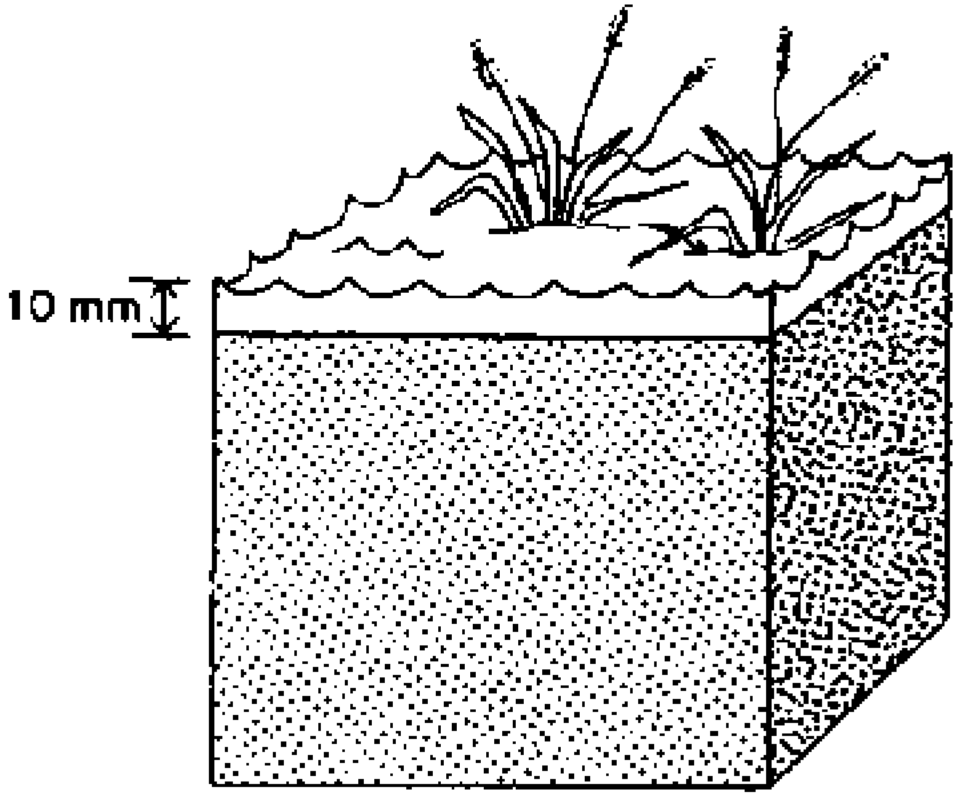


Fig. 5 A crop water need of 10 mm/day



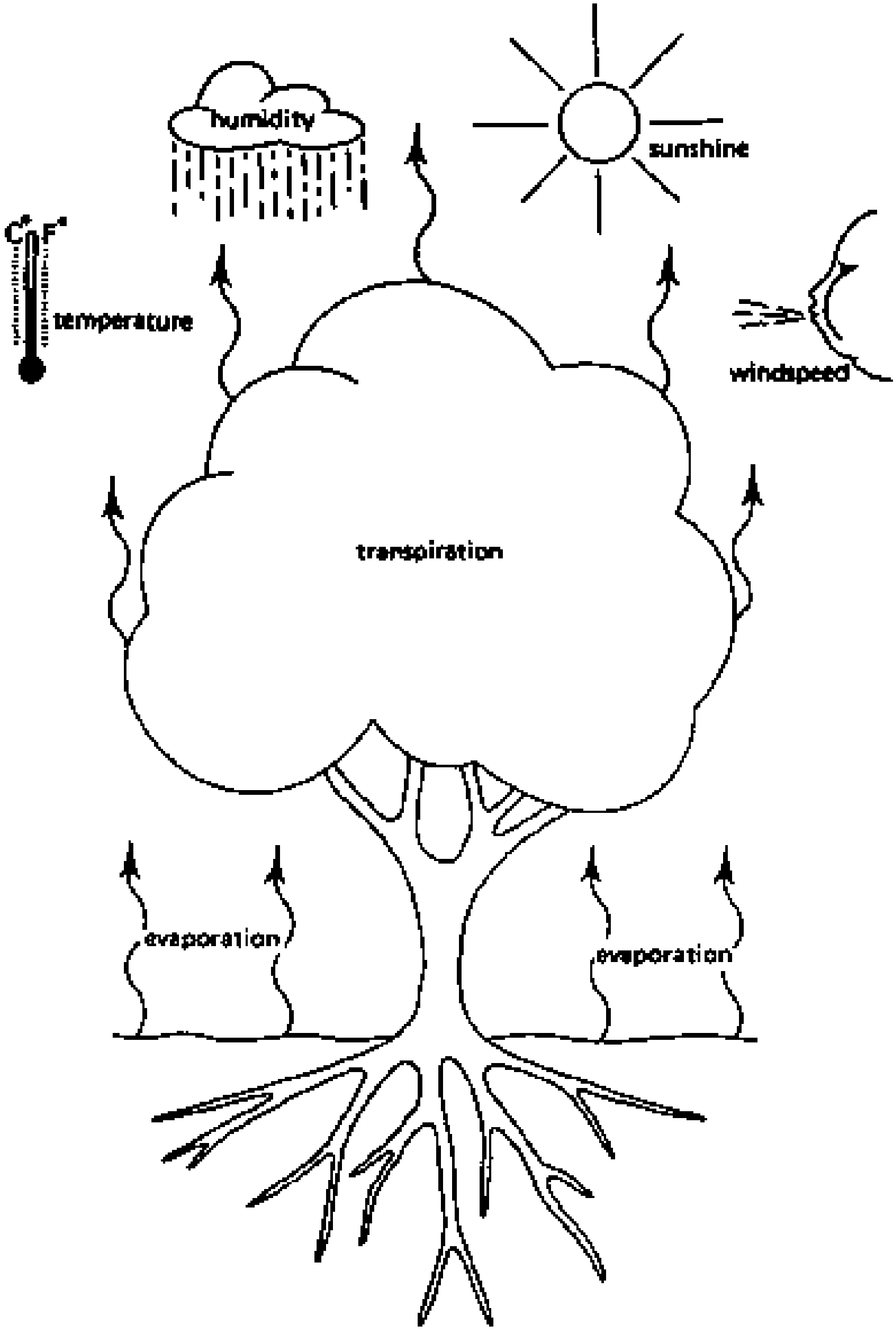
The crop water need mainly depends on:

- **the climate:** for example, in a sunny and hot climate crops need more water per day than in a cloudy and cool climate (see Section 2.1)
- **the crop type:** crops like rice or sugarcane need more water than crops like beans and wheat (see Section 2.2)
- **the growth stage:** grown crops need more water than crops that have just been planted (see Section 2.3).

2.1 THE INFLUENCE OF THE CLIMATE ON CROP WATER NEEDS

A certain crop grown in a sunny and hot climate needs per day more water than the same crop grown in a cloudy and cooler climate. There are, however - apart from sunshine and temperature - other climatic factors which influence the crop water need. These factors are the humidity and the windspeed (see Fig. 6). When it is dry, the crop water needs are higher than when it is humid. In windy climates the crops will use more water than in calm climates.

Fig. 6 Major climatic factors influencing crop water needs



The effect of these four climatic factors on the water need of the crop is shown in Table 1.

Table 1 EFFECT OF MAJOR CLIMATIC FACTORS ON CROP WATER NEEDS

Climatic Factor	Crop water need	
	High	Low
Sunshine	sunny (no clouds)	cloudy (no sun)
Temperature	hot	cool

Humidity	low (dry)	high (humid)
Windspeed	windy	little wind

The highest crop water needs are thus found in areas which are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind.

From the above it is clear that **one crop** grown in **different** climatic zones will have **different** water needs. For example, a certain maize variety grown in a cool climate will need less water per day than the same maize variety grown in a hotter climate.

It is therefore useful to take a certain **standard crop** or **reference crop** and determine how much water this crop needs per day in the various climatic regions. As a standard crop or reference crop **grass** has been chosen.

Table 2 indicates the average daily water needs of this reference grass crop. The daily water needs of the grass depend on the climatic zone (rainfall regime) and daily temperatures.

Table 2 AVERAGE DAILY WATER NEED OF STANDARD GRASS DURING IRRIGATION SEASON

Climatic zone	Mean daily temperature		
	low	medium	high
	(less than 15°C)	(15-25°C)	(more than 25°C)
Desert/arid	4-6	7-8	9-10
Semi arid	4-5	6-7	8-9
Sub-humid	3-4	5-6	7-8
Humid	1-2	3-4	5-6

For example, the standard grass crop grown in a semi-arid climate with a mean temperature of 20°C needs approximately 6.5 mm of water per day. The same grass crop grown in a sub-humid climate with a mean temperature of 30°C needs some 7.5 mm of water per day.

This daily water need of the standard grass crop is also called "reference crop evapotranspiration".

What will be discussed in the next section is "how do the water needs of the crops grown on, for an example, an irrigation scheme relate to the water need of the standard grass".

2.2 INFLUENCE OF THE CROP TYPE ON THE CROP WATER NEEDS

The influence of the crop type on the crop water need is important in two ways:

1. The crop type has an influence on the **daily water needs** of a fully grown crop; i.e. the peak daily water needs: a fully developed maize crop will need more water per day than a fully developed crop of onions.

2. The crop type has an influence on the duration of the total growing season of the crop. There are short duration crops, e.g. peas, with a duration of the total growing season of 90-100 days and longer duration crops, e.g. melons, with a duration of the total growing season of 120-160 days. And then there are, of course, the perennial crops that are in the field for many years, such as fruit trees.

While, for example, the daily water need of melons may be less than the daily water need of peas, the **seasonal water need** of melons will be higher than that of beans because the duration of the total growing season of melons is much longer.

The influences of the crop type on both the daily and seasonal crop water needs are discussed in the sections below.

2.2.1 Influence of Crop Type on the Daily Crop Water Needs

In the previous section it has been indicated how the daily water need of standard grass can be estimated. In this section it will be explained how the daily water needs of other crops can be estimated using as a basis the daily water need of the standard grass.

It will be easy to understand that a fully grown maize crop - with its large leaf area - will use more water per day than, for example, a fully grown crop of radishes or onions; that is when the two crops are grown in the same area.

When determining the influence of the crop type on the **daily** crop water needs, reference is always made to a fully grown crop; the plants have reached their maximum height; they optimally cover the ground; they possibly have started flowering or started grain setting. When the crops are fully grown their water need is the highest. It is the so-called "peak period" of their water needs.

For the various field crops it is possible to determine how much water they need compared to the standard grass (Fig. 7). A number of crops need less water than grass, a number of crops need more water than grass and a number of crops need more or less the same amount of water as grass.

Fig. 7 How much water does maize need, compared to the standard grass?

Table 3 indicates five groups of crops. The crops in column 1 need 30 percent less water than grass in their peak period. The crops in column 2 need 10 percent less water than grass. The crops in column 3 need the same amount of water as grass. The crops in columns 4 and 5 need respectively 10 and 20 percent more water than grass in their peak period.

Table 3 CROP WATER NEEDS IN PEAK PERIOD OF VARIOUS FIELD CROPS AS COMPARED TO STANDARD GRASS

Column 1	Column 2	Column 3	Column 4	Column 5
-30%	-10%	same as standard grass	+ 10%	+20%
citrus	cucumber	carrots	barley	paddy rice

olives	radishes	crucifers (cabbage, cauliflower, broccoli, etc.)	beans	sugarcane
grapes	squash	lettuce	maize	banana
		melons	flax	nuts & fruit trees with cover crop
		onions	small grains	
		peanuts	cotton	
		peppers	tomato	
		spinach	eggplant	
		tea	lentils	
		grass	millet	
		cacao	oats	
		coffee	peas	
		clean cultivated nuts & fruit trees e.g. apples	potatoes	
			safflower	
			sorghum	
			soybeans	
			sugarbeet	
			sunflower	
			tobacco	
			wheat	

EXAMPLE

Suppose in a certain area the standard grass crop needs 5.5 mm of water per day.

Then, in that same area, maize will need 10% more water. Ten percent of 5.5 mm = 10/100 × 5.5 = 0.55 mm. Thus maize would need 5.5 + 0.55 = 6.05 or rounded 6.1 mm of water per day.

QUESTION

Estimate the water needs of citrus, bananas, onions, cucumber, clean cultivated apple trees and millet for an area where the water need of standard grass is 6.0 mm/day.

ANSWER

Citrus:	-30% (compared to grass); thus the water need of citrus is 6.0 - 30% = 6.0 -1.8 = 4.2 mm/day
Bananas:	+20%; thus the water need of bananas is 6.0 + 20% = 6.0 + 1.2 = 7.2 mm/day
Onions:	same as grass; thus the water need of onions is 6.0 mm/day
Cucumber:	-10%; thus the water need of onions is 6.0 - 10% =6.0-0.6 =5.4 mm/day
Apples (clean):	same as grass; thus the water need of clean cultivated apples is 6.0 mm/day

	If the apples have a cover crop in between the trees, the water need would be 20% higher than grass and thus: 6.0 + 20% = 6.0+1.2 = 7.2 mm/day.
Millet:	+10%; thus the water need of millet is 6.0 + 10% =6.0+0.6 = 6.6 mm/day

2.2.2 Influence of Crop Type on the Seasonal Crop Water Needs

The crop type not only has an influence on the **daily water need** of a fully grown crop, i.e. the daily peak water need, but the crop type also has an influence on the duration of the total growing season of the crop, and thus on the **seasonal water need.**

Data on the duration of the total growing season of the various crops grown in an area can best be obtained locally. These data may be obtained from, for example, the seed supplier, the Extension Service, the Irrigation Department or Ministry of Agriculture.

The duration of the total growing season has an enormous influence on the seasonal crop water need. There are, for example, many rice varieties, some with a short growing cycle (e.g. 90 days) and others with a long growing cycle (e.g. 150 days). This has a strong influence on the seasonal rice water needs: a rice crop which is in the field for 150 days will need in total much more water than a rice crop which is only in the field for 90 days. Of course, for the two rice crops the **daily** peak water need may still be the same, but the 150 day crop will need this daily amount for a longer period. The time of the year during which crops are grown is also very important. A certain crop variety grown during the cooler months will need substantially less water than the same crop variety grown during the hotter months.

Table 4 gives some Indicative values or approximate values for the duration of the total growing season for the various field crops. It should, however, be noted that these values are only rough approximations and it is much better to obtain the values locally.

Table 4 INDICATIVE VALUES OF THE TOTAL GROWING PERIOD

Crop	Total growing period (days)	Crop	Total growing period (days)
Alfalfa	100-365	Millet	105-140
Banana	300-365	Onion green	70-95
Barley/Oats/Wheat	120-150	Onion dry	150-210
Bean green	75-90	Peanut/Groundnut	130-140
Bean dry	95-110	Pea	90-100
Cabbage	120-140	Pepper	120-210
Carrot	100-150	Potato	105-145
Citrus	240-365	Radish	35-45
Cotton	180-195	Rice	90-150
Cucumber	105-130	Sorghum	120-130
Eggplant	130-140	Soybean	135-150
Flax	150-220	Spinach	60-100
Grain/small	150-165.	Squash	95-120
Lentil	150-170	Sugarbeet	160-230

Lettuce	75-140	Sugarcane	270-365
Maize sweet	80-110	Sunflower	125-130
Maize grain	125-180	Tobacco	130-160
Melon	120-160	Tomato	135-180

As can be seen from Table 4 there is a large variation of values not only between crops, but also within one crop type. In general it can be assumed that the growing period for a certain crop is longer when the climate is cool and shorter when the climate is warm.

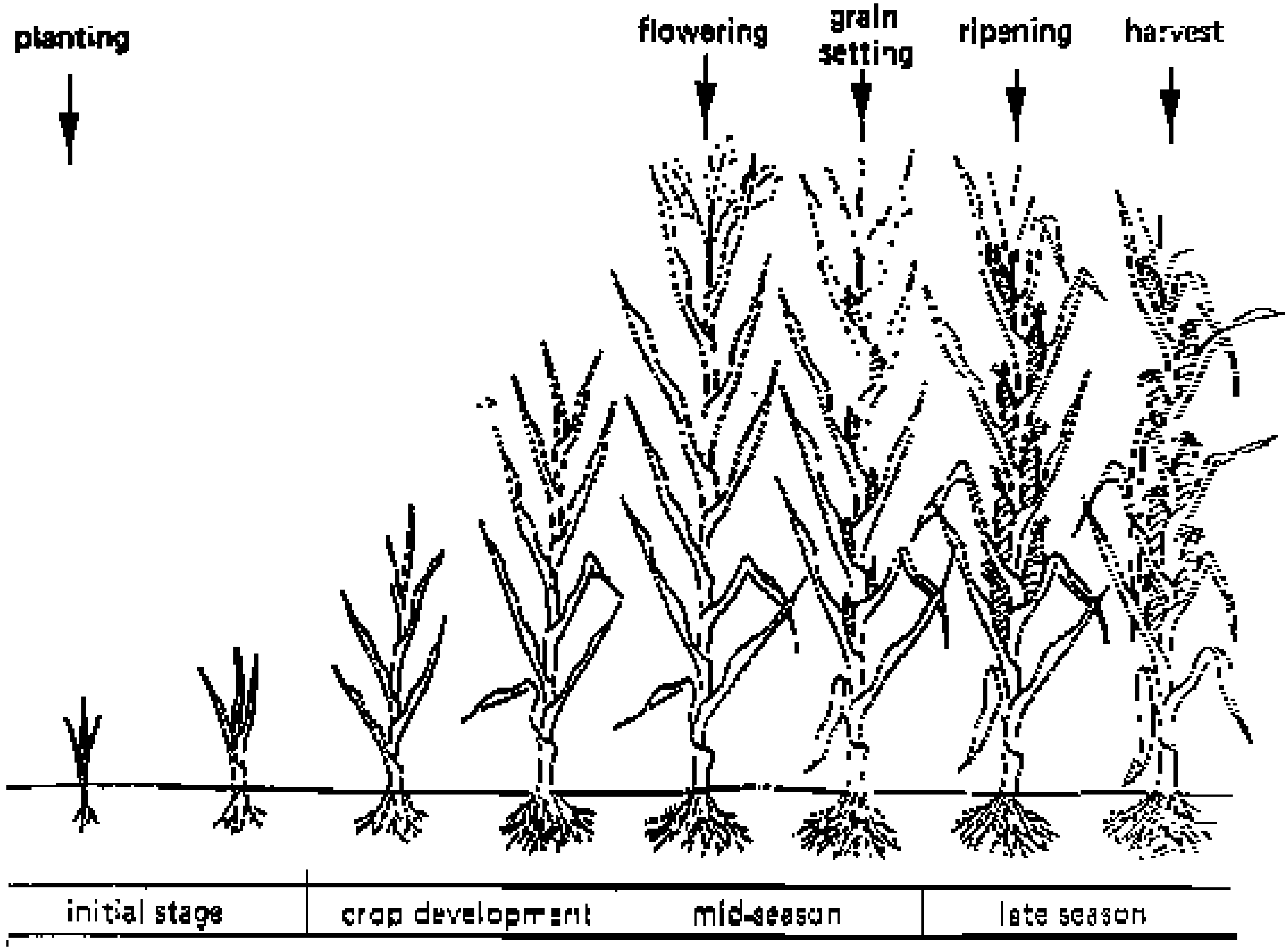
2.3 INFLUENCE OF THE GROWTH STAGE OF THE CROP ON CROP WATER NEEDS

A fully grown maize crop will need more water than a maize crop which has just been planted.

As has been discussed before, the crop water need or crop evapotranspiration consists of transpiration by the plant and evaporation from the soil and plant surface. When the plants are very small the evaporation will be more important than the transpiration. When the plants are fully grown the transpiration is more important than the evaporation.

Figure 8 shows in a schematic way the various development or growth stages of a crop.

Fig. 8 Growth stages of a crop



At planting and during the initial stage, the evaporation is more important than the transpiration and the evapotranspiration or crop water need during the initial stage is estimated at 50 percent of the crop water need during the mid - season stage, when the crop is fully developed.

During the so-called crop development stage the crop water need gradually Increases from 50 percent of the maximum crop water need to the maximum crop water need. The maximum crop water need is reached at the end of the crop development stage which is the beginning of the mid-season stage.

With respect to the late season stage, which is the period during which the crop ripens and is harvested, a distinction can be made between two groups of crops:

> **Fresh harvested crops:** such as lettuce, cabbage, etc. With these crops the crop water need remains the same during the late season stage as it was during the mid-season stage. The crops are harvested fresh and thus need water up to the last moment.
>
> **Dry harvested crops:** such as cotton, maize (for grain production), sunflower, etc. During the late season stage these crops are allowed to dry out and sometimes even die. Thus their water needs during the late season stage are minimal. If the crop is indeed allowed to die, the water needs are only some 25 percent of the crop water need during the mid-season or peak period. Of course, no irrigation is given to these crops during the late season stage.

2.4 DETERMINATION OF CROP WATER NEEDS

In the previous sections it has been explained on which factors - the climate, the crop type and the growth stage - the crop water need depends.

To calculate the water needs for the various months during which the crop is grown is fairly complicated and explained in Part II of this manual.

As stated before, it is often possible to obtain data on crop water needs locally and it is thus not necessary to calculate them. However, to give the reader some idea on values of seasonal water needs for the most important field crops. Table 5 can be used as a guide.

Table 5 APPROXIMATE VALUES OF SEASONAL CROP WATER NEEDS

Crop	Crop water need (mm/total growing period)
Alfalfa	800-1600
Banana	1200-2200
Barley/Oats/Wheat	450-650
Bean	300-500
Cabbage	350-500
Citrus	900-1200
Cotton	700-1300
Maize	500-800
Melon	400-600
Onion	350-550
Peanut	500-700
Pea	350-500
Pepper	600-900
Potato	500-700
Rice (paddy)	450-700
Sorghum/Millet	450-650
Soybean	450-700
Sugarbeet	550-750
Sugarcane	1500-2500
Sunflower	600-1000
Tomato	400-800

CHAPTER 3: EFFECTIVE RAINFALL

Apart from soil, air and sunlight, crops need water to grow. How much water the various crops need has been explained in Chapter 2.

This water can be supplied to the crops by rainfall (also called precipitation), by irrigation or by a combination of rainfall and irrigation.

If the rainfall is sufficient to cover the water needs of the crops, irrigation is not required.

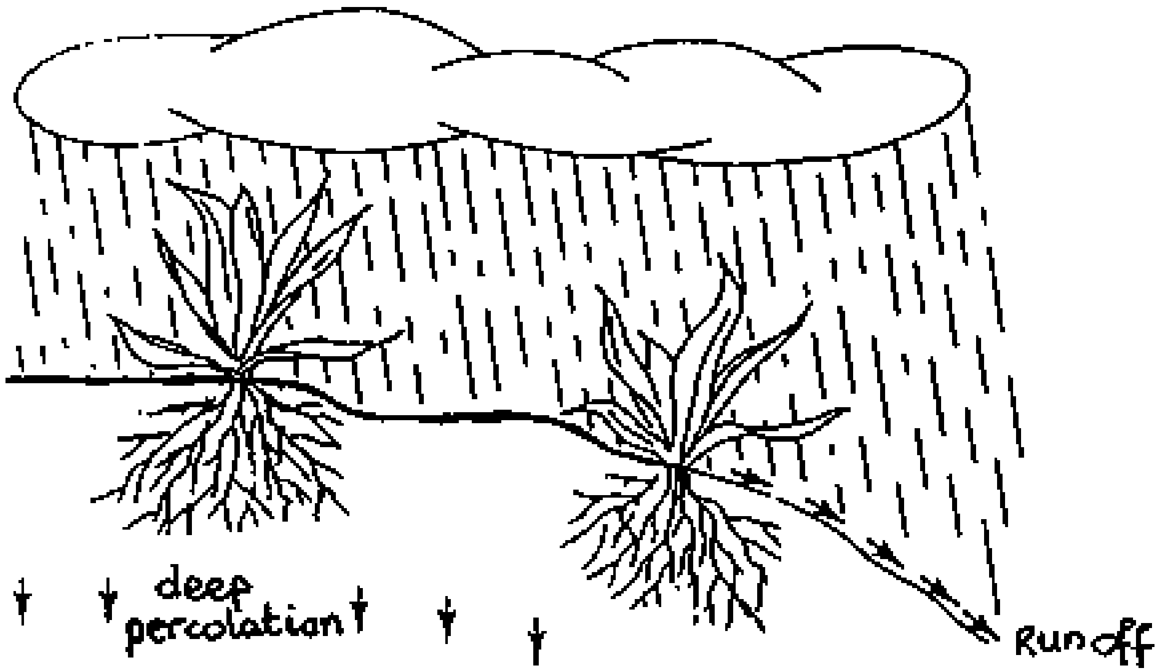
If there is no rainfall, all the water that the crops need has to be supplied by irrigation.

If there is some rainfall, but not enough to cover the water needs of the crops, irrigation water has to supplement the rain water in such a way that the rain water and the irrigation water together cover the water needs of the crop. This is often called **supplemental irrigation:** the irrigation water supplements or adds to the rain water.

As has already been explained in Volume 1, section 4.1.4, not all rain water which falls on the soil surface can indeed by used by the plants.

Part of the rain water percolates below the root zone of the plants and part of the rain water flows away over the soil surface as run-off (Fig. 9). This deep percolation water and run-off water cannot be used by the plants. In other words, part of the rainfall is **not effective.** The remaining part is stored in the root zone and can be used by the plants. This remaining part is the so-called **effective** rainfall. The factors which influence which part is effective and which part is not effective include the climate, the soil texture, the soil structure and the depth of the root zone. These factors have been discussed in some detail in Volume 1, section 4.1.4.

Fig. 9 Part of the rain water is lost through deep percolation and run-off



If the rainfall is high, a relatively large part of the water is lost through deep percolation and run-off.

Deep percolation: If the soil is still wet when the next rain occurs, the soil will simply not be able to store more water, and the rain water will thus percolate below the root zone and eventually reach the groundwater. Heavy rainfall may cause the groundwater table to rise temporarily.

Run-off: Especially in sloping areas, heavy rainfall will result in a large percentage of the rainwater being lost by surface run-off.

Another factor which needs to be taken into account when estimating the effective rainfall is the variation of the rainfall over the years. Especially in low rainfall climates, the little rain that falls is often unreliable; one year may be relatively dry and another year may be relatively wet.

In many countries, formulae have been developed locally to determine the effective precipitation. Such formulae take into account factors like rainfall reliability, topography, prevailing soil type etc. If such formulae or other local data are available, they should be used.

If such data are not available. Table 6 could be used to obtain a rough estimate of the effective rainfall.

Table 6 RAINFALL OR PRECIPITATION (P) AND EFFECTIVE RAINFALL OR EFFECTIVE PRECIPITATION (Pe) in mm/month

P (mm/month)	Pe (mm/month)	P (mm/month)	Pe (mm/month)
0	0	130	79
10	0	140	87
20	2	150	95
30	8	160	103
40	14	170	111
50	20	180	119

60	26	190	127
70	32	200	135
80	39	210	143
90	47	220	151
100	55	230	159
110	63	240	167
120	71	250	175

EXAMPLE

Estimate the effective rainfall in mm/month if the rainfall is 60 mm/month. From Table 6 it can be seen that the effective rainfall is 26 mm/month. This means that out of 60 mm/month, some 26 mm can be used by the plants; and it is estimated that the remaining (60 - 26 =) 34 mm is lost through deep percolation and run-off.

QUESTION

Determine the effective rainfall for the following monthly rainfall figures: 65, 210, 175 and 5 mm.

ANSWER (see Table 6)

P (mm/month)	Pe (mm/month)
65	29
210	143
175	115
5	0

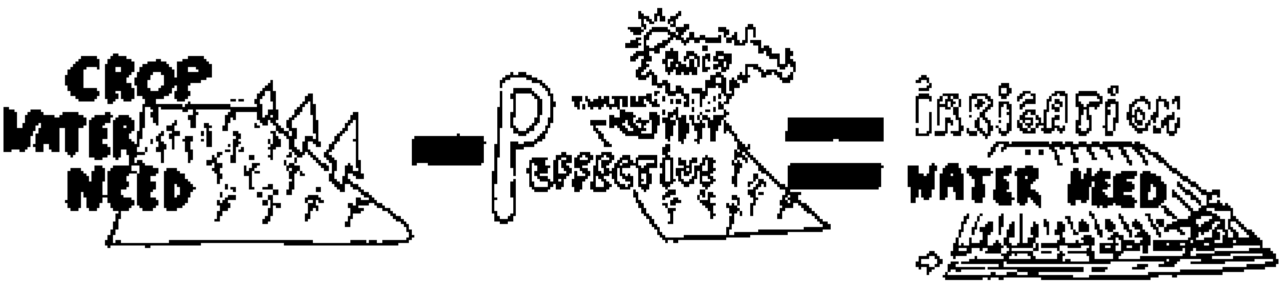
CHAPTER 4: IRRIGATION WATER NEEDS

The irrigation water need of a certain crop is the difference between the crop water need and that part of the rainfall which can be used by the crop (the effective rainfall).

For each of the crops grown on an irrigation scheme the crop water need is determined, usually on a monthly basis; the crop water need is expressed in mm water layer per time unit, in this case mm/month.

The effective precipitation is estimated on a monthly basis, using measured rainfall data and Table 6 (or local information, if available).

For all crops and for each month of the growing season, the irrigation water need is calculated by subtracting the effective rainfall from the crop water need.



<u>EXAMPLE</u>

Suppose a tomato crop grown in a certain area has a total growing season of 150 days and the following monthly crop water needs:

	Feb	Mar	Apr	May	June	Total
Crop water need (mm/month)	69	123	180	234	180	786

This means that in February the tomatoes need 69 mm of water, in March 123 mm of water, etc. The water need of tomatoes over the total growing season (February-June: 150 days) is 786 mm.

Suppose the following rainfall data for the area where the tomatoes are grown have been obtained from the Meteorological Service or Ministry of Agriculture.

	Feb	Mar	Apr	May	June	Total
Rainfall: P (mm/month)	20	38	40	80	16	194

This means that the average rainfall for February is 20 mm, for March 38 mm, etc. The rainfall over the total growing season of tomatoes (February-June: 150 days) is 194 mm.

Only part of this rainfall is effective, and the effective rainfall is estimated using Table 6.

	Feb	Mar	Apr	May	June	Total
Rainfall: P (mm/month)	20	38	40	80	16	194
Effective rainfall: Pe (mm/month)	2	13	14	39	0	68

This means that the effective rainfall during February is only 2 mm, during April 13 mm, etc. The effective rainfall during the total growing season of tomatoes (February-June: 150 days) is 68 mm.

Now the Irrigation water need for the tomatoes can be calculated on a monthly basis, as follows:

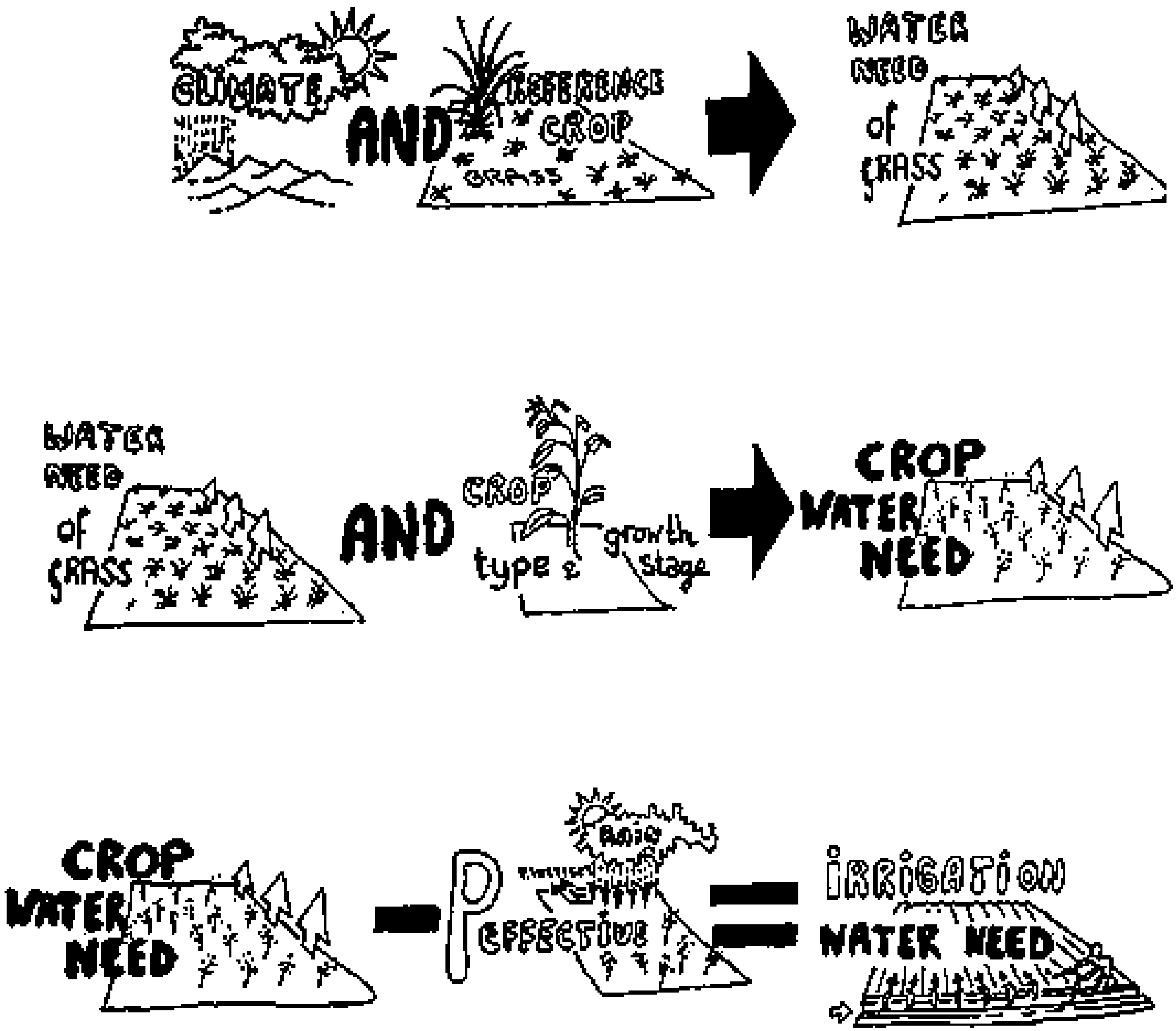
	Feb	**Mar**	**Apr**	**May**	**June**	**Total**
Crop water need (mm/month)	69	123	180	234	180	786
Effective rainfall: Pe (mm/month)	2	13	14	39	0	68
Irrigation water need (mm/month)	67	110	166	195	180	718

Looking at the example for the month March, it can be seen that tomatoes need 123 mm during March. Of this 123 mm, 13 mm is supplied by the rainfall. The remaining (123 -13 =) 110 mm have to be supplied by irrigation. The total water need of tomatoes over the entire growing season is 786 mm of which 68 mm is supplied by rainfall. The remaining quantity (786 - 68 = 718 mm) has to be supplied by irrigation.

When looking at the calculations above, it is obvious that the month May is the month of peak irrigation water need (195 mm Irrigation water in May). If the tomatoes would be the only crop grown on the Irrigation scheme, the canals would have to be designed in such a way that they allow a flow large enough to supply indeed a net water layer of 195 mm to the whole area covered by tomatoes during the month May. In other words, for designing an irrigation scheme, the month of peak water supply is the critical month.

How to go about determining the scheme irrigation water supply and how to divide the irrigation water between the various crops and fields will be dealt with in Volume 4 of the Irrigation Water Management Training Manuals.

In Summary:


CLIMATE
AND
REFERENCE CROP
GRASS
WATER NEED of GRASS
WATER NEED of GRASS
AND
CROP
type & growth stage
CROP WATER NEED
CROP WATER NEED
P EFFECTIVE
IRRIGATION
WATER NEED

CHAPTER 1: INTRODUCTION

Part II of this manual describes how the water needs of the various crops, grown on an irrigation scheme, can be calculated.

The **crop water need,** or in other words the amount of water needed by a certain crop to grow optimally, mainly depends on:

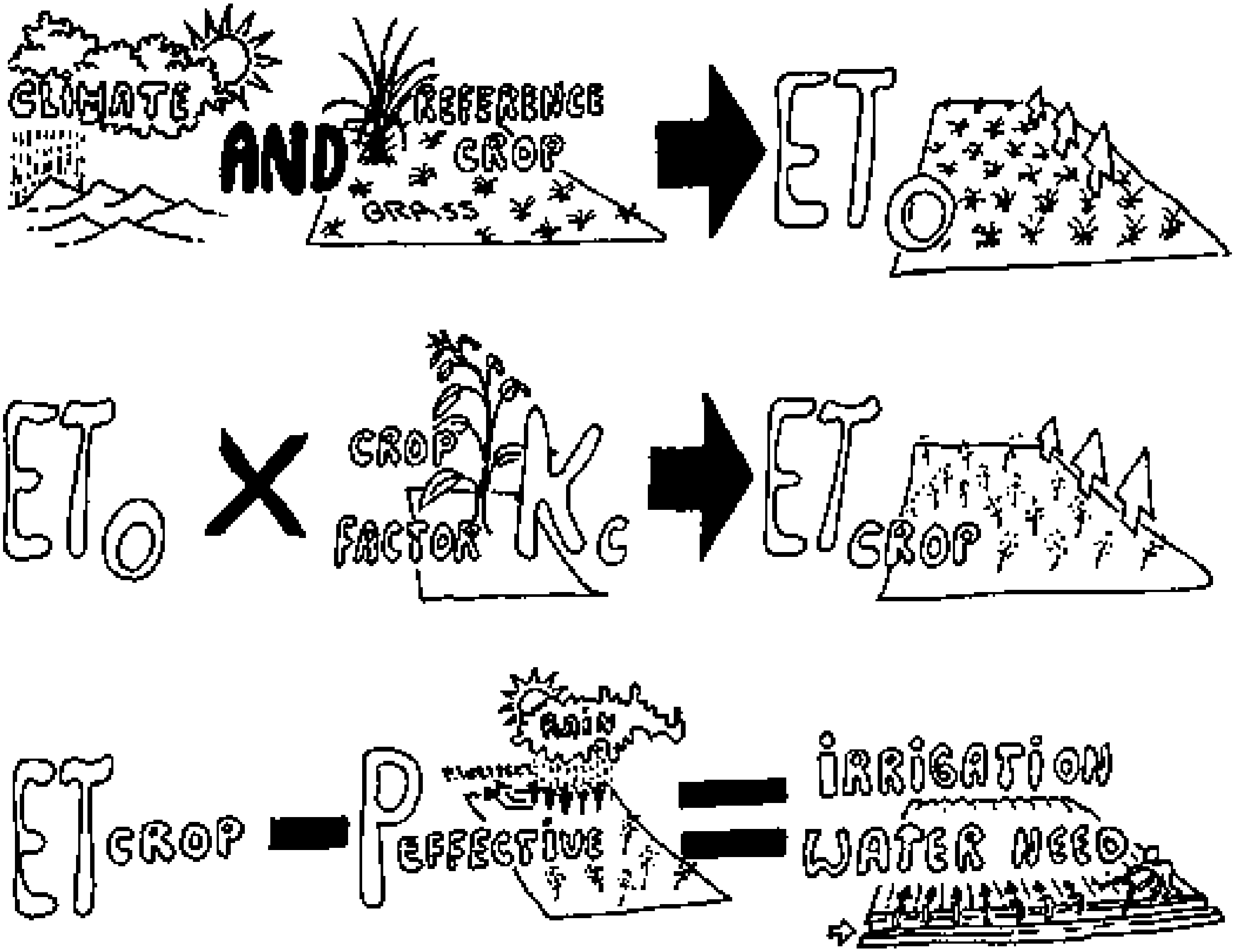
- the climate: in a sunny and hot climate crops need more water per day than in a clouded and cool climate
- the crop type: crops like rice or sugarcane need more water than crops like beans or wheat
- the growth stage of the crop: fully grown crops need more water than crops that have just been planted.

The amount of water needed can be supplied to the crops by rainfall, by irrigation, or by a combination of both. Usually the irrigation water supplements or adds to the rainwater. Only in desert or arid areas - or in the dry season - will all the water needed by the crops have to be supplied by irrigation.

The **irrigation water** need is the difference between the crop water need and that part of the rainfall which can be used by the plants (effective rainfall). The irrigation water need calculation provides the basis for the determination of the irrigation schedule (usually by agronomists) and the design of the irrigation scheme, e.g. canal dimensions (usually by engineers). An overview of all the subjects that are dealt with in this manual is given.

Fig. 1 Irrigating maize

Overview of the determination of the reference crop evapotranspiration (ETo), the crop water need (ET crop) and the irrigation water need


CLIMATE
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WATER NEED

CHAPTER 2: CLIMATE AND CROP GROWTH

2.1 MAJOR CLIMATIC ZONES

The major climatic factor which influences crop growth is rainfall. In areas with little rainfall the natural vegetation is limited, while in areas with high annual rainfall dense tropical rain forests are found.

Based on the annual rainfall, a distinction can be made between 6 major climatic zones as is shown in Table 1. Figure 2 indicates, as an example, the major climatic zones of Africa.

Table 1 MAJOR CLIMATIC ZONES

Climatic Zone	Annual Rainfall (mm)	Wet period (months)	Vegetation
Desert	less than 100	0-1	Little or no vegetation
Arid	100-400	1-3	Some scrubs, some grassland
Semi-arid	400-600	3-4	Scrubs & bushes, grassland
Sub - humid	600-1200	4-6	Bushes to woodland, grassland
Moist sub-humid	1200-1500	6-9	Forest and woodland
Humid	more than 1500	9-12	Tropical rain forest

The wet period (see Table 1) refers to the period during which the rainfall is higher than the evapotranspiration. Evapotranspiration is the sum of the evaporation from the soil surface and the transpiration by the plants (see Volume 1, Chapter 4).

Fig. 2 Major climatic zones of Africa

Desert and arid areas

In desert and arid areas irrigation is absolutely essential for crop growth. In these areas the wet period is maximum 3 months. Even when some water is stored in the root zone during the wet period and used later by the plants, it is still not enough to obtain a good harvest. In addition the rainfall is unreliable in desert and arid regions: one year there is a lot of rainfall, the next year there may be only a little. On top of that, the rainfall usually comes in heavy showers resulting in high water losses due to runoff.

Fig. 3a Rainfall and irrigation in desert and arid areas

Semi arid areas

Even in the semi-arid areas irrigation is indispensable for a reliable and good harvest. Some drought resistant crops such as sorghum and millet may give reasonable yields, but also here is a risk of unreliable rainfall and subsequent crop failure.

Fig. 3b Rainfall and irrigation in semi-arid areas

Sub-humid and moist sub-humid areas

In the sub-humid and moist sub-humid areas, irrigation is required only during the dry season. In principle, on a yearly basis there is a rainfall excess: the yearly rainfall is higher than the yearly evapotranspiration. During the rainy season it may even be too wet for crops like sorghum and millet.

Fig. 3c Rainfall and irrigation in sub-humid and moist sub-humid areas

Humid areas

In the humid areas irrigation is usually not required, except maybe for paddy rice (see section 4.4). During more than 9 months per year there is excess rainfall and even in the remaining drier months the plants may use water which has been stored in the root zone during the rainy season.

Fig. 3d Rainfall In humid areas

2.2 MAJOR CROP ZONES

Crop growth depends not only on rainfall, but also on other climatic factors (most notably sunshine and temperature) and non-climatic factors such as the availability of suitable soils.

During some periods of the year (the cool season) or at high altitudes (i.e. in mountainous areas) crop growth may be prohibited by the low temperature. Other areas may not be suitable for certain crops due to high temperatures.

Table 2 provides, as an example, data on land use, i.e. the most important crops grown in the 6 major climatic zones of Africa.

Table 2 MAJOR CLIMATIC ZONES AND LAND USE IN AFRICA

Climatic Zone	Land Use (Major Crops)
Desert	Hunters and gatherers, nomadic pastoralists, sedentary irrigators around oases, no rainfed agriculture.
Arid	Extensive grazing (nomadic pastoralists), some millet and sorghum under flood irrigation in moist depressions.
Semi-arid	Both nomadic pastoralists and cultivators. Mainly millet and sorghum, also short cycle cowpea, phaseolus beans and groundnuts. No fodder or sown pasture. In cooler parts maize.

Sub-humid	Traditional nomadic pastoralists in dry season and drought years. Crops grown by settlers: millet, sorghum, maize, groundnuts; also cassava, cowpeas, cotton, sweet potatoes, tobacco, rainfed rice, soybean, mango, cashewnuts. Fodder and sown pasture possible.
Moist sub-humid	Transition zone for agriculture: too wet for seasonal crops, too dry for tree crops. Tropics: maize, cassava; also yams, bananas, pineapple, sugarcane and rice. Winter rainfall areas and East African highlands: wheat and barley.
Humid	Tree crops: oilpalm, rubber, cacao; shifting cultivation based on root crops (yams, cassava, etc.). Also some sorghum, maize, banana, sugarcane, rice. Some tropical hard woods.

CHAPTER 3: CROP WATER NEEDS

The crop water need (ET crop) is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally.

The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favourable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The crop water need mainly depends on:

- the climate: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate
- the crop type: crops like maize or sugarcane need more water than crops like millet or sorghum
- the growth stage of the crop; fully grown crops need more water than crops that have just been planted.

Section 3.1 indicates the influence of the climate on crop water needs: this influence is given by the reference crop evapotranspiration (ETo). Section 3.2 indicates the influence of the crop type and growth stage on crop water needs: the influence of the crop is expressed in the crop factor (Kc).

3.1 INFLUENCE OF CLIMATE ON CROP WATER NEEDS (ETo)

3.1.1 Introduction

The major climatic factors (see Fig. 4) which influence the crop water needs are:

- sunshine
- temperature
- humidity
- windspeed

Fig. 4 Major climatic factors influencing crop water needs

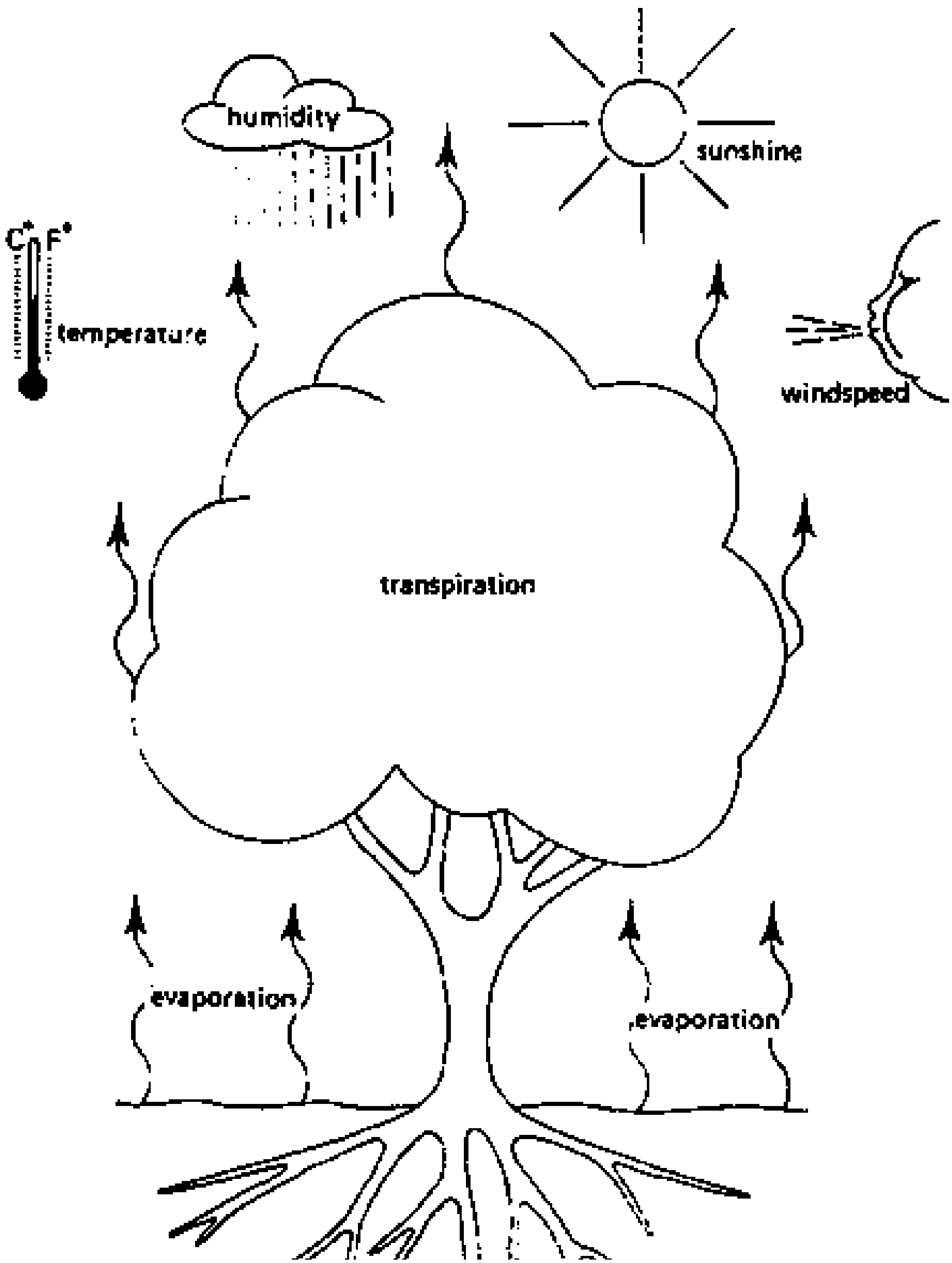


Table 3 indicates the effect of the various climatic factors on crop water needs.

Table 3 EFFECT OF MAJOR CLIMATIC FACTORS ON CROP WATER NEEDS

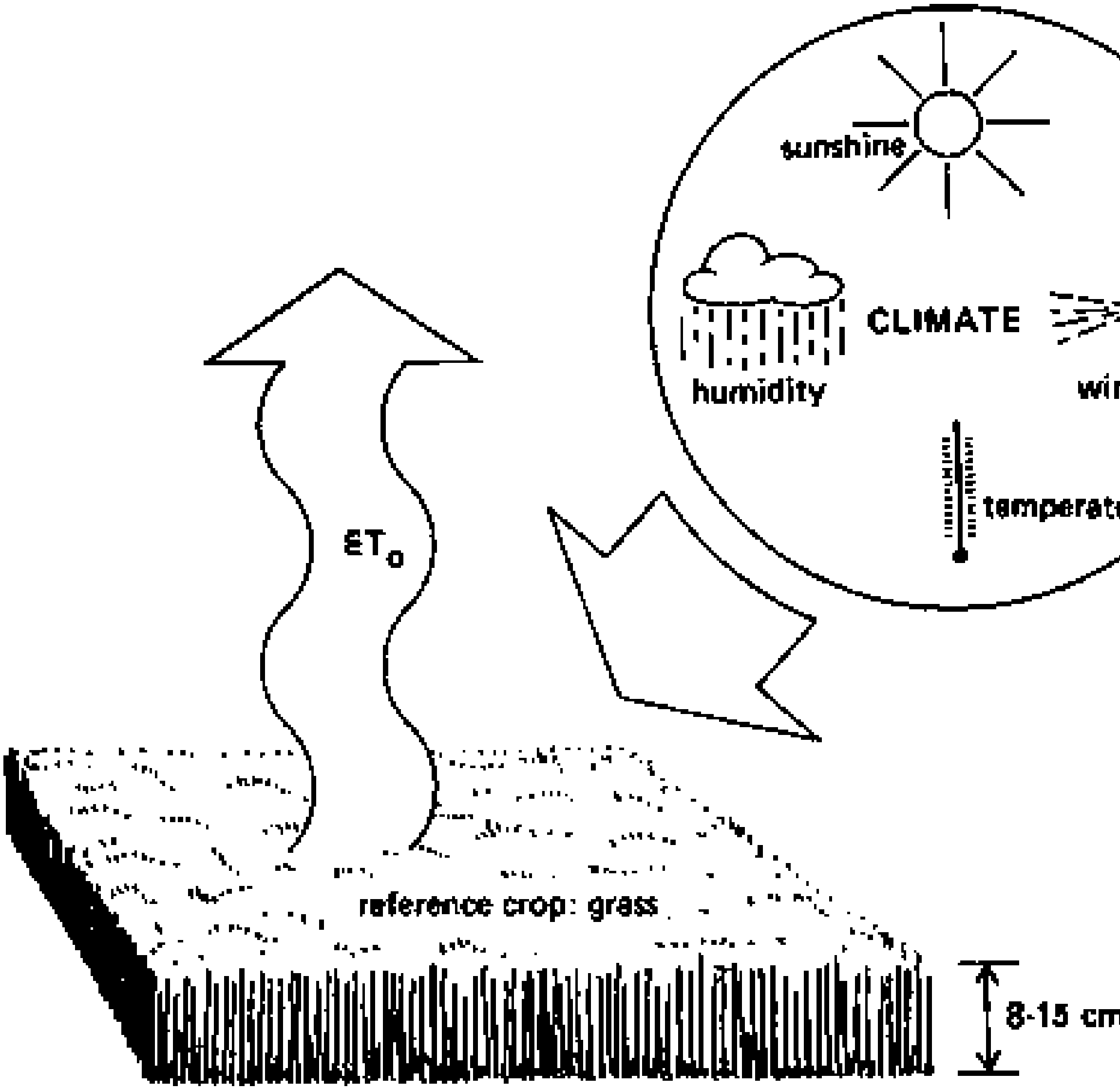
Climatic Factor	Crop water need	
	High	**Low**
Temperature	hot	cool
Humidity	low (dry)	high (humid)
Windspeed	windy	little wind
Sunshine	sunny (no clouds)	cloudy (no sun)

The highest crop water needs are thus found in areas which are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind.

The influence of the climate on crop water needs is given by the **reference crop evapotranspiration** (ETo). The ETo is usually expressed in millimetres per unit of time, e.g. mm/day, mm/month, or mm/season. Grass has been taken as the reference crop.

Definition of the reference crop evapotranspiration (ETo):
ETo is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water (see Fig. 5).

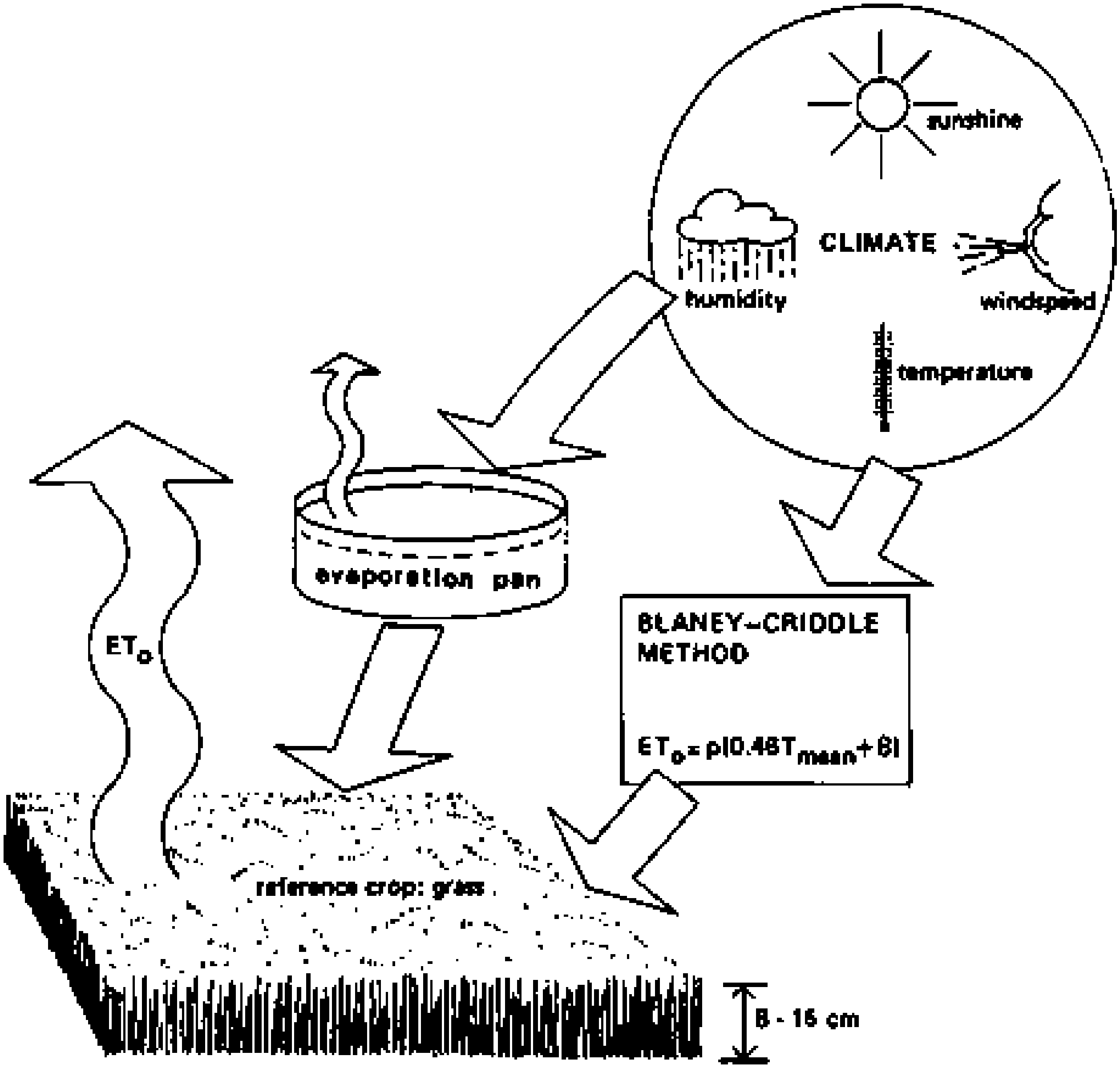
Fig. 5 Reference crop evapotranspiration



There are several methods to determine the ETo (see Fig. 6). They are either:

- experimental, using an evaporation pan, or
- theoretical, using measured climatic data, e.g. the Blaney-Criddle method

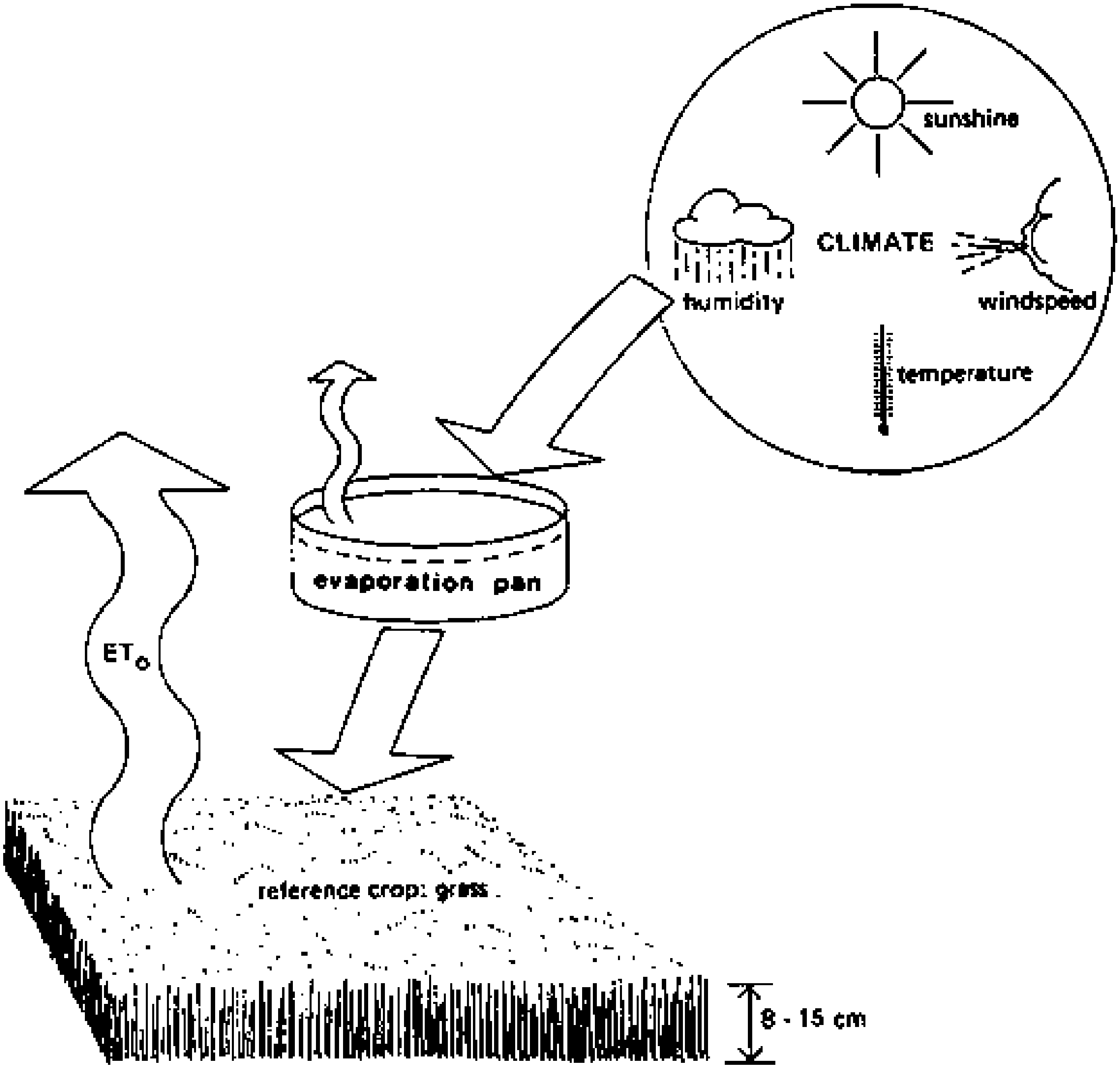
Fig. 6 Methods to determine reference crop evapotranspiration



3.1.2 Pan Evaporation Method

Evaporation pans provide a measurement of the combined effect of temperature, humidity, windspeed and sunshine on the reference crop evapotranspiration ETo (see Fig. 7).

Fig. 7 Pan evaporation method



Many different types of evaporation pans are being used. The best known pans are the Class A evaporation pan (circular pan) (Fig. 8a) and the Sunken Colorado pan (square pan) (Pig. 8b).

Fig. 8a Class A evaporation pan

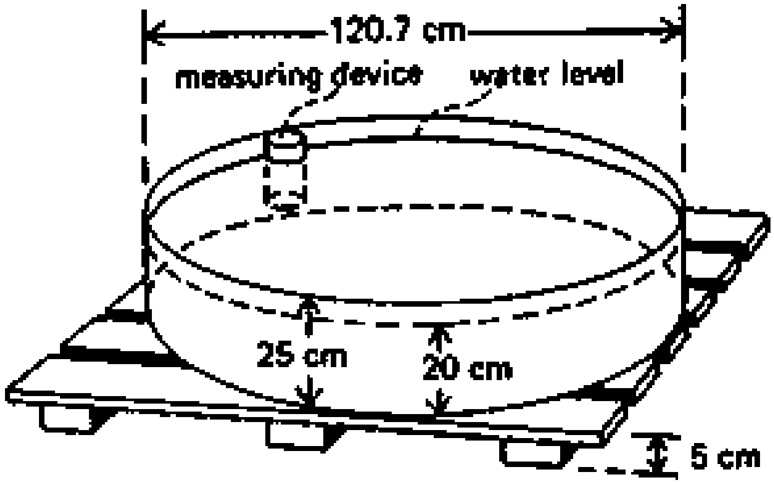
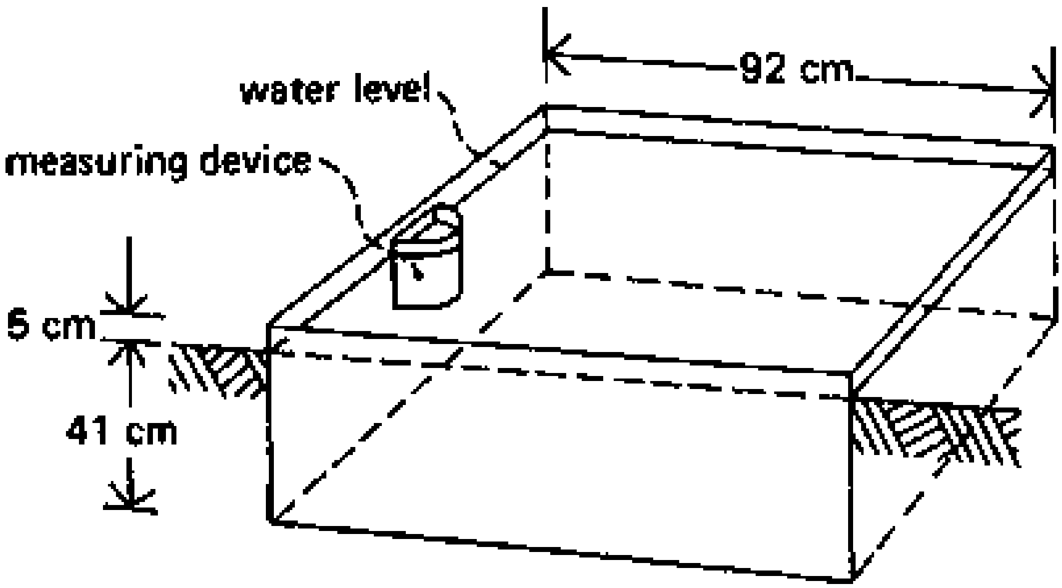


Fig. 8b Sunken Colorado pan



The principle of the evaporation pan is the following:

- the pan is installed in the field
- the pan is filled with a known quantity of water (the surface area of the pan is known and the water depth is measured)
- the water is allowed to evaporate during a certain period of time (usually 24 hours). For example, each morning at 7 o'clock a measurement is taken. The rainfall, if any, is measured simultaneously
- after 24 hours, the remaining quantity of water (i.e. water depth) is measured
- the amount of evaporation per time unit (the difference between the two measured water depths) is calculated; this is the pan evaporation: E pan (in mm/24 hours)
- the E pan is multiplied by a pan coefficient, K pan, to obtain the ETo.

Formula: ETo = K pan × E pan

with:

> ETo: reference crop evapotranspiration
> K pan: pan coefficient
> E pan: pan evaporation

If the water depth in the pan drops too much (due to lack of rain), water is added (see Fig. 9a) and the water depth is measured before and after the water is added. If the water level rises too much (due to rain) water is taken out of the pan (see Fig. 9b) and the water depths before and after are measured.

Fig. 9a Add water when the water depth in the pan drops too much

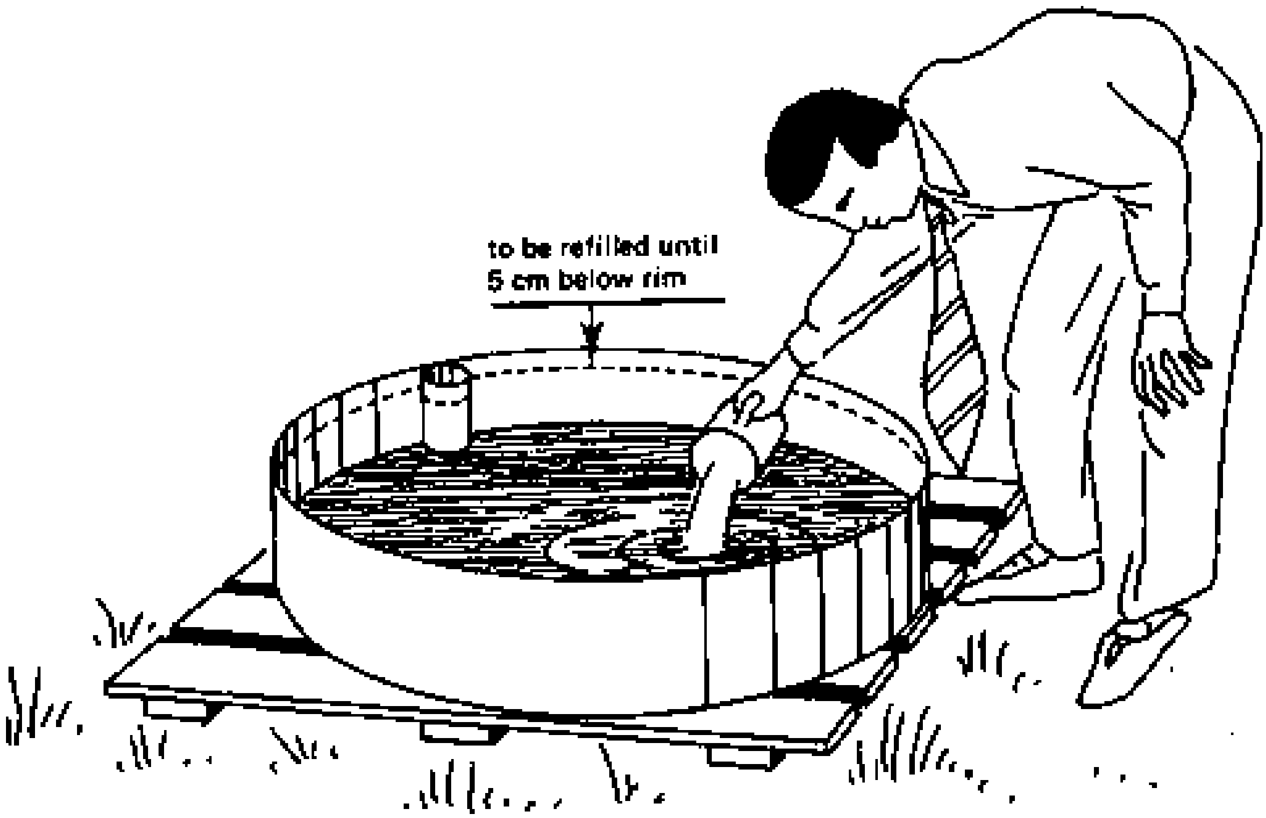
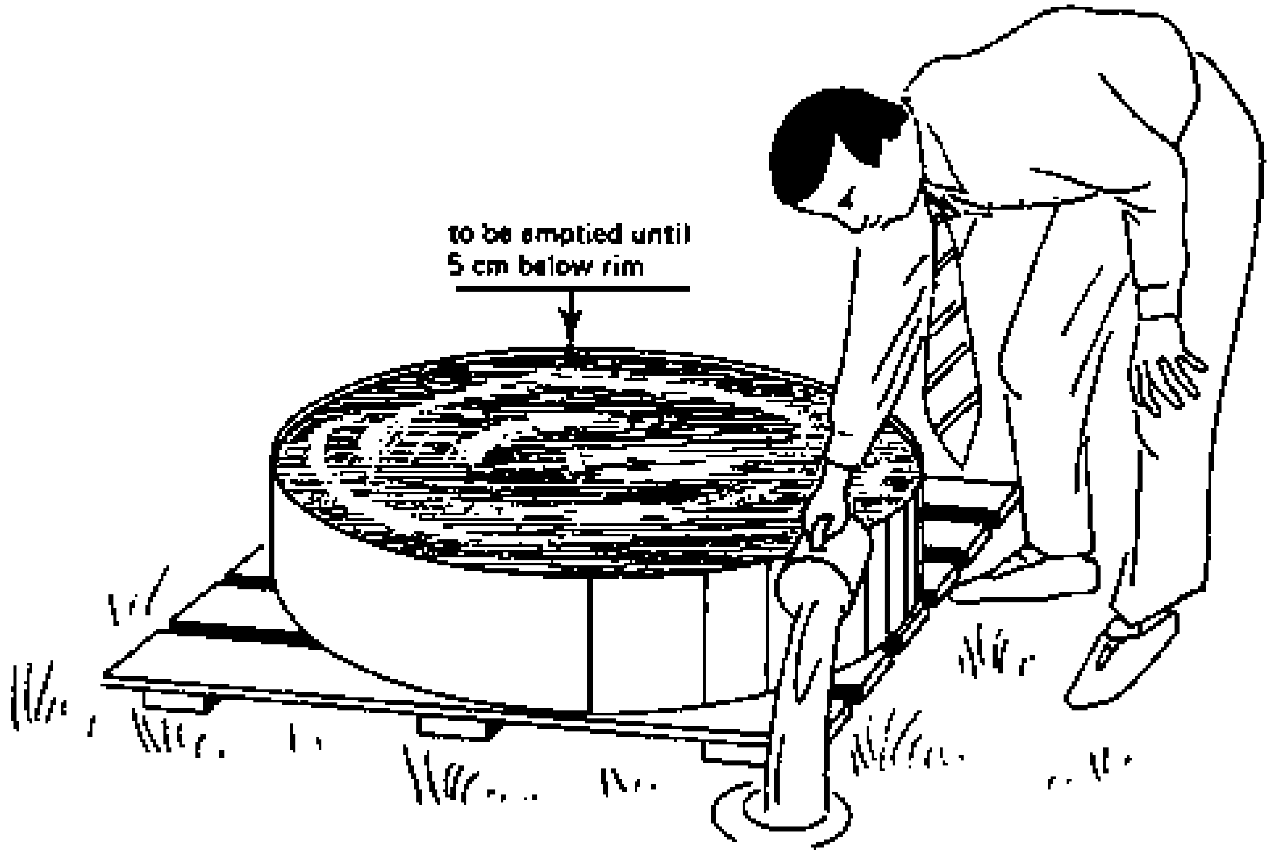


Fig. 9b Take water out of the pan when the water depth rises too much



Determination of K pan

When using the evaporation pan to estimate the ETo, in fact, a comparison is made between the evaporation from the water surface in the pan and the evapotranspiration of the standard grass. Of course the water in the pan and the grass do not react in exactly the same way to the climate. Therefore a special coefficient is used (K pan) to relate one to the other.

The pan coefficient, K pan, depends on:

- the type of pan used
- the pan environment: if the pan is placed in a fallow or cropped area
- the climate: the humidity and windspeed

For the Class A evaporation pan, the K pan varies between 0.35 and 0.85. Average K pan = 0.70.
For the Sunken Colorado pan, the K pan varies between 0.45 and 1.10. Average K pan = 0.80.

The K pan is high if:	**The K pan is low if:**
the pan is placed in a fallow area	the pan is placed in a cropped area
the humidity is high (i.e. humid)	the humidity is low (i.e. dry)
the windspeed is low	the windspeed is high

Details of the pan coefficient are usually provided by the supplier of the pan.

If the pan factor is not known the average value could be used (see box). If more accuracy is required, the pan factors given in Annex 1 should be applied. These values, however, only refer to the Class A evaporation pan and the Sunken Colorado pan.

Some examples

1) Type of pan: Class A evaporation pan
Water depth in pan on day 1 = 150 mm (see Fig. 10a)
Water depth in pan on day 2 = 144 mm (after 24 hours; see Fig. 10b)
Rainfall (during 24 hours) = 0 mm
K pan = 0.75

Formula: ETo = K pan × E pan

Calculation: E pan = 150 - 144 = 6 mm/day
ETo = 0.75 × 6 =4.5 mm/day

Fig. 10a Measuring the water depth on day 1*

Fig. 10b Measuring the water depth on day 2 (after 24 hours)*

* Measuring devices are usually more accurate than the ruler indicated in Fig. 10 and thus allow for more accurate readings (see Data Sheet 1).

2) Type of pan: Sunken Colorado pan
Water depth in pan on day 1 = 411 mm
Water depth in pan on day 2 = 409 mm (after 24 hours)
Rainfall (during 24 hours) = 7 mm
K pan = 0.90

Formula: ETo = K pan × E pan

Calculation: E pan = 411 - 409 + 7 = 9 mm/day
ETo = 0.90 × 9 = 8.1 mm/day

DATA SHEET 1 Determination ETo: Pan Evaporation Method

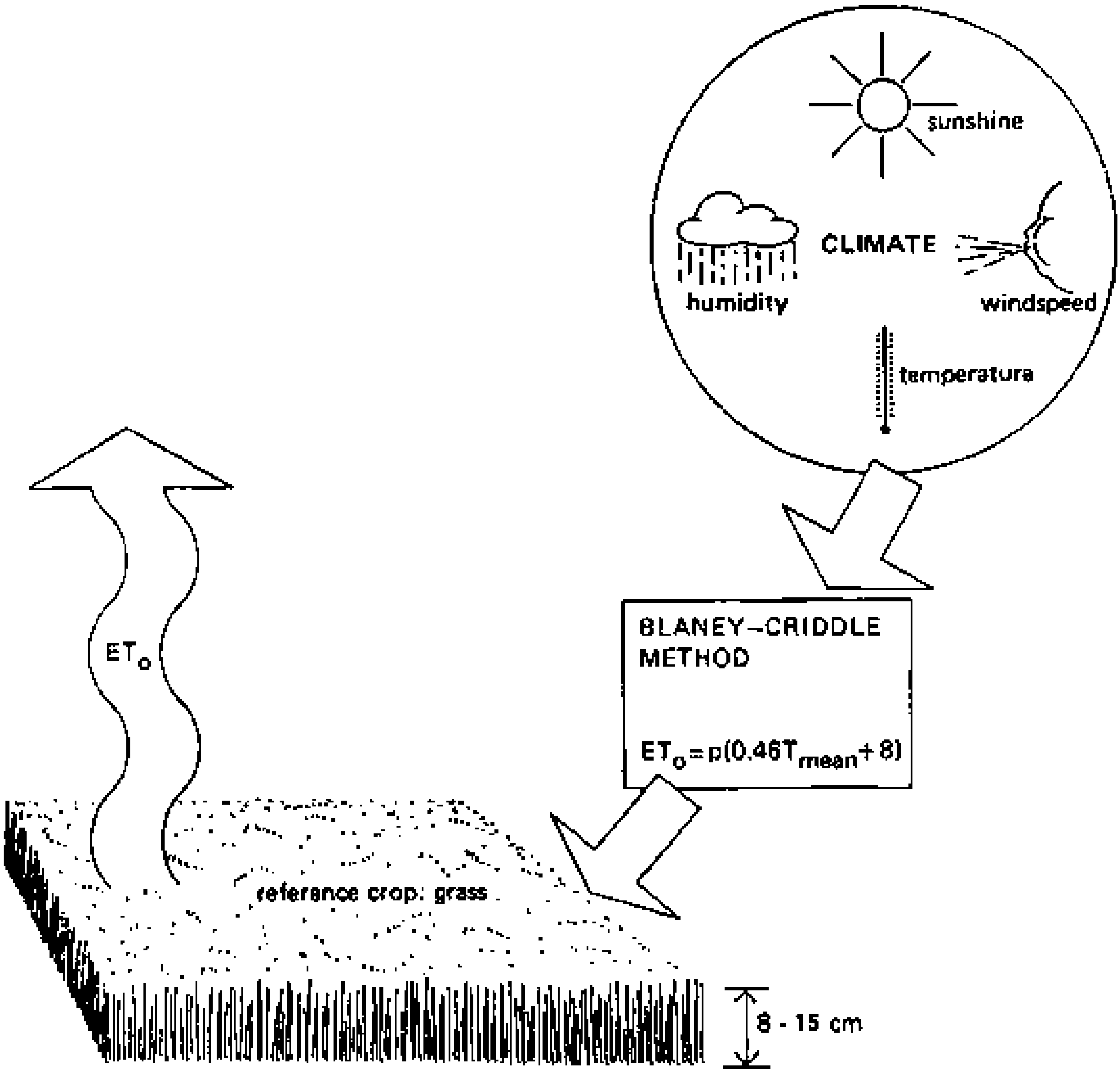
3.1.3 Blaney-Criddle Method

If no measured data on pan evaporation are available locally, a theoretical method (e.g. the Blaney-Criddle method) to calculate the reference crop evapotranspiration ETo has to be used. There are a large number of theoretical methods to determine the ETo. Many of them have been determined and tested locally. If such local formulae are available they should be used. If such local formulae are not available one of the general theoretical methods has to be used.

The most commonly used theoretical method is the modified Penman method which is described in detail in FAO Irrigation and Drainage Paper 24. This method, however, is rather complicated and beyond the scope of this manual.

Here only the Blaney-Criddle method is given. The Blaney-Criddle method is simple, using measured data on temperature only (see also Fig. 11). It should be noted, however, that this method is not very accurate; it provides a rough estimate or "order of magnitude" only. Especially under "extreme" climatic conditions the Blaney-Criddle method is inaccurate: in windy, dry, sunny areas, the ETo is underestimated (up to some 60 percent), while in calm, humid, clouded areas, the ETo is overestimated (up to some 40 percent).

Fig. 11 The Blaney-Criddle method



The Blaney-Criddle formula: ETo = p (0.46 T mean +8)

ETo = Reference crop evapotranspiration (mm/day) as an average for a period of 1 month
T mean = mean daily temperature (°C)
p = mean daily percentage of annual daytime hours

The use of the Blaney-Criddle formula

Step 1**: Determination of the mean daily temperature: T mean**

The Blaney-Criddle method always refers to mean **monthly** values, both for the temperature and the ETo. If, for example, it is found that T mean in March is 28°C, it means that during the whole month of March the mean daily temperature is 28°C.

If in a local meteorological station the daily minimum and maximum temperatures are measured, the mean daily temperature is calculated as follows:

$$T\ max = \frac{\text{sum of all T max values during the month}}{\text{number of days of the month}}$$

$$T\ min = \frac{\text{sum of all T min values during the month}}{\text{number of days of the month}}$$

$$T\ mean = \frac{T\ max + T\ min}{2}$$

Step 2: **Determination of the mean daily percentage of annual daytime hours: p**

To determine the value of p. Table 4 is used. To be able to determine the p value it is essential to know the approximate latitude of the area: the number of degrees north or south of the equator (see Fig. 12).

Suppose the p value for the month **March** has to be determined for an area with a latitude of 45° South. From Table 4 it can be seen that the p value during March = 0.28.

Fig. 12 The latitude

Table 4 MEAN DAILY PERCENTAGE (p) OF ANNUAL DAYTIME HOURS FOR DIFFERENT LATITUDES

Latitude	North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	South	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
60°		.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
55		.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
50		.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
45		.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
40		.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35		.23	.25	.27	.29	.31	.32	.32	.30	.28	.25	.23	.22
30		.24	.25	.27	.29	.31	.32	.31	.30	.28	.26	.24	.23
25		.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20		.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15		.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10		.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5		.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0		.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

Step 3**: Calculate ETo,** using the formula: ETo = p (0.46 T mean + 8)

For example, when p = 0.29 and T mean = 21.5°C the ETo is calculated as follows:

ETo = 0.29 (0.46 × 21.5 + 8) = 0.29 (9.89 + 8) = 0.29 × 17.89 = 5.2 mm/day

3.1.4 Calculation Example Blaney-Criddle

Given

Latitude - 35° North
Mean T max in April = 29.5°C
Mean T min in April = 19.4°C

Question

Determine for the month April the mean ETo in mm/day using the Blaney-Criddle method

Answer

Formula: ETo = p (0.46 T mean + 8)

Step 1: determine T mean: $$T\,mean = \frac{T\,max + Tmin}{2} = \frac{29.5 + 19.4}{2} = 24.5°C$$

Step 2: determine p: Latitude: 35° North
Month: April
From Table 4: p = 0.29

Step 3: calculate ETo: ETo = 0.29 (0.46 × 24.5 + 8) = 5.6 mm/day

Thus the mean reference crop evapotranspiration ETo =5.6 mm/day during the whole month of April.

3.1.5 Indicative Values of ETo

If only a rough estimate of the ETo value is required. Table 5 can be used.

Table 5 INDICATIVE VALUES OF ETo (mm/day)

	Mean daily temperature		
Climatic zone	**low (less than 15°C)**	**medium (15-25°C)**	**high (more than 25°C)**
Desert/arid	4-6	7-8	9-10
Semi arid	4-5	6-7	8-9
(Moist) Sub-humid	3-4	5-6	7-8
Humid	1-2	3-4	5-6

DATA SHEET 2 Calculation of the mean monthly temperature: T max and T min

DATA SHEET 3 Determination ETo: Blaney-Criddle Method

Location: EXAMPLE... Date: 1/8/86...

Latitude: ....13..... °North/~~South~~

Month	T min (°C)	T max (°C)	T mean (°C)	p Table 4	ETo mm/day
Jan	15.5	32.1	23.8	0.26	4.9
Feb	18.8	35.8	27.3	0.26	5.3
Mar	21.8	38.0	29.9	0.27	5.9
Apr	24.5	38.7	31.6	0.28	6.3
May	26.0	39.0	32.5	0.29	6.7
Jun	25.0	36.6	30.8	0.29	6.4
Jul	22.7	32.6	27.6	0.29	6.0
Aug	22.0	30.8	26.4	0.28	5.6
Sep	23.0	31.8	27.4	0.28	5.8
Oct	21.3	34.8	28.0	0.27	5.6
Nov	18.7	35.0	26.8	0.26	5.3
Dec	16.6	32.0	24.3	0.25	4.8

Note:

$$T\ mean = \frac{T\ max + T\ min}{2}$$

ETo = p (0.46 T mean +8)

3.2 INFLUENCE OF CROP TYPE ON CROP WATER NEEDS (Kc)

3.2.1 Introduction

In section 3.1 the influence of the climate on crop water needs has been discussed. The influence of the climate is given by the reference crop evapotranspiration ETo; the reference crop used for this purpose is grass (see Fig. 13a).

Fig. 13a Reference crop evapotranspiration

This section (3.2) deals with the influence of the crop type and growth stage on crop water needs. In other words, this section discusses the relationship between the reference grass crop and the crop actually grown in the field.

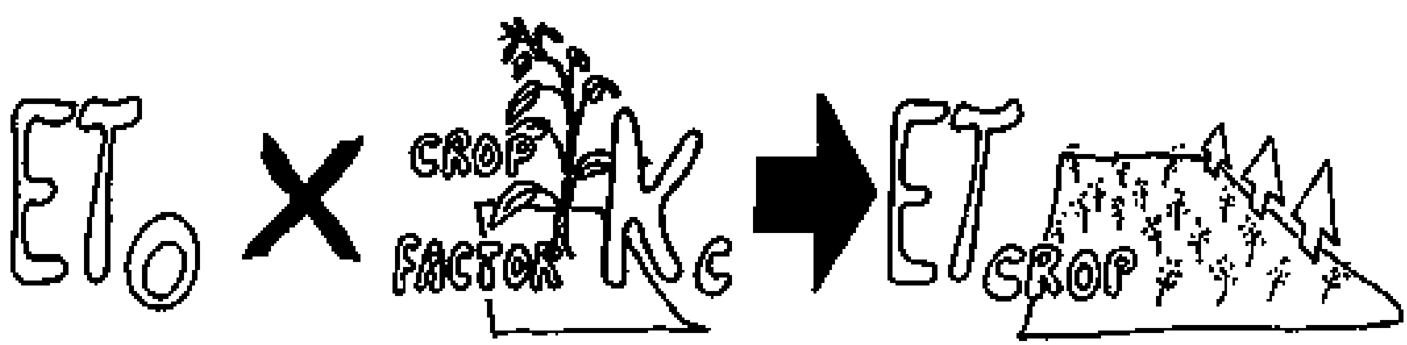
The relationship between the reference grass crop and the crop actually grown is given by the **crop factor,** Kc, as shown in the following formula:

ETo × Kc = ET crop

with ET crop = crop evapotranspiration or crop water need (mm/day)
Kc = crop factor
ETo = reference evapotranspiration (mm/day)

Both ET crop and ETo are expressed in the same unit: usually in mm/day (as an average for a period of one month) or in mm/month.

Fig. 13b Crop evapotranspiration or crop water need



The crop factor, Kc, mainly depends on:

- the type of crop
- the growth stage of the crop
- the climate

Kc and the type of crop

Fully developed maize, with its large leaf area will be able to transpire, and thus use, more water than the reference grass crop: Kc, maize is higher than 1. Cucumber, also fully developed, will use less water than the reference grass crop: Kc, cucumber is less than 1.

Kc and the growth stage of the crop

A certain crop will use more water once it is fully developed, compared to a crop which has just recently been planted.

Kc and the climate

The climate influences the duration of the total growing period and the various growth stages. In a cool climate a certain crop will grow slower than in a warm climate.

Thus, to determine the crop factor Kc, it is necessary, for each crop, to know the total length of the growing season and the lengths of the various growth stages.

The determination of the Kc values for the various growth stages of the crops involves several steps:

Step 1 - Determination of the total growing period of each crop
Step 2 - Determination of the various growth stages of each crop
Step 3 - Determination of the Kc values for each crop for each of the growth stages

The 3 steps mentioned above are dealt with in the sections 3.2.2, 3.2.3 and 3.2.4 respectively. Section 3.3 explains how the crop water need or crop evapotranspiration is determined.

3.2.2 Determination of the Total Growing Period

The total growing period (in days) is the period from sowing or transplanting to the last day of the harvest. It is mainly dependent on:

- the type of crop and the variety
- the climate
- the planting date

As the growing period heavily depends on local circumstances (e.g. local crop varieties) it is always best to obtain these data locally. Only if no data are available locally should Table 6 be used.

As can be seen from Table 6 there is a large variation of values not only between crops but also within one crop type. In general it can be assumed that the growing period for a certain crop is longer when the climate is cool and shorter when the climate is warm.

Table 6 INDICATIVE VALUES OF THE TOTAL GROWING PERIOD

Crop	Total growing period (days)	Crop	Total growing period (days)
Alfalfa	100-365	Millet	105-140
Banana	300-365	Onion green	70-95
Barley/Oats/Wheat	120-150	Onion dry	150-210
Bean green	75-90	Peanut/Groundnut	130-140

Bean dry	95-110	Pea	90-100
Cabbage	120-140	Pepper	120-210
Carrot	100-150	Potato	105-145
Citrus	240-365	Radish	35-45
Cotton	180-195	Rice	90-150
Cucumber	105-130	Sorghum	120-130
Eggplant	130-140	Soybean	135-150
Flax	150-220	Spinach	60-100
Grain/small	150-165	Squash	95-120
Lentil	150-170	Sugarbeet	160-230
Lettuce	75-140	Sugarcane	270-365
Maize sweet	80-110	Sunflower	125-130
Maize grain	125-180	Tobacco	130-160
Melon	120-160	Tomato	135-180

3.2.3 Determination of the Growth Stages

Once the total growing period is known, the duration (in days) of the various growth stages has to be determined.

The total growing period is divided into 4 growth stages (see Fig. 14):

1. **The initial stage:** this is the period from sowing or transplanting until the crop covers about 10% of the ground.

2. **The crop development stage:** this period starts at the end of the initial stage and lasts until the full ground cover has been reached (ground cover 70-80%); it does not necessarily mean that the crop is at its maximum height.

3. The **mid - season stage:** this period starts at the end of the crop development stage and lasts until maturity; it includes flowering and grain-setting.

4. The **late season stage:** this period starts at the end of the mid season stage and lasts until the last day of the harvest; it includes ripening.

Table 7 shows the duration of the various growth stages for some of the major field crops. For each crop the "minimum" and "maximum" duration of total growing period (see also Table 6) have been taken and sub-divided in the various growth stages.

Fig. 14 Growth stages

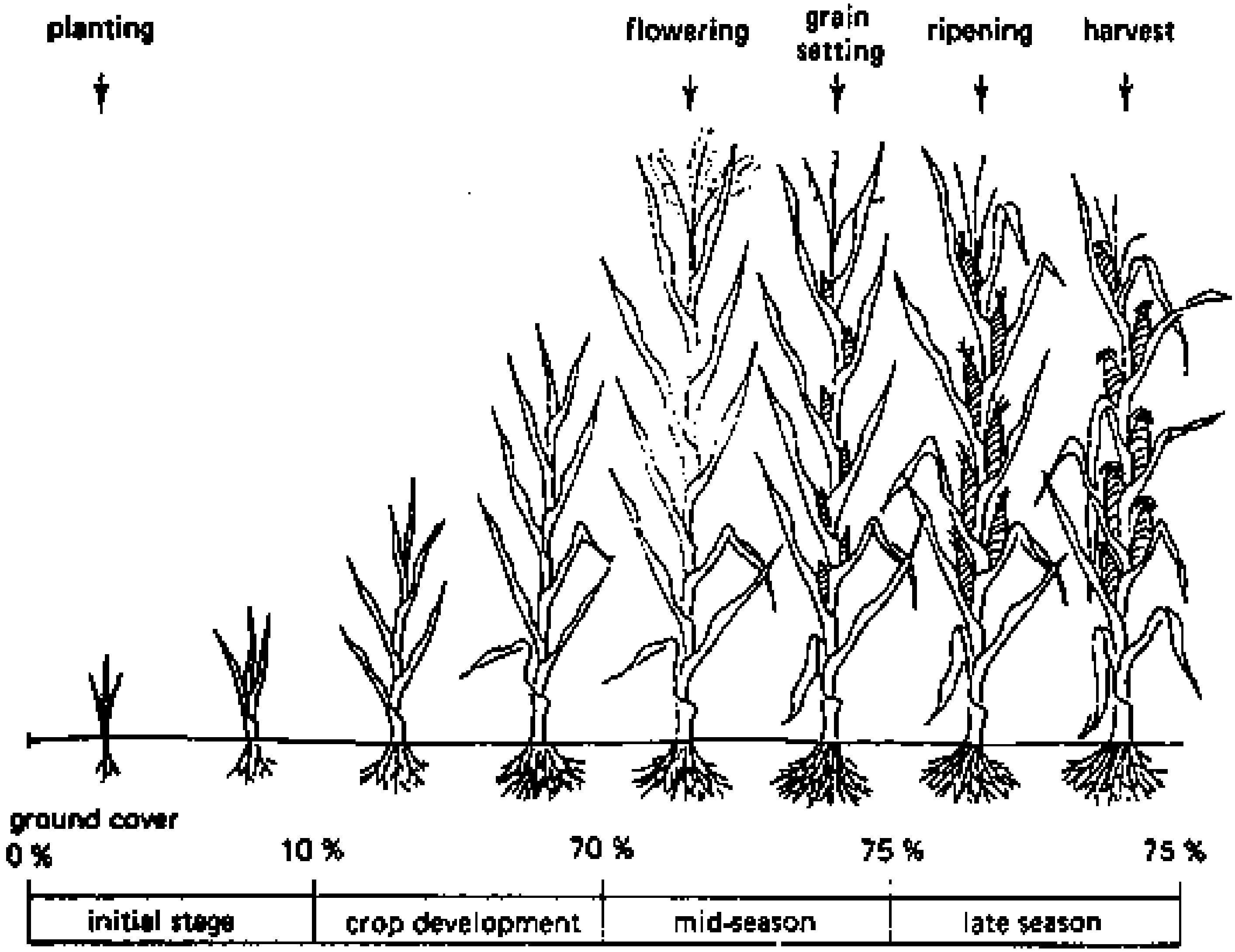


Table 7 APPROXIMATE DURATION OF GROWTH STAGES FOR VARIOUS FIELD CROPS

	Total	Initial stage	Crop Development stage	Mid season stage	Late season stage
Barley/Oats/Wheat	120	15	25	50	30
	150	15	30	65	40
Bean/green	75	15	25	25	10
	90	20	30	30	10
Bean/dry	95	15	25	35	20
	110	20	30	40	20
Cabbage	120	20	25	60	15
	140	25	30	65	20
Carrot	100	20	30	30	20
	150	25	35	70	20
Cotton/Flax	180	30	50	55	45
	195	30	50	65	50
Cucumber	105	20	30	40	15
	130	25	35	50	20

Eggplant	130	30	40	40	20
	140	30	40	45	25
Grain/small	150	20	30	60	40
	165	25	35	65	40
Lentil	150	20	30	60	40
	170	25	35	70	40
Lettuce	75	20	30	15	10
	140	35	50	45	10
Maize, sweet	80	20	25	25	10
	110	20	30	50	10
Maize, grain	125	20	35	40	30
	180	30	50	60	40
Melon	120	25	35	40	20
	160	30	45	65	20
Millet	105	15	25	40	25
	140	20	30	55	35
Onion/green	70	25	30	10	5
	95	25	40	20	10
Onion/dry	150	15	25	70	40
	210	20	35	110	45
Peanut/Groundnut	130	25	35	45	25
	140	30	40	45	25
Pea	90	15	25	35	15
	100	20	30	35	15
Pepper	120	25	35	40	20
	210	30	40	110	30
Potato	105	25	30	30	20
	145	30	35	50	30
Radish	35	5	10	15	5
	40	10	10	15	5
Sorghum	120	20	30	40	30
	130	20	35	45	30
Soybean	135	20	30	60	25
	150	20	30	70	30
Spinach	60	20	20	15	5
	100	20	30	40	10
Squash	95	20	30	30	15
	120	25	35	35	25
Sugarbeet	160	25	35	60	40

	230	45	65	80	40
Sunflower	125	20	35	45	25
	130	25	35	45	25
Tomato	135	30	40	40	25
	180	35	45	70	30

Example

Carrots: the "minimum" growing period is 100 days. This growing period corresponds with the following duration of growth stages:

Initial stage	: 20 days
Crop development stage	: 30 days
Mid-season stage	: 30 days
Late season stage	: 20 days
	Total 100 days

For the "maximum" growing period of 150 days the following values apply: respectively 25, 35, 70 and 20 days.

Should, under certain local circumstances, the duration of the growing period be 120 days, the duration of the growth stages could be estimated as follows:

Initial stage	: 25 days
Crop development stage	: 35 days
Mid-season stage	: 40 days
Late season stage	: 20 days
	Total 120 days

With respect to Table 7 the following should be noted:

1. The table always refers to "sown" crops. When the crop is transplanted, the length of the initial stage should be reduced. For example:

Tomatoes:	growing period 180 days from sowing
Direct sowing:	initial stage 35 days
Transplanted:	(estimated) initial stage 15 days

The growing period from transplant is thus (180 - 20) = 160 days

Direct sowing			
Initial stage	crop development stage	mid-season stage	late season stage
35 days	45 days	70 days	30 days
Transplanting			
Initial. Stage	crop development stage	mid-season stage	late season stage
15 days	45 days	70 days	30 days

2. When a crop is harvested "green" or "fresh" the late season stage is short.

Compare, for example, green beans with dry beans (Table 7). The duration of the late season stage is 10 and 20 days respectively.

3. If a crop is planted in the winter or is growing in the cool season the total growing period is long. The same is the case with the individual lengths of growing stages. The difference will be most pronounced for the stage during which the temperature is the lowest.

It should be kept in mind that the influence of variations in the total growing period on the crop water need is very important. Less important is the choice of the various lengths of growth stages.

In other words: it is important to obtain (preferably locally) an accurate estimate of the total growing period. The duration of the four growth stages can be estimated with the help of Table 7.

Note: The sum of the four growth stages should always equal the total growing period.

SOME EXAMPLES

QUESTION

Estimate the duration of the four growth stages for the following crops: cotton (190 days), lentils (160 days), sweet maize (100 days), potatoes (130 days), tomatoes/transplanted (140 days from transplant), etc. (the figures in brackets refer to the total growing period).

ANSWER

Crop	Initial stage (day)	Crop dev. stage (days)	Mid-season stage (days)	Late season stage (days)
Cotton (190 days)	30	50	60	50
Lentils (160 days)	25	30	65	40
Sweet Maize (100 days)	20	30	40	10
Potatoes (130 days)	30	35	40	25
Tomatoes/Transplanted (140 days from transplant)	15	40	60	25

Surface irrigation of a large field

3.2.4 Determination of Crop Factors

Per crop, **four** crop factors have to be determined: one crop factor for each of the **four** growth stages. Table 8 indicates per crop the Kc values for each of the four growth stages.

Table 8 VALUES OF THE CROP FACTOR (Kc) FOR VARIOUS CROPS AND GROWTH STAGES

Crop	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Barley/Oats/Wheat	0.35	0.75	1.15	0.45
Bean, green	0.35	0.70	1.10	0.90
Bean, dry	0.35	0.70	1.10	0.30
Cabbage/Carrot	0.45	0.75	1.05	0.90

Cotton/Flax	0.45	0.75	1.15	0.75
Cucumber/Squash	0.45	0.70	0.90	0.75
Eggplant/Tomato	0.45	0.75	1.15	0.80
Grain/small	0.35	0.75	1.10	0.65
Lentil/Pulses	0.45	0.75	1.10	0.50
Lettuce/Spinach	0.45	0.60	1.00	0.90
Maize, sweet	0.40	0.80	1.15	1.00
Maize, grain	0.40	0.80	1.15	0.70
Melon	0.45	0.75	1.00	0.75
Millet	0.35	0.70	1.10	0.65
Onion, green	0.50	0.70	1.00	1.00
Onion, dry	0.50	0.75	1.05	0.85
Peanut/Groundnut	0.45	0.75	1.05	0.70
Pea, fresh	0.45	0.80	1.15	1.05
Pepper, fresh	0.35	0.70	1.05	0.90
Potato	0.45	0.75	1.15	0.85
Radish	0.45	0.60	0.90	0.90
Sorghum	0.35	0.75	1.10	0.65
Soybean	0.35	0.75	1.10	0.60
Sugarbeet	0.45	0.80	1.15	0.80
Sunflower	0.35	0.75	1.15	0.55
Tobacco	0.35	0.75	1.10	0.90

The table above shows average Kc values for the various crops and growth stages. In fact, the Kc is also dependent on the climate and, in particular, on the relative humidity and the windspeed. The values indicated above should be reduced by 0.05 if the relative humidity is high (RH > 80%) and the windspeed is low (u < 2 m/sec), e.g. Kc = 1.15 becomes Kc = 1.10. The values should be increased by 0.05 if the relative humidity is low (RH < 50%) and the windspeed is high (u > 5 m/sec), e.g. Kc = 1.05 becomes Kc = 1.10.

DATA SHEET 4 Determination of crop factors

Location : ..Example... Date : ..1/8/86...

Humidity : crop 1: high/(medium)/low Wind speed : crop 1: high/(medium)/low

crop 2: high/(medium)/low crop 2: high/(medium)/low

Crop 1 : ..Maize (grain).......... Planting Date : ..1 July........

Duration of total growing period : ...130... days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) : | Dates

Initial stage	:	...20..... days	1 July - 20 July
Crop dev. stage	:	...35..... days	21 July - 25 August
Mid-season stage	:	...45..... days	26 August - 10 October
Late season stage	:	...30.... days	11 October - 10 November

Crop factors, Kc (Table 8) :

Initial stage	:	....0.40*....
Crop dev. stage	:	....0.80*....
Mid-season stage	:	....1.15*....
Late season stage	:	....0.70*....

Crop 2 : ..Cotton.............................. Planting Date : ..1 JUNE....

Duration of total growing period : ..165.... days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) : | Dates

Initial stage	:	...25..... days	1 June - 25 June
Crop dev. stage	:	...45..... days	26 June - 10 August
Mid-season stage	:	...50..... days	11 August - 30 September
Late season stage	:	...45..... days	1 October - 15 November

Crop factors, Kc (Table 8) :

Initial stage	:	.....0.45.....
Crop dev. stage	:	.....0.75.....
Mid-season stage	:	.....1.15.....
Late season stage	:	.....0.75.....

* In case of low RH & high windspeed the Kc values would resp. be: 0.45, 0.85, 1.20 & 0.75. In case of high RH & low windspeed the Kc values would resp. be: 0.35, 0.75, 1.10 & 0.65.

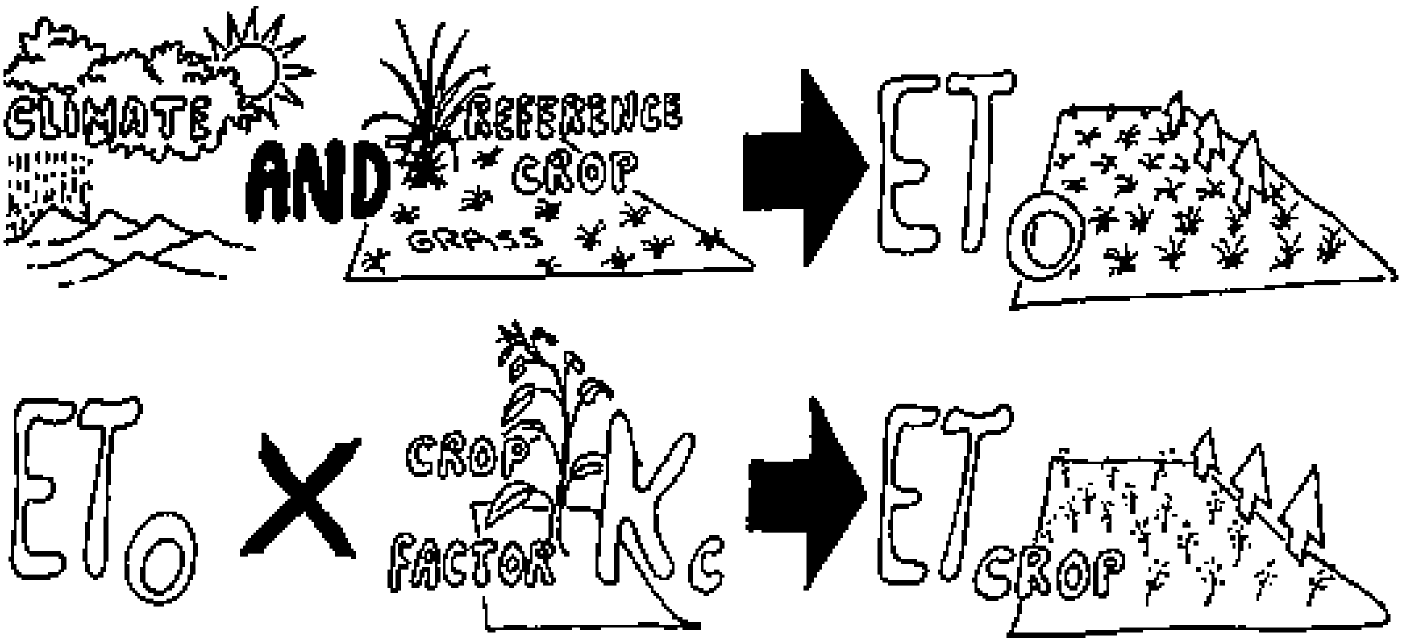
3.3 CALCULATION OF THE CROP WATER NEED

3.3.1 Introduction

In section 3.1 the determination of the reference crop evapotranspiration ETo has been discussed, while in section 3.2 it has been indicated how the crop factor Kc can be determined.

This section (3.3) explains how the crop water need ET crop is calculated (see Fig. 15) on a monthly basis, using the formula: ET crop = ETo × Kc.

Fig. 15 Calculation of the crop water need (ET crop)



Although the formula to calculate ET crop is easy to apply, there are still some practical problems to be overcome, which can best be explained using an example.

3.3.2 Crop Water Need Calculation Example

QUESTION

Determine the crop water need of tomatoes

GIVEN

Month	Jan	Feb Mar	Apr	May	June	July
ETo (mm/day)	4.0	5.0 5.8	6.3	6.8	7.1	6.5
Humidity	medium	(60%)				
Windspeed	medium	(3 m/sec)				
Duration of growing period (from sowing): 150 days						

Planting date: 1 February (direct sowing)

CALCULATION

Step 1: Estimate the duration of the various growth stages, using Table 7.

Crop	Total growing period (days)	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Tomatoes	150	35	40	50	25

Step 2: Indicate on table, as per example below, the ETo values and the duration of the growth stages.

Note: When calculating the crop water needs, all months are assumed to have 30 days. For the calculation of the reference crop evapotranspiration (ETo, section 3.1), the actual number of days of each month is used e.g., January 31 days, February 28 or 29 days, etc.

Crop: Tomatoes... Planting Date: 1 February..

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		INITIAL ST.	CROP dev. st	mid season st		late s. st						

Planting date	1 Feb
Initial stage, 35 days	1 Feb-5 Mar
Crop development stage, 40 days	6 Mar-15 Apr
Mid season stage, 50 days	16 Apr-5 Jun
Late season stage, 25 days	6 Jun-30 Jun
Last day of the harvest	30 Jun

Step 3: Estimate the Kc factor for each of the 4 growth stages, using Table 8 and bearing in mind that the humidity and windspeed are medium

Kc, initial stage =	0.45
Kc, crop development stage =	0.75
Kc, mid season stage =	1.15
Kc, late season stage =	0.8

The Kc values are inserted in the Table:

Crop: Tomatoes Planting Date: 4 February

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		Initial st.	Crop dev. st	Mid season st		Late s.st						
Kc per gr. st.		0.45	0.75	1.15		0.8						

It can be seen from the table above that the months and growth stages do not correspond. As a consequence the ETo and the Kc values do not correspond.

Yet the ET crop (= ETo × Kc) has to be determined on a monthly basis. It is thus necessary to determine the Kc on a monthly basis, which is done as follows:

(see also the table above)

February: Kc Feb = 0.45
March: 5 days: Kc = 0.45
25 days: Kc = 0.75

$$\text{Kc March}: \text{Kc} = \frac{5}{30} \times 0.45 + \frac{25}{30} \times 0.75 = 0.07 + 0.62 = 0.69 = \text{approx}\ 0.70$$

NOTE: The Kc values are rounded to the nearest 0.05 or 0.00.
Thus Kc, March = 0.70

April: 15 days: Kc = 0.75
15 days: Kc = 1.15

$$\text{Kc, April}: \text{Kc} = \frac{15}{30} \times 0.75 + \frac{15}{30} \times 1.15 = 0.38 + 0.58 = 0.96 = \text{approx.}\ 0.95$$

Thus Kc, April =0.95

May: Kc, May = 1.15
June: 5 days: Kc = 1.15
: 25 days: Kc = 0.80

$$\text{Kc, June}: = \frac{5}{30} \times 1.15 + \frac{25}{30} \times 0.80 = 0.19 + 0.67 = 0.86 = \text{approx.}\ 0.85$$

Thus Kc, June =0.85

In summary:

Crop: Tomatoes..... Planting Date: 1 February

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		initial st.	crop dev. st	mid season st		late s.st						
Kc per gr. st.		0.45	0.75	1.15		0.8						
Kc per month		0.45	0.70	0.95	1.15	0.85						

Step 4: Calculate, on a monthly basis, the crop water need, using the formula:

ET crop = ETo × Kc (mm/day)

February: ET crop = 5.0 × 0.45 = 2.3 mm/day
March: ET crop = 5.8 × 0.70 = 4.1 mm/day
April: ET crop = 6.3 × 0.95 = 6.0 mm/day
May: ET crop = 6.8 × 1.15 = 7.8 mm/day
June: ET crop = 7.1 × 0.85 = 6.0 mm/day

In summary:

Crop: Tomatoes..... Planting Date: 1 February

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		initial st.	crop dev st.	mid season st		late s.st						
Kc per gr. st.		0.45	0.75	1.15		0.8						
Kc per month		0.45	0.70	0.95	1.15	0.85						
ET crop (mm/day)		2.3	4.1	6.0	7.8	6.0						

Step 5: Calculate the monthly and seasonal crop water needs.

Note: all months are assumed to have 30 days.

February ET crop = 30 × 2.3 = 69 mm/month
March ET crop = 30 × 4.1 = 123 mm/month
April ET crop = 30 × 6.0 = 180 mm/month
May ET crop = 30 × 7.8 = 234 mm/month
June ET crop = 30 × 6.0 = 180 mm/month

The crop water need for the whole growing season of tomatoes is 786 mm. In summary:

Crop: Tomatoes Planting Date: 1 Februery

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		initial st.	crop dev. st.	mid season st.		late s. st						
Kc per gr. st.		0.45	0.75	1.15		0.8						
Kc per month		0.45	0.70	0.95	1.15	0.85						
ET crop (mm/day)		2.3	4.1	6.0	7.8	6.0						
ET crop (mm/m)		69	123	180	234	180						

3.3.3 Special Cases

In the previous sections it has been indicated how the crop water need is calculated for a variety of field crops: ET crop = Kc × ETo. However there are some crops that do not directly fit this model: their crop factor Kc is determined in a different way. The determination of their crop factor is explained in this section. Once the crop factor Kc has been determined, the same procedure (as described in the sections 3.3.1 and 3.3.2) is used to calculate the crop water needs.

The special cases include:

- alfalfa, pasture and clover
- bananas
- citrus
- rice
- sugarcane
- cacao, coffee, tea
- olives
- grapes

Alfalfa, Pasture and Clover

Alfalfa, pasture and clover are regularly cut during the year. Just after cutting they are in the "initial stage", while just before the next cutting, they are in the "late season stage". To determine the crop water need it is best to use an average value of the crop factor Kc. The average Kc values are given in Table 9.

Table 9 Kc VALUES FOR ALFALFA. PASTURE AND CLOVER

Climate:	Alfalfa	Pasture	Clover
Humid Light/medium wind	0.85	0.95	1.0
Dry Light/medium wind	0.95	1.0	1.05
Humid or Dry Strong wind	1.05	1.05	1.05

Bananas

The establishment of a new banana plantation takes approximately 6 months from planting to full ground cover. One year after planting, the first harvest takes place, after which the shoots that have produced are removed. Meanwhile young shoots have fully developed and take over the production.

The Kc values for the first 6 months after planting are indicated in Table 10. After 6 months the Kc value remains constant: Kc = 1.1.

Table 10 Kc VALUES FOR BANANA

Months after planting	**1**	**2**	**3**	**4**	**5**	**6**	**7 onward**
Kc	0.7	0.75	0.8	0.75	0.9	1.0	1.1

Citrus

The crop factor Kc for clean cultivated citrus is 0.70 year-round. This value is applicable for large mature trees, covering some 70% of the ground surface. If there is no weed control, a Kc value of 0.90 year-round should be used.

Rice

For paddy rice the values indicated in Table 11 should be used.

Table 11 Kc VALUES FOR PADDY RICE

Climate	Little wind		Strong wind	
Growth stage (days)	dry	humid	dry	humid
0-60 days after transplant or direct sowing	1.1	1.1	1.1	1.1
Mid-season	1.2	1.05	1.35	1.3
last 30 days before harvest	1.0	1.0	1.0	1.0

Example: Suppose the total growing season of rice from sowing to harvest =150 days in a humid climate with strong wind

Kc day 0 to 60:	1.1
Kc day 60 to 120:	1.3
Kc day 120 to 150:	1.0

Sugarcane

Crop coefficients for sugarcane vary widely depending on climate and sugarcane variety. It is best to use locally available data. If such data are not available. Tables 12a and 12b can be used.

Table 12a refers to a virgin sugarcane crop from establishment to first harvest, which is assumed to take 18 months. Table 12b refers to a ratoon crop, which is the regrowth after the harvest of the virgin crop. The regrowth is assumed to take 12 months. Sometimes, depending on local practices, a virgin crop is followed by 2 or 3 ratoon crops.

Table 12a Kc VALUES FOR VIRGIN SUGARCANE

Climate	Little wind		Strong wind	
Growth stage (days)	dry	humid	dry	humid
0-2	0.4	0.5	0.5	0.6
2-4	0.8	0.8	0.8	0.85
4-6	1.1	1.0	1.2	1.1
6-12	1.25	1.05	1.3	1.15
12-17	0.95	0.8	1.05	0.85
17-18	0.7	0.6	0.75	0.65

Table 12b Kc VALUES FOR RATOON SUGARCANE

Climate	Little wind		Strong wind	
Growth stage (days)	dry	humid	dry	humid
0-1	0.4	0.5	0.5	0.6
1-2	0.8	0.8	0.8	0.85
2-4	1.1	1.0	1.2	1.1
4-10	1.25	1.05	1.3	1.15
10-11	0.95	0.8	1.05	0.85
11-12	0.7	0.6	0.75	0.65

Cacao, coffee, tea

For cacao, coffee and tea the following year-round Kc values are recommended:

- no cover crop, no shade: Kc = 0.95
- with cover crops and shade trees: Kc = 1.1

Olives

For mature olive trees the following year-round Kc values are recommended:

- wide spacing of trees: Kc = 0.4
- close spacing of trees: Kc = 0.7

Grapes

With the assumption that the grape harvest starts some 5 months after the first leaves appear, the Kc values indicated in Table 13 can be used for the months starting with the first leaf appearance.

Table 13 Kc VALUES FOR GRAPES (35% GROUND COVER)

Months after first leaves appear	1	2	3	4	5	6	7	8	9
Kc	0.25	0.45	0.65	0.75	0.75	0.7	0.55	0.45	0.35

3.3.4 Indicative Values of Crop Water Needs

Table 14 gives indicative values of the crop water needs for the total growing period of various important field crops.

The values indicated in the table provide a rough estimate and should only be used if the crop water needs cannot be calculated more accurately due to lack of data.

Table 14 gives for each crop a minimum and a maximum value for the crop water need. As the crop water needs depend heavily on the duration of the total growing period, the maximum value should be used in the case of a long total growing period (see also Table 6) and the minimum value should be used when the total growing period is short. An average value is to be used with a medium total growing period.

In addition, Table 14 gives an indication of the sensitivity of the various crops to water shortages or drought. If the sensitivity is high it means that the crop cannot withstand water shortages very well and such shortages should be avoided. If the sensitivity is low it means that the crop is relatively drought resistant and can withstand water shortages fairly well.

Table 14 INDICATIVE VALUES OF CROP WATER NEEDS AND SENSITIVITY TO DROUGHT

Crop	Crop water need (mm/total growing period)	Sensitivity to drought
Alfalfa	800-1600	low-medium
Banana	1200-2200	high
Barley/Oats/Wheat	450-650	low-medium
Bean	300-500	medium-high
Cabbage	350-500	medium-high
Citrus	900-1200	low-medium
Cotton	700-1300	low
Maize	500-800	medium-high
Melon	400-600	medium-high
Onion	350-550	medium-high
Peanut	500-700	low-medium
Pea	350-500	medium-high
Pepper	600-900	medium-high
Potato	500-700	high
Rice (paddy)	450-700	high
Sorghum/Millet	450-650	low
Soybean	450-700	low-medium
Sugarbeet	550-750	low-medium
Sugarcane	1500-2500	high
Sunflower	600-1000	low-medium

Tomato	400-800	medium-high

DATA SHEET 5 Determination of crop water needs (see also Data Sheet 4)

Location : Example. Date : 1/8/86

Crop: Maize (grain) Planting date: 1 July

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.9	5.3	5.9	6.3	6.7	6.4	6.0	5.6	5.8	5.6	5.3	4.8
Growth stages							ini. st.	crop dev. st.	mid season st.	late s.st.		
Kc per gr. st.							0.40	0.80	1.15	0.70		
Kc per month							0.55	0.85	1.15	0.85	(0.70)*	
ET crop (mm/d)							3.3	4.8	6.7	4.8	(3.7)*	
ET crop (mm/m)							99	144	201	144	37**	

* 10 days in November
** 10 days × 3.7 mm/day

Crop: Cotton Planting date: 1 June

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.9	5.3	5.9	6.3	6.7	6.4	6.0	5.6	5.8	5.6	5.3	4.8
Growth stages						ini. st.	crop dev. st	mid season st.		late season st.		
Kc per gr. st.						0.45	0.75	1.15		0.75		
Kc per month						0.50	0.75	1.00	1.15	0.75	(0.75)*	
ET crop (mm/d)						3.2	4.5	5.6	6.7	4.2	(4.0)*	
ET crop (mm/m)						96	135	168	201	126	60**	

Note: ETcrop (mm/day) = Kc (per month) x ETo (mm/day)
ETcrop (mm/month) = 30 x ETcrop (mm/day)

* 15 days in Nov.
** 15 x 4.0 mm/day

CHAPTER 4: IRRIGATION WATER NEEDS

4.1 INTRODUCTION

In Chapter 3 it has been indicated how the crop water need (ET crop) is determined. This water can be supplied to the crops in various ways:

- by rainfall
- by irrigation
- by a combination of irrigation and rainfall

In some cases, part of the crop water need is supplied by the groundwater through capillary rise (see Volume 1, Section 2.5.3). For the purpose of this paper however, the contribution of capillary rise is not taken into account.

In cases where all the water needed for optimal growth of the crop is provided by rainfall, irrigation is not required and the **Irrigation water need (IN)** equals zero: IN = 0.

In cases where there is no rainfall at all during the growing season, all water has to be supplied by irrigation. Consequently, the irrigation water need (IN) equals the crop water need (ET crop): IN = ET crop.

In most cases, however, part of the crop water need is supplied by rainfall and the remaining part by irrigation. In such cases the irrigation water need (IN) is the difference between the crop water need (ET crop) and that part of the rainfall which is effectively used by the plants (Pe). In formula: IN = ET crop - Pe.

In summary:

If sufficient rainfall	: IN = 0
If no rainfall at all	: IN = ET crop
If partly irrigation, partly rainfall	: IN = ET crop - Pe

Section 4.2 provides a method to determine the effective rainfall, while Section 4.3 gives a calculation example for the irrigation water need. As the determination of the irrigation water need for paddy rice is a

special case, it is discussed separately in Section 4.4.

4.2 DETERMINATION OF THE EFFECTIVE RAINFALL*

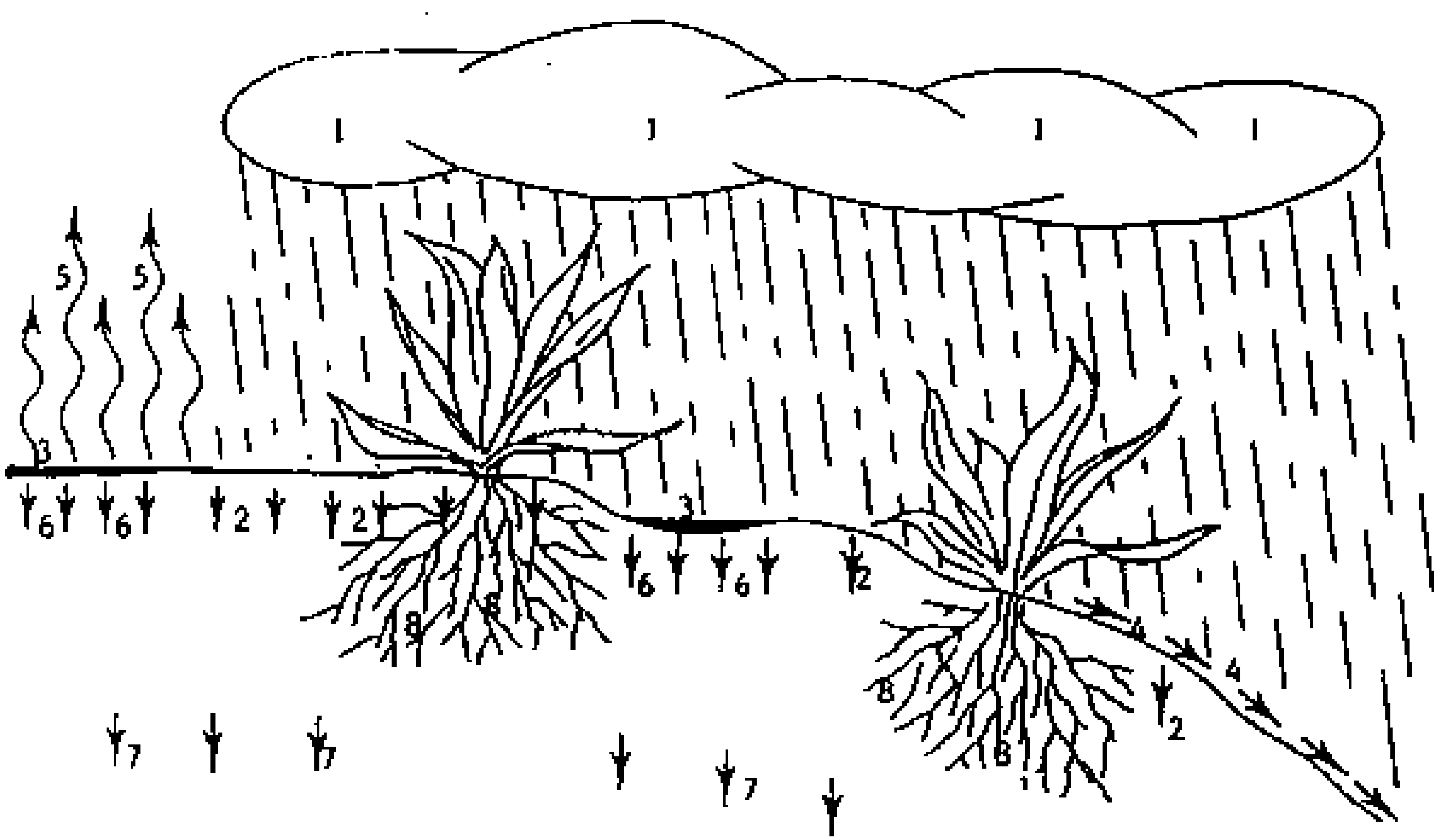
> * For general information on rainfall: the amount, the intensity and the distribution, refer to Volume 1, Section 4.1.1, 4.1.2 and 4.1.3 respectively.

When rain water ((1) in Fig. 16) falls on the soil surface, some of it infiltrates into the soil (2), some stagnates on the surface (3), while some flows over the surface as runoff (4).

When the rainfall stops, some of the water stagnating on the surface (3) evaporates to the atmosphere (5), while the rest slowly infiltrates into the soil (6).

From all the water that infiltrates into the soil ((2) and (6)), some percolates below the root zone (7), while the rest remains stored in the root zone (8).

Fig. 16 Effective rainfall (8)=(1) - (4) = (5) = (7)



In other words, the effective rainfall (8) is the total rainfall (1) minus runoff (4) minus evaporation (5) and minus deep percolation (7); only the water retained in the root zone (8) can be used by the plants, and represents what is called the effective part of the rainwater. The term effective rainfall is used to define this fraction of the total amount of rainwater useful for meeting the water need of the crops.

For the purpose of this manual only 2 simple formulae are provided to estimate the fraction of the total rainfall which is used effectively. These formulae can be applied in areas with a maximum slope of 4-5%:

Pe = 0.8 P 25 if P > 75 mm/month Pe = 0.6 P 10 if P < 75 mm/month

with P = rainfall or precipitation (mm/month)
Pe = effective rainfall or effective precipitation (mm/month)

NOTE: Pe is always equal to or larger than zero; never negative

QUESTION

Calculate the effective rainfall for the following monthly rainfall figures: P = 35, 90,116, 5, 260, 75 mm

ANSWER

P (mm/month)	Formula	Pe (mm/month)
35	Pe = 0.6 P - 10	11
90	Pe = 0.8 P - 25	47
116	Pe = 0.8 P - 25	68
5	Pe = 0.6 P - 10	0
260	Pe = 0.8 P - 25	183
75	Pe = 0.8 P - 25 or 0.6 P - 10	35

4.3 CALCULATION OF THE IRRIGATION WATER NEEDS

The following example, which Illustrates the irrigation water need calculation method, is a continuation of the example from Section 3.3.2:

Month	Feb	Mar	Apr	May	June
ET crop (mm/month)	69	123	180	234	180

In addition, the following rainfall figures are given:

P (mm/month) 20 38 40 80 16

Step 1: Calculate for each month the effective rainfall using the formulae:

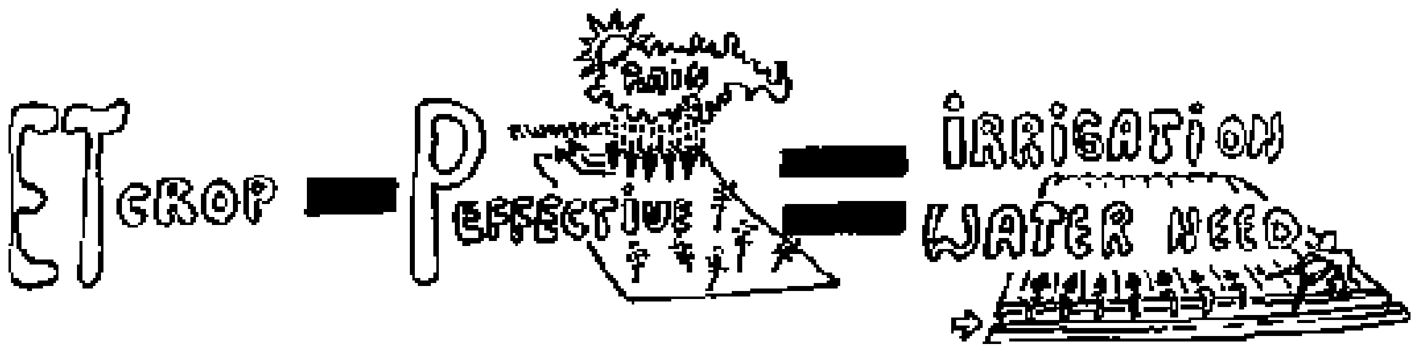
Pe = 0.8 P 25 if P > 75 mm/month Pe = 0.6 P 10 if P < 75 mm/month

	Feb	Mar	Apr	May	June
P (mm/month)	20	38	40	80	16
Pe (mm/month)	2	13	14	39	0

Step 2: Calculate the irrigation water need, both in mm/month and mm/day, using the formula: IN = ET crop - Pe; e.g. Feb: IN = 69 - 2 = 67 mm, etc.

	Feb	Mar	Apr	May	June
ET crop (mm/month)	69	123	180	234	180
Pe (mm/month)	2	13	14	39	0
IN (mm/month)	67	110	166	195	180
IN (mm/day)	2.2	3.7	5.5	6.5	6.0

Fig. 17 Irrigation water need



DATA SHEET 6 Determination of Irrigation water needs (see also Data sheet 5)

4.4 IRRIGATION WATER NEED OF RICE

For all field crops, as has been explained in the previous section, the irrigation water need (IN) is determined as follows:

Step 1: Determine the reference crop evapotranspiration: ETo
Step 2: Determine the crop factors: Kc
Step 3: Calculate the crop water need: ET crop = ETo × Kc
Step 4: Determine the effective rainfall: Pe
Step 5: Calculate the irrigation water need: IN = ET crop - Pe

Paddy rice, growing with "its feet in the water", is an exception. Not only has the crop water need (ET crop) to be supplied by irrigation or rainfall, but also water is needed for:

- saturation of the soil before planting
- percolation and seepage losses
- establishment of a water layer

In summary, the determination of the irrigation water need for paddy rice requires the following steps:

Step 1: Determine the reference crop evapotranspiration: ETo

Step 2: Determine the crop factors: Kc

Step 3: Calculate the crop water need: ET crop = ETo × Kc

Step 4: Determine the amount of water needed to saturate the soil for land preparation by puddling: SAT

Step 5: Determine the amount of percolation and seepage losses: PERC

Step 6: Determine the amount of water needed to establish a water layer: WL

Step 7: Determine the effective rainfall: Pe

Step 8: Calculate the irrigation water need: IN = ET crop + SAT + PERC + WL - Pe

These steps are discussed in detail below.

Step 1, 2 and 3: Determine ETo, Kc and ET crop

ET crop is determined similarly to all other field crops as discussed in Sections 3.1 to 3.3

Step 4: Determine the amount of water needed to saturate the soil for land preparation by puddling: SAT

In the month before sowing or transplanting, water is needed to saturate the root zone. The amount of water needed depends on the soil type and rooting depth. For the purpose of this manual it is however assumed that the amount of water needed to saturate the root zone is 200 mm. Thus:

SAT = 200 mm

Step 5: Determine the amount of percolation and seepage losses: PERC

The percolation and seepage losses depend on the type of soil. They will be low in very heavy, well-puddled clay soils and high in the case of sandy soils. The percolation and seepage losses vary between 4 and 8 mm/day.

for heavy clay: PERC = 4 mm/day for sandy soils: PERC = 8 mm/day on average: PERC = 6 mm/day

Step 6: Determine the amount of water needed to establish a water layer: WL

A water layer is established during transplanting or sowing and maintained throughout the growing season. The amount of water needed for maintaining the water layer has already been taken into account with the determination of the percolation and seepage losses. The amount of water needed to establish the water layer, however, still has to be considered. For the purpose of this manual it is assumed that a water layer of 100 mm is established. Thus:

WL = 100 mm

Step 7: Determine the effective rainfall: Pe

The effective rainfall is calculated using the same formulae as described in Section 4.2.

Pe = 0.8 P - 25 if P > 75 mm/month Pe = 0.6 P - 10 if p < 75 mm/month

Step 8: Calculate the irrigation water need: IN = ET crop + SAT + PERC + WL - Pe

The irrigation water need is calculated using the following formula;

IN = ET crop + SAT + PERC + WL - Pe

CALCULATION EXAMPLE

QUESTION

Calculate the irrigation water need (IN) of paddy rice for the month of April when given:

- ETo = 6 mm/day
- Kc = 1.1
- the root zone has already been saturated in the previous month
- PERC = 5 mm/day
- the water layer (100 mm) needs to be established during April
- Pe = 135 mm/month

ANSWER

IN = ET crop + SAT + PERC + WL - Pe
ET crop = ETo × Kc = 6 × 1.1 = 6.6 mm/day = 6.6 × 30 = 198 mm/month
SAT = 0 mm
PERC = 5 mm/day = 5 × 30 = 150 mm/month
WL = 100 mm
Pe = 135 mm/month
IN = 198 + 0 + 150 + 100 - 135 = 313 mm/month = 10.4 mm/day

Thus the irrigation water need during April is 313 mm or 10.4 mm/day.

DATA SHEET 7 Determination of Irrigation water need of paddy rice

Location : Example/Rice Date : 2/6/86

Humidity : crop 1 : high/medium/low
crop 2 : high/medium/low

Windspeed : crop 1 : high/medium/low
crop 2 : high/medium/low

No of crops per year : 2

Planting date : crop 1 : 1 August
crop 2 : 1 February

Rice crop 1 : Duration total growing period from sowing or transplant : 130 days
Duration mid-season stage* : 40 days

Rice crop 2 : Duration total growing period from sowing or transplant : 120 days
Duration mid-season stage* : 30 days

Crop factors (Table 11)	Crop : 1	Crop : 2
day : 0 - 60	1.10	1.10
mid-season	1.15	1.25
last 30 days	1.00	1.00

Saturation requirement : 200 mm crop 1 : Month July

crop 2 : Month January

Percolation and seepage : 6 mm/day = 180 mm/month

Establishment water layer : 100 mm crop 1 : Month August

crop 2 : Month February

* Duration mid-season stage = Duration total growing period - 90 days

Figure

Crop: Rice 1 Planting date: 1 August

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	5.8	7.3	8.0	8.1	7.6	6.5	4.1	4.2	4.5	4.6	5.1	5.3
Growth stages								day 1-60		mid season	last 30 days	
Kc per gr. st.								1.10		1.15	1.00	
Kc per month								1.10	1.10	1.15	1.05	1.00*
ET crop (mm/d)								4.6	5.0	5.3	5.4	5.3*
ET crop (mm/m)								138	150	159	162	53
SAT (mm)							200					
PERC (mm/mo)								180	180	180	180	60*
WL (mm)								100				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

P (mm/mo)	0	0	3	9	20	94	202	239	127	27	3	0
Pe (mm/mo)	0	0	0	0	2	50	137	166	78	6	0	0
IN (mm/mo)							63	251	252	333	342	113*
IN (mm/day)							2.1	8.4	8.4	11.1	11.4	11.3

* 10 days

Crop: Rice 2 Planting date: 1 february

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	5.8	7.3	8.0	8.1	7.6	6.5	4.1	4.2	4.5	4.6	5.1	5.3
Growth stages		day 1-60		mid seas.	last 30 days							
Kc per gr. st.		1.10		1.25	1.00							
Kc per month		1.1	1.1	1.25	1.00							
ET crop (mm/d)		8.0	8.8	10.1	7.6							
ET crop (mm/m)		240	264	303	228							
SAT (mm)	200											
PERC (mm/mo)		180	180	180	180							
WL (mm)		100										
P (mm/mo)	0	0	3	9	20	94	202	239	127	27	3	0
Pe (mm/mo)	0	0	0	0	2	50	137	166	78	6	0	0
IN (mm/mo)	200	520	444	483	408							
IN (mm/day)	6.7	17.3	14.8	16.1	13.6							

Note: For ET crop and Pe, see Data Sheet 6

IN (mm/mo) = ET crop (mm/mo) + SAT (mm) + PERC (mm/mo) + WL (mm) − Pe (mm/mo)

$$\text{IN (mm/d)} = \frac{\text{IN (mm/mo)}}{30}$$

CHAPTER 5: CALCULATION EXAMPLE

In this chapter a full calculation example is given. The necessary data are provided below and the aim is to determine:

1. the reference crop evaporation (Data Sheet 3: ETo)
2. the crop water need for the various crops (Data Sheets 4: Kc and 6: ET crop)
3. the Irrigation water needs for the various crops (Data Sheet 6: IN)

GENERAL DATA

Location: Example (2)
Latitude: 8° North

CROP DATA

Three crops are grown: onions (dry) followed on the same fields by potatoes, and cotton.

Crop	Planting date	Total season growing (days)
Onions (dry)	1 April	150
Potatoes	1 Oct	120
Cotton	1 July	190

CLIMATIC DATA

Relative humidity (year round): medium
Windspeed (year round): medium

	J	F	M	A	M	J	J	A	S	O	N	D
T min (°C)	14.4	15.5	17.4	18.5	18.9	21.0	20.1	19.3	18.7	15.6	13.8	12.3
T max (°C)	29.9	31.1	32.1	33.9	34.5	35.2	32.2	31.5	32.9	32.6	29.9	29.5
P (mm)	19	21	28	33	37	38	121	134	44	28	19	5

Irrigating onions

DATA SHEET 3 Determination ETo: Blaney-Criddle Method

Location: Example (7). Date: 10/9/86

Latitude: 8 °North/°South

Month	T min (°C)	T max (°C)	T mean (°C)	P Table 4	ETo mm/day
Jan	14.4	29.9	22.2	0.26	4.7
Feb	15.5	31.1	23.3	0.27	5.1
Mar	17.4	32.1	24.8	0.27	5.2
Apr	18.5	33.9	26.2	0.28	5.6
May	18.9	34.5	26.7	0.28	5.7
Jun	21.0	35.2	28.1	0.29	6.1
Jul	20.1	32.2	26.2	0.29	5.8
Aug	19.3	31.5	25.4	0.28	5.5
Sep	18.7	32.9	25.8	0.28	5.6
Oct	15.6	32.6	24.1	0.27	5.2
Nov	13.8	29.9	21.9	0.26	4.7
Dec	12.3	29.5	20.9	0.26	4.6

DATA SHEET 4 Determination of crop factors

Location : Example (2) Date : 10/9/86

Humidity : crop 1: ~~high~~/medium/~~low~~ Wind speed : crop 1: ~~high~~/medium/~~low~~

crop 2: ~~high~~/medium/~~low~~ crop 2: ~~high~~/medium/~~low~~

Crop 1 : Onions (dry) Planting Date : 1 April

Duration of total growing period : 150 days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) :

		Dates
Initial stage	: 15 days	1 april - 15 April
Crop dev. stage	: 26 days	16 April - 10 may
Mid season stage	: 70 days	11 May - 20 July
Late season stage	: 40 days	21 July - 30 Aug.

Crop factors, Kc (Table 8) :

Initial stage	: 0.50
Crop dev. stage	: 0.75
Mid season stage	: 1.05
Late season stage	: 0.85

Crop 2 : Potatoes Planting Date : 1 October

Duration of total growing period : 120 days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) :

		Dates
Initial stage	: 25 days	1 Oct. - 25 Oct
Crop dev. stage	: 35 days	26 OCT - 30 NOV
Mid season stage	: 35 days	1 Dec - 5 Jan
Late season stage	: 25 days	6 Jan - 30 Jan

Crop factors, Kc (Table 8) :

Initial stage	: 0.45
Crop dev. stage	: 0.75
Mid season stage	: 1.15
Late season stage	: 0.85

DATA SHEET 4 - No. 2 - Determination of crop factors

Location : Example (2) Date : 10/9/86

Humidity : crop 3: ~~high~~/medium/~~low~~ Wind speed : crop 3: ~~high~~/medium/~~low~~

~~crop 2: high/medium/low~~ ~~crop 2: high/medium/low~~

Crop 3 : Cotton Planting Date : 1 July

Duration of total growing period : 190 days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) :

		Dates
Initial stage	30 days	1 July - 30 July
Crop dev. stage	50 days	1 Aug - 20 Sept
Mid season stage	60 days	21 Sept - 20 Nov
Late season stage	50 days	21 Nov - 10 Jan

Crop factors, Kc (Table 8) :

Initial stage	0.45
Crop dev. stage	0.75
Mid season stage	1.15
Late season stage	0.75

Crop 2 : .... Planting Date : ....

Duration of total growing period : .... days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) :

		Dates
Initial stage	.... days	....
Crop dev. stage	.... days	....
Mid season stage	.... days	....
Late season stage	.... days	....

Crop factors, Kc (Table 8) :

Initial stage	....
Crop dev. stage	....
Mid season stage	....
Late season stage	....

DATA SHEET 6 Determination of Irrigation water needs (see also Data sheet 5)

Location : Example (2) Date : 10/9/86

Crop: Onions (dry) Planting date: 1 April

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)				5.6	5.7	6.1	5.8	5.5				
Growth stages				ini st. / crop devt	mid season stage			late s. st.				
Kc per gr. st.				0.5 / 0.75	1.05			0.85				
Kc per month				0.65	0.95	1.05	1.00	0.85				
ET crop (mm/d)				3.6	5.4	6.4	5.8	4.7				
ET crop (mm/m)				108	162	192	174	141				
P (mm/m)				33	37	38	121	134				
Pe (mm/m)				10	12	13	72	82				
IN (mm/m)				98	150	179	102	59				
IN (mm/day)				3.3	5.0	6.0	3.4	2.0				

Crop: Potatoes Planting date: 1 October

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.7									5.2	4.7	4.6
Growth stages	late s.st									ini. st	crop devt.	mid s.st.
Kc per gr. st.	0.85									0.45	0.75	1.15
Kc per month	0.90									0.50	0.75	1.15
ET crop (mm/d)	4.2									2.6	3.5	5.3
ET crop (mm/m)	126									78	105	159
P (mm/m)	19									28	19	5
Pe (mm/m)	1									7	1	0
IN (mm/m)	125									71	104	159
IN (mm/day)	4.2									2.4	3.5	5.3

Note: ET crop (mm/day) = Kc (per month) x ETo (mm/day)
ET crop (mm/month) = 30 x ET crop (mm/day)
Pe = 0.6 P - 10 (if P < 75 mm/month)

Pe = 0.6 P - 10 if P < 75 mm/month
Pe = 0.8 P - 25 if P > 75 mm/month

IN (mm/month) = ET crop (mm/month) - Pe (mm/month)

$$\text{IN (mm/day)} = \frac{\text{IN (mm/month)}}{30}$$

DATA SHEET 6 Determination of Irrigation water needs No. 2 (see also Data sheet 5)

Location : Example (2) Date : 10/9/86

Crop: Cotton Planting date: 1 July

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.7						5.8	5.5	6.6	5.2	4.7	4.6
Growth stages							ini. st.	crop dev. st.		mid season stage		late s. stage
Kc per gr. st.							0.45	0.75		1.15		0.75
Kc per month	(0.75)*						0.45	0.75	0.90	1.15	1.00	0.75
ET crop (mm/d)	(3.5)*						2.6	4.1	5.0	6.0	4.7	3.5
ET crop (mm/m)	35*						78	123	150	180	141	105
P (mm/m)	19**						121	134	44	28	19	5
Pe (mm/m)	1**						72	82	16	7	1	0
IN (mm/m)	(35)*						6	41	134	173	140	105
IN (mm/day)	3.5*						0.2	1.4	4.5	5.8	4.7	3.5

* refers to 10 days ** refers to 30 days

Crop: .... Planting date: ....

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)												
Growth stages												
Kc per gr. st.												
Kc per month												
ET crop (mm/d)												
ET crop (mm/m)												
P (mm/m)												
Pe (mm/m)												

IN (mm/m)												
IN (mm/day)												

Note:

ET crop (mm/day) = Kc (per month) x ETo (mm/day)

ET crop (mm/month) = 30 x ET crop (mm/day)

Pe = 0.6 P - 10 if P < 75 mm/month

Pe = 0.8 P - 25 if P > 75 mm/month

IN (mm/month) = ET crop (mm/month) - Pe (mm/month)

$$\text{IN (mm/day)} = \frac{\text{IN (mm/month)}}{30}$$

ANNEX I - PAN COEFFICIENTS FOR CLASS A PAN AND SUNKEN COLORADO PAN

PAN COEFFICIENT (K pan) FOR CLASS A PAN FOR DIFFERENT GROUND COVER AND LEVELS OF MEAN RELATIVE HUMIDITY AND 24 HOUR WIND

Class A pan	**Case A: Pan placed in short green cropped area**				**Case B[1]: Pan placed in fallow area**			
RH mean %		**low < 40**	**medium 40-70**	**high > 70**		**low < 40**	**medium 40-70**	**high > 70**
Wind km/day	**Windward side distance of green crop m**				**Windward side distance of dry fallow m**			
Light	1	.55	.65	.75	1	.7	.8	.85
< 175	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1000	.75	.85	.85	1000	.5	.6	.7
Moderate	1	.5	.6	.65	1	.65	.75	.8
175-425	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75	.8	100	.5	.6	.65
	1000	.7	.8	.8	1000	.45	.55	.6
Strong	1	.45	.5	.6	1	.6	.65	.7
425-700	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1000	.65	.7	.75	1000	.4	.45	.55
Very strong	1	.4	.45	.5	1	.5	.6	.65
> 700	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1000	.55	.6	.65	1000	.35	.4	.45

PAN COEFFICIENT (K pan) FOR SUNKEN COLORADO PAN FOR DIFFERENT GROUND COVER AND LEVELS OF MEAN RELATIVE HUMIDITY AND 24 HOUR WIND

Class A pan	**Case A: Pan placed in cropped short green area**				**Case B[1]: Pan placed in fallow area**			
RH mean %		**low < 40**	**medium 40-70**	**high > 70**		**low < 40**	**medium 40-70**	**high > 70**
Wind km/day	**Windward side distance of green crop m**				**Windward side distance of dry fallow**			
Light	1	.75	.75	.8	1	1.1	1.1	1.1
< 175	10	1.0	1.0	1.0	10	.85	.85	.85
	> 100	1.1	1.1	1.1	100	.75	.75	.8
					1000	.7	.7	.75
Moderate	1	.65	.7	.7	1	.95	.95	.95
175-425	10	.85	.85	.9	10	.75	.75	.75
	> 100	.95	.95	.95	100	.65	.65	.7
					1000	.6	.6	.65
Strong	1	.55	.6	.65	1	.8	.8	.8
425-700	10	.75	.75	.75	10	.65	.65	.65
	> 100	.8	.8	.8	100	.55	.6	.65
					1000	.5	.55	.6
Very strong	1	.5	.55	.6	1	.7	.75	.75
> 700	10	.65	.7	.7	10	.55	.6	.65
	> 100	.7	.75	.75	100	.5	.55	.6
					1000	.45	.5	.55

[1] For extensive areas of barefallow soils and no agricultural development, reduce K pan by 20% under hot, windy conditions; by 5-10% for moderate wind, temperature and humidity conditions.

ANNEX II - DATA SHEETS

DATA SHEET 1
Determination ETo: Pan Evaporation Method

Location: ....
Date: ....
Type of evaporation pan: ....
Month: ....

Day	Water depth (mm)	Rainfall (mm)	E pan (mm)	Day	Water depth (mm)	Rainfall (mm)	E pan (mm)
1				17			
2				18			
3				19			
4				20			
5				21			
6				22			
7				23			
8				24			
9				25			
10				26			
11				27			
12				28			
13				29			
14				30			
15				31			
16				1 (next month)			

Note: The difference in water depth between day 1 and 2 plus the rainfall during day 1 is the E pan for day 1

Calculate:

Sum E pan = ... mm/month

number of days in month = ...

$$E\ pan = \frac{Sum\ E\ pan}{number\ of\ days\ in\ month} = \ldots\ldots\ldots\ldots\ldots mm/day$$

K pan = ...

ETo = K pan × E pan = ... × ...... = ... mm/day

DATA SHEET 2
Calculation of the mean monthly temperature: T max and T min

Location: ....
Date: ....
Month: ....
Number of days in the month: ....

Day	T max (°C)	T min (°C)	Day	T max (°C)	T min (°C)
1			16		
2			17		
3			18		
4			19		
5			20		
6			21		
7			22		
8			23		
9			24		
10			25		
11			26		
12			27		
13			28		
14			29		
15			30		
			31		

Calculate:

Sum T max = ...

Sum T min = ...

$$\text{Mean T max} = \frac{\text{Sum T max}}{\text{number of days in month}} = \frac{\qquad}{\qquad} = \ldots\ldots\ldots\ldots\ldots\%$$

$$\text{Mean T min} = \frac{\text{Sum T min}}{\text{number of days in month}} = \frac{\qquad}{\qquad} = \ldots\ldots\ldots\ldots\ldots\%$$

DATA SHEET 3

Determination ETo: Blaney-Criddle Method

Location: ....
Date: ......
Latitude: ....º North/º South

Month	T min (°C)	T max (°C)	T mean (°C)	P Table 4	ETo mm/day
Jan					
Feb					
Mar					
Apr					
May					
Jun					
Jul					
Aug					
Sep					
Oct					
Nov					
Dec					

Note:

$$T\ mean = \frac{T\ max + T\ min}{2}$$

$$\mathbf{ETo = p(0.46T\,mean + 8)}$$

DATA SHEET 4
Determination of crop factors

Location:		Date:	
Humidity:	crop 1: high/medium/low crop 2: high/medium/low	Wind speed:	crop 1: high/medium/low crop 2: high/medium/low

Location : ....   Date : ....

Humidity : crop 1: high/medium/low   Wind speed : crop 1: high/medium/low

crop 2: high/medium/low   crop 2: high/medium/low

Crop 1 : ....   Planting Date : ....

Duration of total growing period : .... days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) :   **Dates**

Initial stage	:	.... days	....
Crop dev. stage	:	.... days	....
Mid season stage	:	.... days	....
Late season stage	:	.... days	....

Crop factors, Kc (Table 8) :

Initial stage	:	....
Crop dev. stage	:	....
Mid season stage	:	....
Late season stage	:	....

Crop 2 : ....   Planting Date : ....

Duration of total growing period : .... days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) :   **Dates**

Initial stage	:	.... days	....
Crop dev. stage	:	.... days	....
Mid season stage	:	.... days	....
Late season stage	:	.... days	....

Crop factors, Kc (Table 8) :

Initial stage	:	....
Crop dev. stage	:	....
Mid season stage	:	....
Late season stage	:	....

DATA SHEET 5

Determination of crop water needs
(see also Data Sheet 4)

Location:...............
Date: ....
Crop: ....
Planting date: ....

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)												
Growth stages												
Kc per gr. St.												
Kc per month												
ET crop (mm/d)												
ET crop (mm/m)												

Crop: ....
Planting date: ....

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)												
Growth stages												
Kc per gr. St												
Kc per month												
ET crop (mm/d)												
ET crop (mm/m)												

Note:

ET crop (mm/day) = Kc (per month) × ETo (mm/day)
ET crop (mm/month) = 30 × ET crop (mm/day)

DATA SHEET 6
Determination of Irrigation water needs
(see also Data sheet 5)

Location: ....
Date: ....
Crop:..................
Planting date:................

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)												
Growth stages												
Kc per gr. St.												
Kc per month												

ET crop (mm/d)												
ET crop (mm/m)												
P (mm/m)												
Pe (mm/m)												
IN (mm/m)												
IN (mm/day)												

Crop: ....
Planting date: ....

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)												
Growth stages												
Kc per gr. St.												
Kc per month												
ET crop (mm/d)												
ET crop (mm/m)												
P (mm/m)												
Pe (mm/m)												
IN (mm/m)												
IN (mm/day)												

Note:

ET crop (mm/day) = Kc (per month) × ETo (mm/day)

ET crop (mm/month) = 30 × ET crop (mm/day)

Pe = 0.6 P - 10 if P < 75 mm/month

Pe = 0.8 P - 25 if P > 75 mm/month

IN (mm/month) = ET crop (mm/month) - Pe (mm/month)

$$\text{IN (mm/day)} = \frac{\text{IN (mm/month)}}{30}$$

DATA SHEET 7
Determination of Irrigation water need of paddy rice

Location: ....
Date: ....

Humidity: crop 1: high/medium/low
crop 2 high/medium/low

Wind speed: crop 1: high/medium/low
crop 2 high/medium/low

No. of crops per year: ....

Planting date: crop 1: ....
crop 2: ....

Rice crop 1: Duration total growing period from sowing or transplant: ....days
Duration mid season stage* ....days

Rice crop 2: Duration total growing period from sowing or transplant: ....days
Duration mid season stage* ....days

*Duration mid season stage = Duration total growing period - 90 days

Crop factors (Table 11)	**Crop: 1**	**2**
day: 0-60	....	....
mid season	....	....
last 30 days	....	....

Saturation requirement: 200 mm crop 1: Month: ....
crop 2: Month: ....

Percolation and seepage: .... mm/day = ... mm/month

Establishment water layer: 100 mm crop 1: Month: ....
crop 2: Month: ....

Crop: ....
Planting date: ....

Months	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
ETo (mm/day)												
Growth stages												
Kc per gr. St.												
Kc per month												
ET crop (mm/d)												
ET crop (mm/m)												
SAT (mm)												
PERC (mm/mo)												
WL (mm)												
P (mm/mo)												
Pe (mm/mo)												
IN (mm/mo)												
IN (mm/day)												

Crop: ....
Planting date: ....

Months	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**

ETo (mm/day)												
Growth stages												
Kc per gr. St.												
Kc per month												
ET crop (mm/d)												
ET crop (mm/m)												
SAT (mm)												
PERC (mm/mo)												
WL (mm)												
P (mm/mo)												
Pe (mm/mo)												
IN (mm/mo)												
IN (mm/day)												

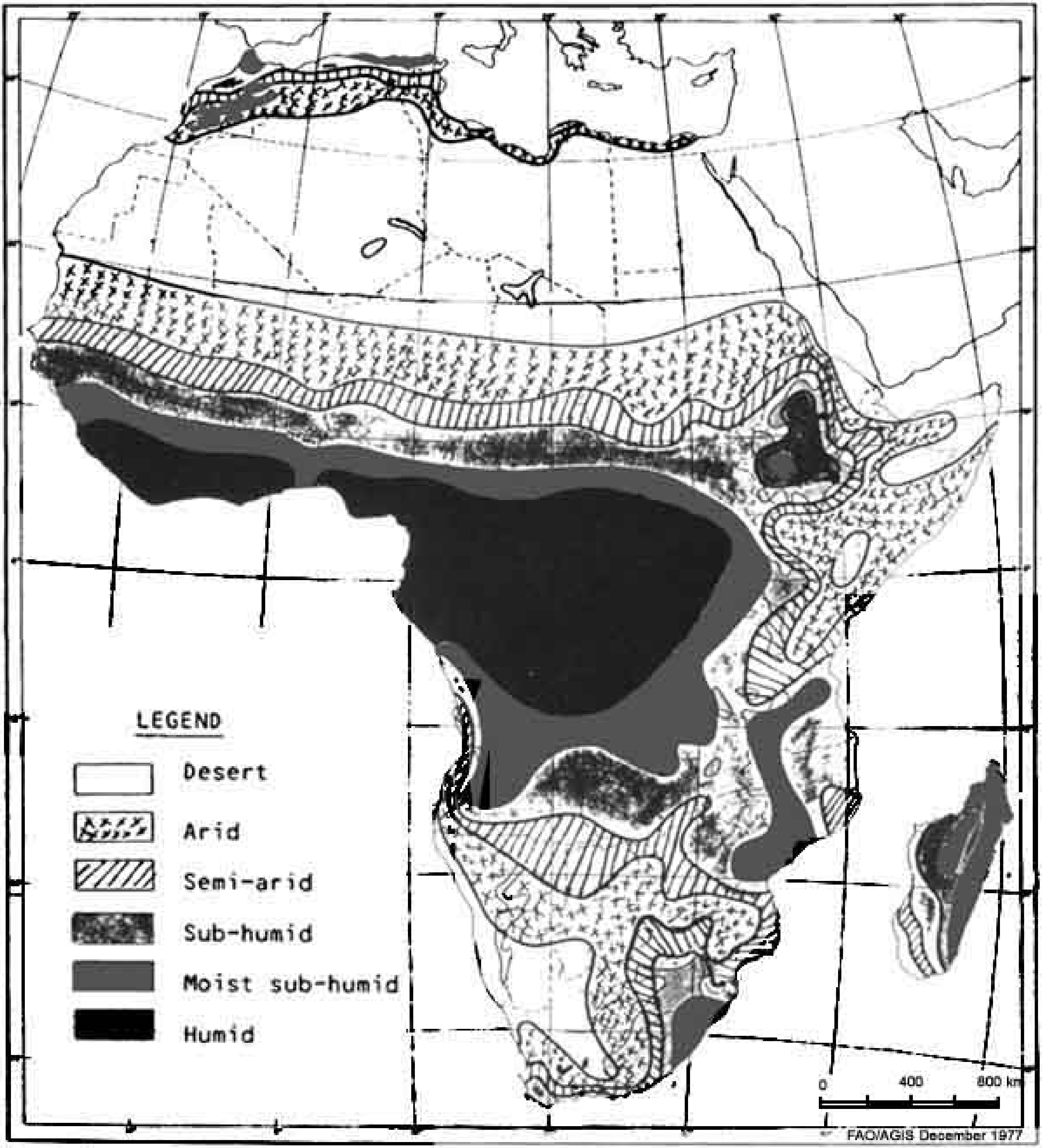
Note:

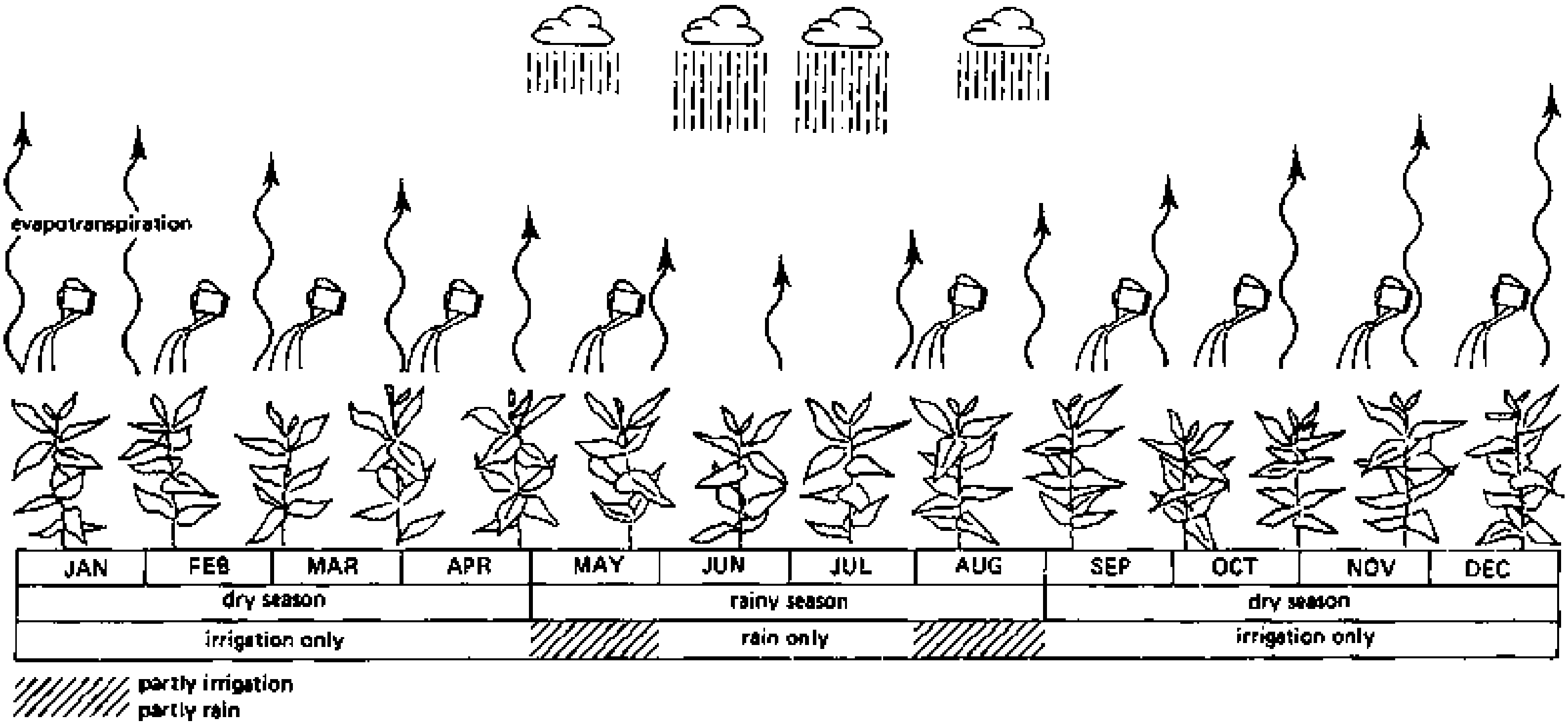
For ET crop and Pe, see Data Sheet 6

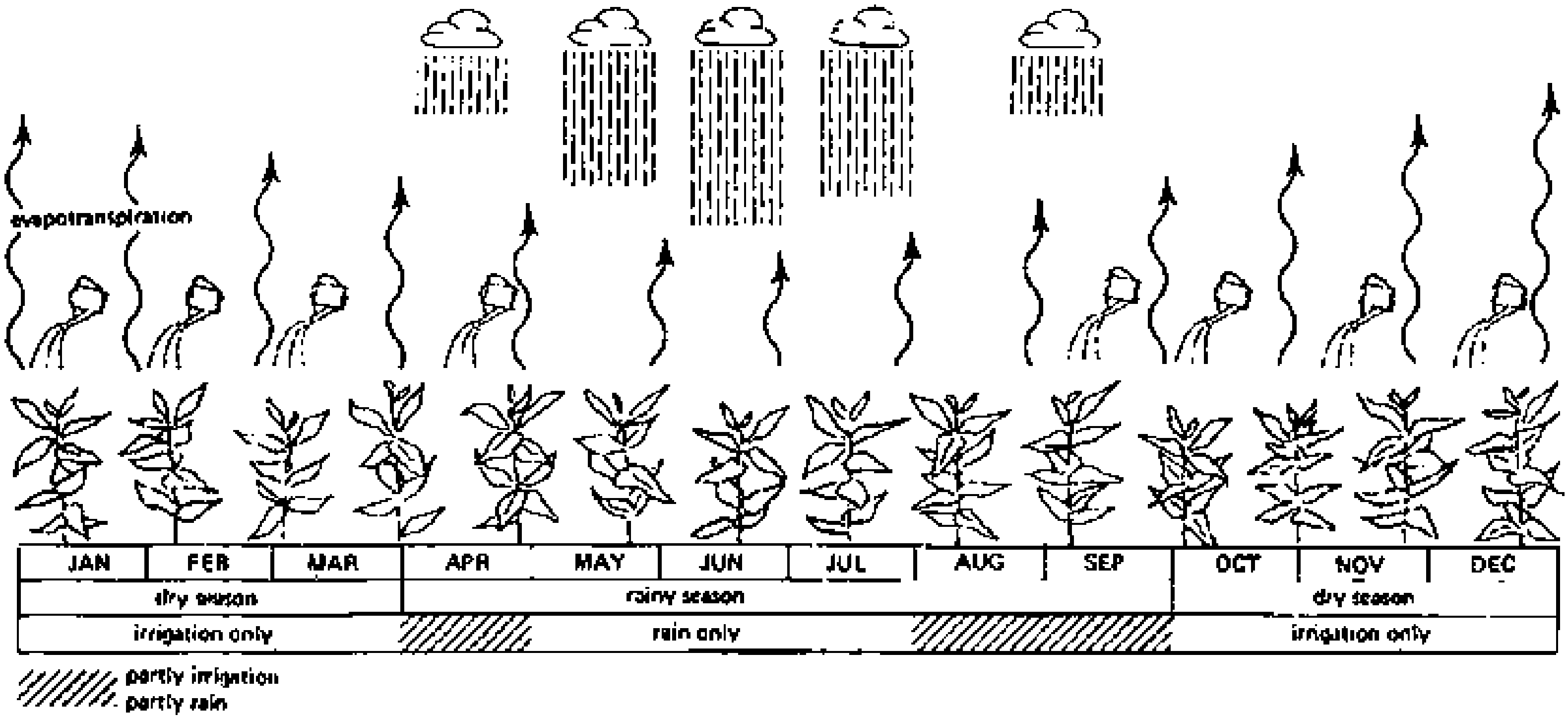
IN (mm/mo) = ET crop (mm/mo) + SAT (mm) + PERC (mm/mo) + WL (mm) - Pe (mm/mo)

$$IN\ (mm/d) = \frac{IN\ (mm/mo)}{30}$$

Tipo-lito SAGRAF - Napoli


LEGEND
Desert
Arid
Semi-arid
Sub-humid
Moist sub-humid
Humid
0
400
800 km
FAO/AGIS December 1977


evapotranspiration
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
dry season
rainy season
dry season
irrigation only
rain only
irrigation only
partly irrigation
partly rain


evapotranspiration
JAN
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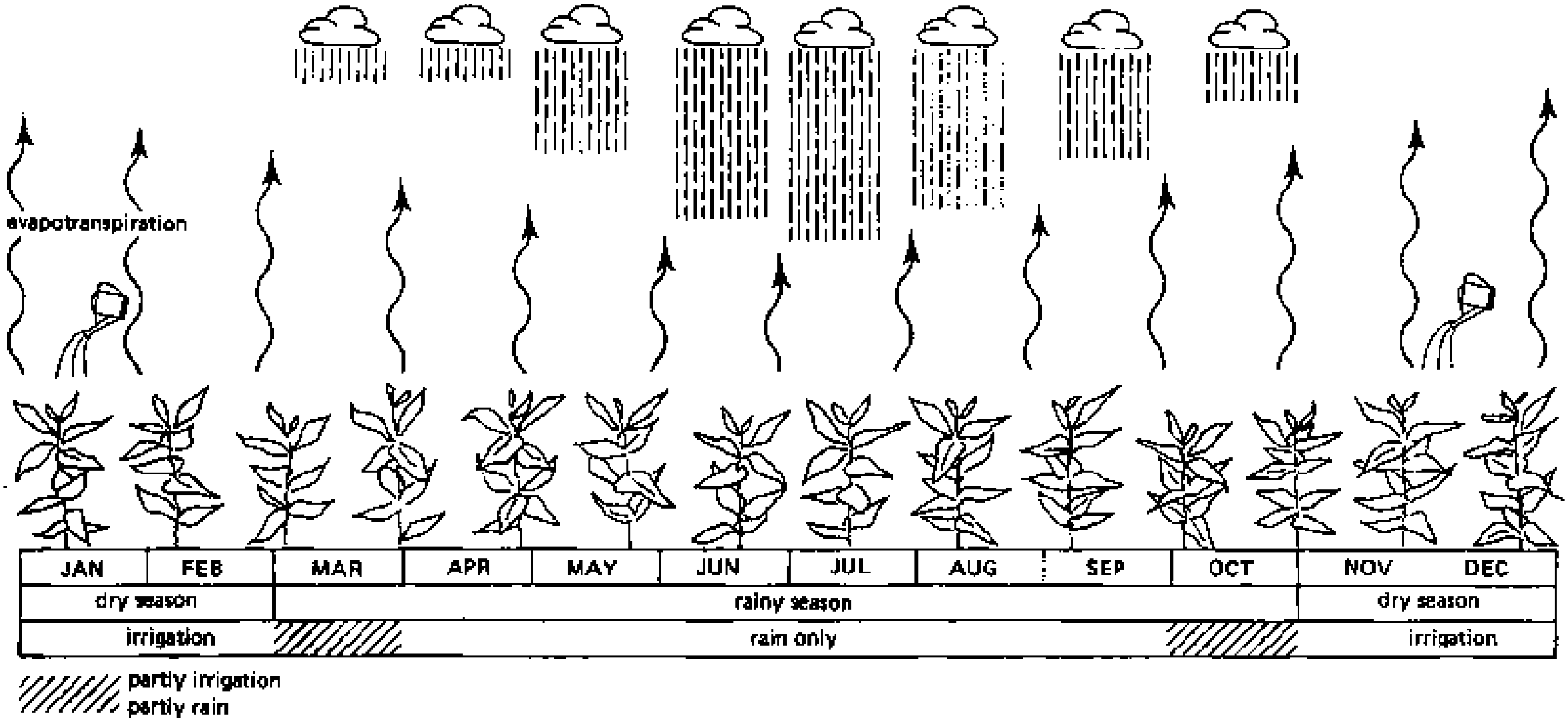
OCT
NOV
DEC
dry season
rainy season
dry season
irrigation only
rain only
irrigation only
partly irrigation
partly rain


evapotranspiration
JAN
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DEC
dry season
rainy season
dry season
irrigation
rain only
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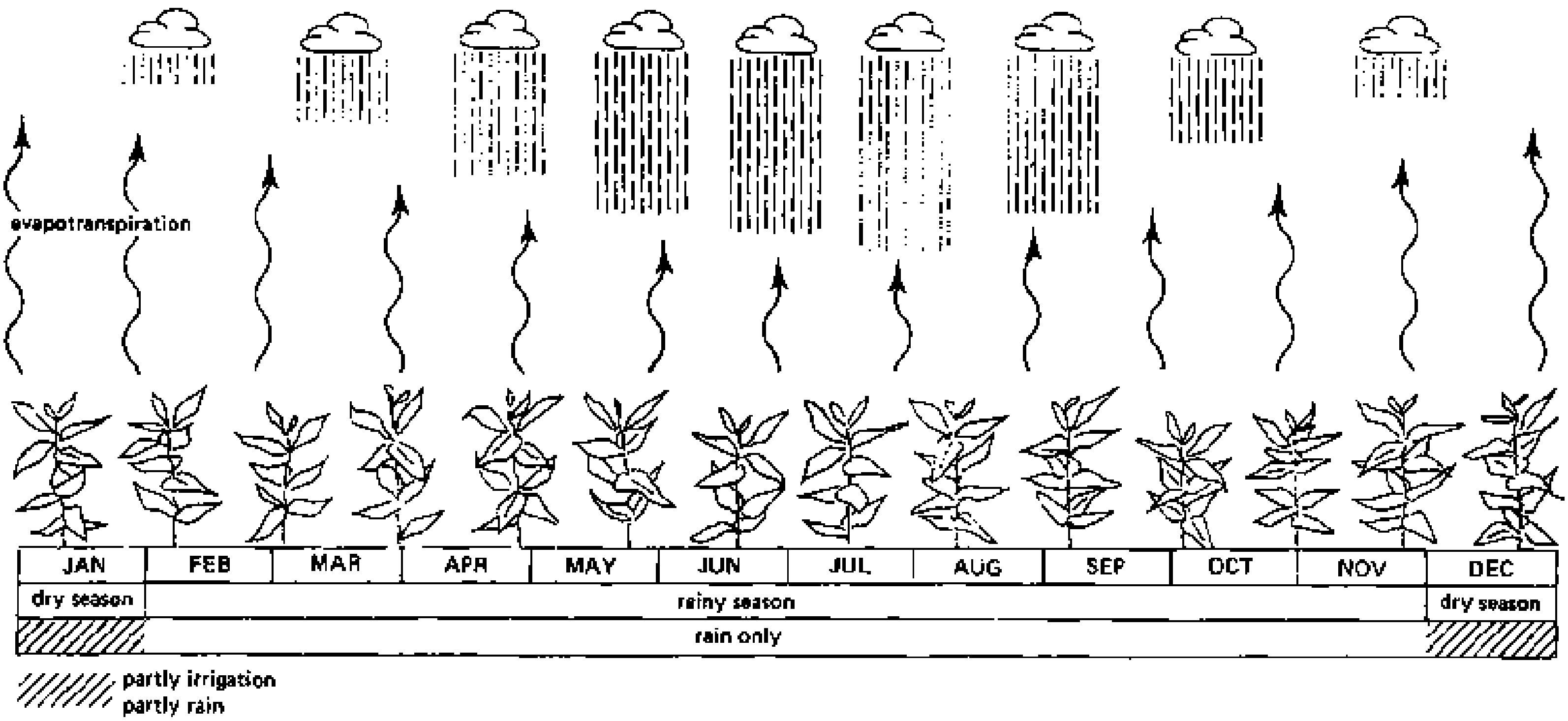
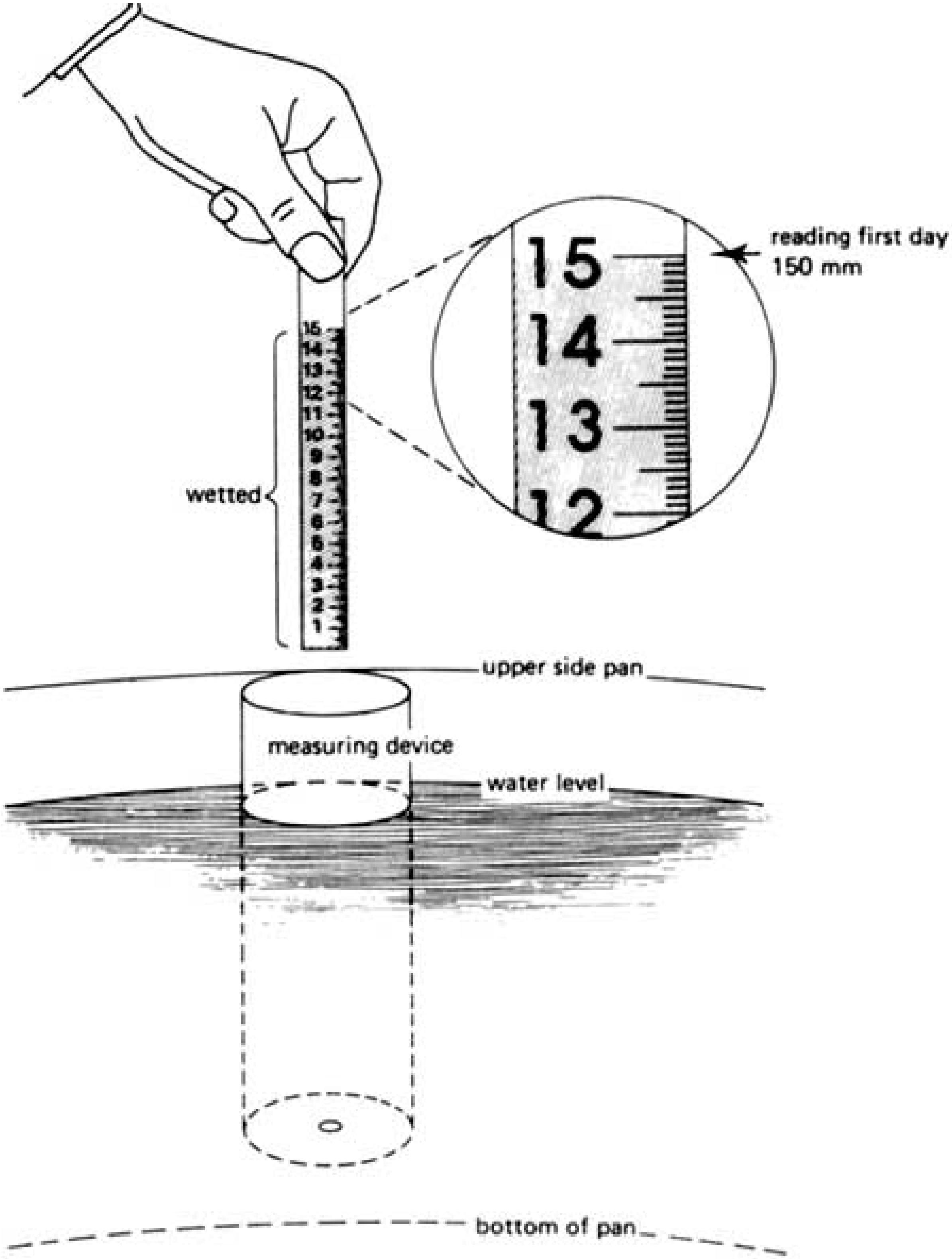
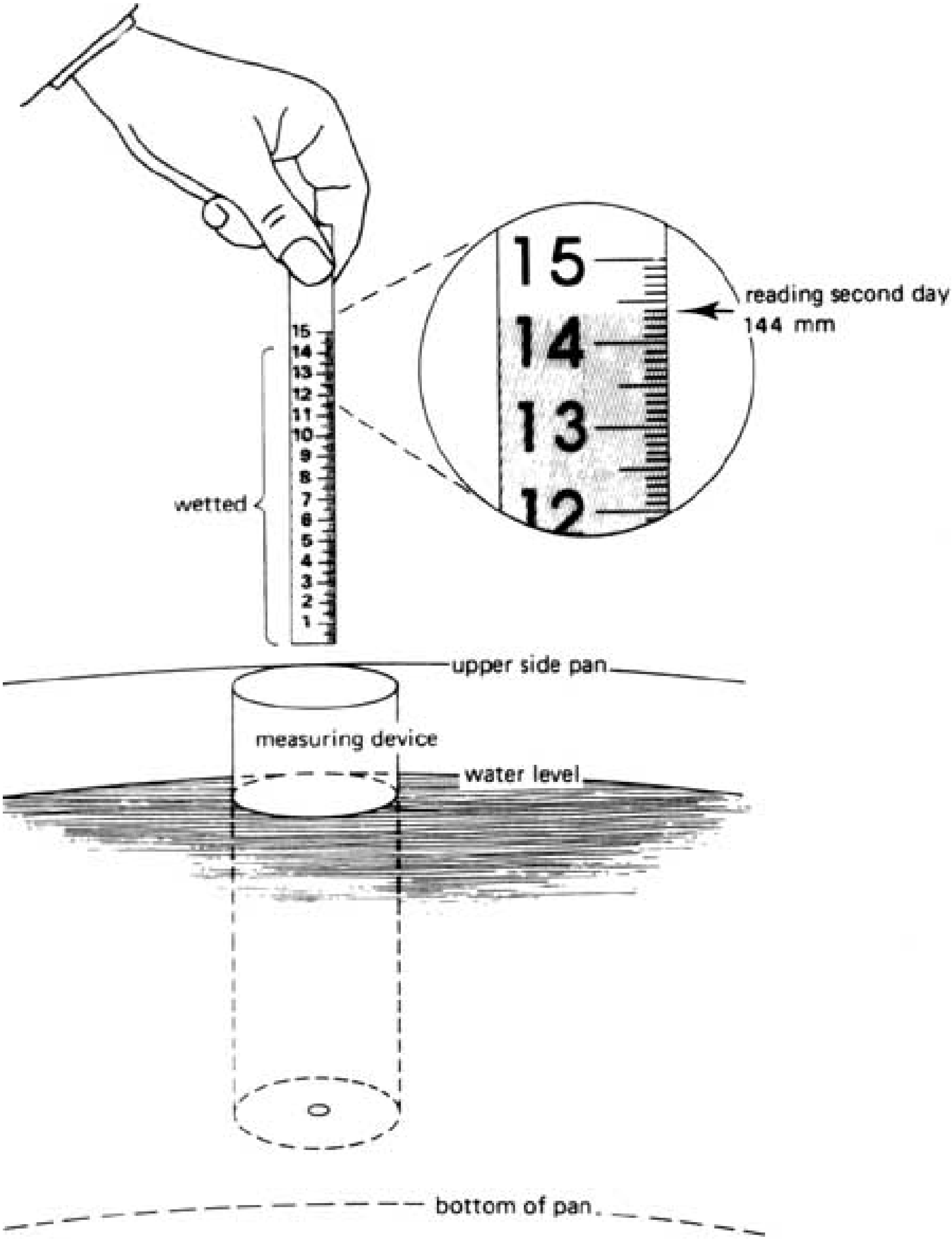
partly irrigation
partly rain


evapotranspiration
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
dry season
reiny season
dry season
rain only
partly irrigation
partly rain


reading first day
150 mm
wetted
upper side pan
measuring device
water level
bottom of pan


15
14
13
12
reading second day
144 mm
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
wetted
upper side pan
measuring device
water level
bottom of pan.

Day	Water depth (mm)	Rainfall (mm)	E pan (mm)	Day	Water depth (mm)	Rainfall (mm)	E pan (mm)
1	155.0	–	6.0	17	151.9	19.6	3.9
2	149.0	2.1	5.9	18	167.6	25.4	3.5
3	145.2	3.2	7.6	19	189.5	33.1	3.0
4	140.8	–	7.7	20	219.6/156.1**	14.1	4.2
5	133.1	–	7.4	21	166.0	–	5.8
6	125.7	–	6.8	22	160.2	–	6.7
7	118.9	–	7.7	23	153.5	–	7.4
8	111.2	–	5.9	24	146.1	–	7.6
9	105.3	–	5.9	25	138.5	–	7.3
10	99.4/157.0*	3.6	6.5	26	131.2	–	8.1
11	154.1	–	7.1	27	123.1	–	8.2
12	147.0	–	7.7	28	114.9	–	7.6
13	139.3	–	7.8	29	107.3	–	7.3
14	131.5	–	6.2	30	100.0	12.0	6.1
15	125.3	14.1	6.5	31	105.9	–	7.4
16	132.9	23.8	4.8	1 (next month)	98.5		

Note: The difference in water depth between day 1 and 2 plus the rainfall during day 1 is the E pan for day 1

* 57.6 mm of water added.
** 63.5 mm of water taken out.

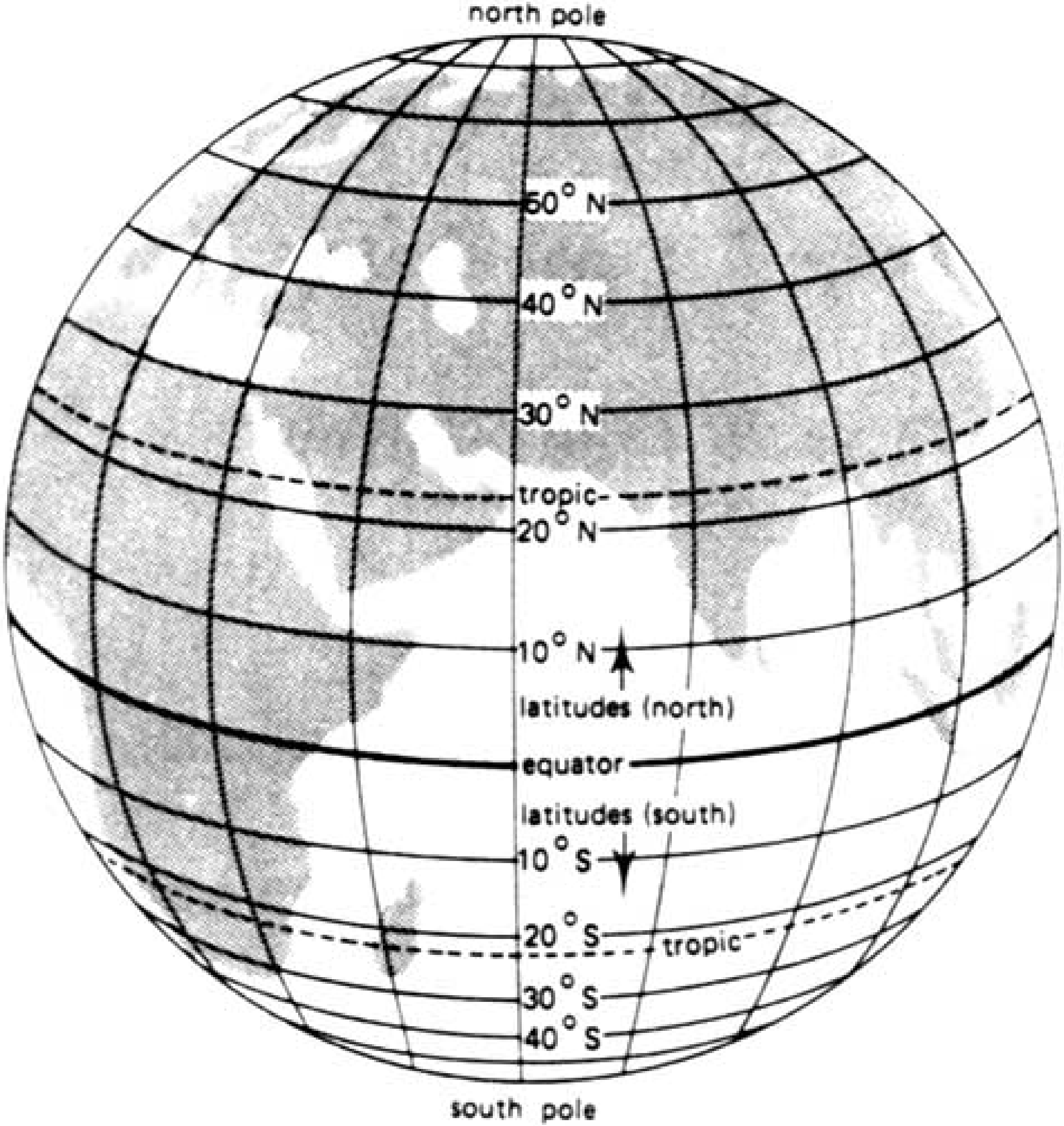
Calculate: Sum E pan = ..201.6.. mm/month

number of days in month = ..31....

$$\text{E pan} = \frac{\text{Sum E pan}}{\text{number of days in month}} = ...6.5.... \text{ mm/day}$$

K pan = ..0.70..

ETo = K pan x E pan = 0.70 x 6.5 = 4.6 mm/day


north pole
50° N
40° N
30° N
tropic
20° N
10° N
latitudes (north)
equator
latitudes (south)
10° S
20° S
tropic
30° S
40° S
south pole

Location: EXAMPLE Date: 1/8/86

Month: JUNE

Number of days in the month: 30

Day	T max (°C)	T min (°C)	Day	T max (°C)	T min (°C)
1	34.6	23.2	16	37.5	25.8
2	35.6	24.1	17	37.7	25.8
3	35.9	24.6	18	37.1	25.5
4	36.5	24.9	19	36.9	25.6
5	37.1	25.4	20	36.5	25.4
6	37.0	25.3	21	36.0	24.8
7	37.6	26.0	22	35.1	24.0
8	37.3	25.5	23	35.5	24.1
9	37.1	25.3	24	35.9	24.4
10	36.0	24.5	25	36.1	24.4
11	35.9	24.3	26	36.5	25.0
12	35.5	23.9	27	37.0	25.5
13	36.6	25.1	28	37.1	25.6
14	37.4	25.5	29	37.5	25.8
15	37.6	26.0	30	37.1	25.5
			31	—	—

Calculate : Sum T max = 1097.2

Sum T min = 750.8

$$\text{Mean T max} = \frac{\text{Sum T max}}{\text{number of days in month}} = \frac{1097.2}{30} = 36.6\ ^{\circ}C$$

$$\text{Mean T min} = \frac{\text{Sum T min}}{\text{number of days in month}} = \frac{750.8}{30} = 25.0\ ^{\circ}C$$

Location : Example Date : 1/8/86

Crop: Maize (grain). Planting date: 1 July

See datasheet 5

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)												
Growth stages												
Kc per gr. st.												
Kc per month												
ET crop (mm/d)												
ET crop (mm/m)							99	144	201	144	37**	
P (mm/m)	0	0	10	14	23	106	144	40	16	0	0	0
Pe (mm/m)	0	0	0	0	4	63	90	14	0	0	0	0
IN (mm/m)							9	130	201	144	37**	
IN (mm/day)							0.3	4.3	6.7	4.8	3.7	

** 10 days

Crop: Cotton Planting date: 1 June

See datasheet 5

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)												
Growth stages												
Kc per gr. st.												
Kc per month												
ET crop (mm/d)												
ET crop (mm/m)						96	135	168	201	126	60**	
P (mm/m)	0	0	10	14	23	106	144	40	16	0	0	0
Pe (mm/m)	0	0	0	0	4	63	90	14	0	0	0	0
IN (mm/m)						33	45	154	201	126	60**	
IN (mm/day)						1.1	1.5	5.1	6.7	4.2	4.0	

** 15 days

Note:

ET crop (mm/day) = Kc (per month) x ETo (mm/day)

ET crop (mm/month) = 30 x ET crop (mm/day)

Pe = 0.6 P - 10 if P < 75 mm/month

Pe = 0.8 P - 25 if P > 75 mm/month

$$IN\ (mm/month) = ET\ crop\ (mm/month) - Pe\ (mm/month)$$

$$IN\ (mm/day) = \frac{IN\ (mm/month)}{30}$$