Irrigation Water Management: Irrigation Methods

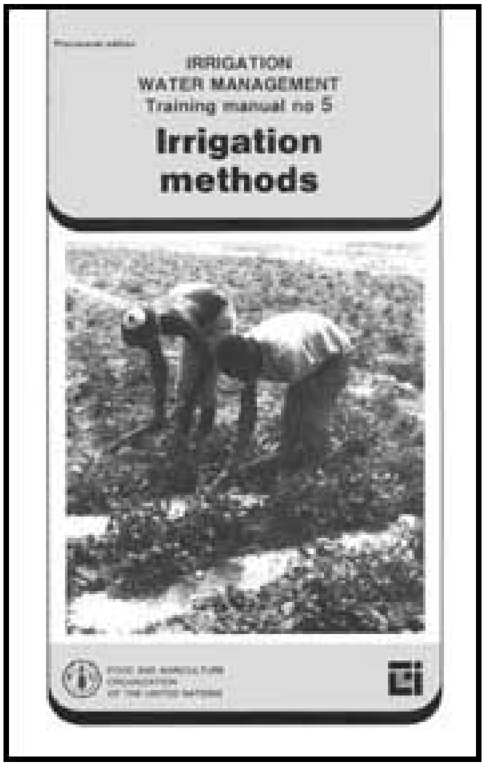


Table of Contents

Training manual no 5

Provisional edition

a manual prepared jointly
by
C. Brouwer
International Institute
for Land Reclamation and Improvement

and

K. Prins, Consultant
M. Kay, Consultant
M. Heibloem

FAO Land and Water
Development Division

FAO - FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Drawings by J. Van Dijk, The International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands

---

Table of Contents

PREFACE

This is one in a series of training manuals on subjects related to irrigation that will be issued in the period from 1985 to 1990.

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 nay 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 to 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:

Water Resources, Development and Management Service
Land and Water Development Division
FAO
Via delle Terme di Caracalla
00100 Rome
Italy

ABOUT THIS PAPER

Irrigation methods is the fifth in a series of training manuals on irrigation. The manual describes in some detail the basin and furrow irrigation methods. Also the border, sprinkler and drip irrigation methods are discussed, but in less detail. One chapter is devoted to the choice of an appropriate irrigation method. Several annexes are Included providing the reader with additional information on the various types of field Intakes, the measuring of the discharge of a siphon or spile, the determination of the soil infiltration rate, the determination of appropriate stream size and irrigation time, and the evaluation of irrigation performance.

ACKNOWLEDGEMENTS

Much appreciation is expressed to the Board of Specialists of the Irrigation Water Management Training Manuals for their valuable comments and suggestions. The Board consists of Messrs. J.F. Alfaro, J. Berengena, J. Dula-Navarrete, H.M. Horning, L. Horst, E. Jensen, M. Kay, J.L. Millo, S. Pazvakavambwa and I. Sewrajsing.

CHAPTER 1. INTRODUCTION

An adequate water supply is important for plant growth. When rainfall is not sufficient, the plants must receive additional water from irrigation. Various methods can be used to supply irrigation water to the plants. Each method has its advantages and disadvantages. These should be taken into account when choosing the method which is best suited to the local circumstances.

A simple irrigation method is to bring water from the source of supply, e.g. a well, to each plant with a bucket or a watering can (see Figure 1).

Figure 1 Watering plants with a can

This can be a very time-consuming method and involves very heavy work. However, it can be used successfully to irrigate very small plots of land, such as vegetable gardens, that are close to the water source.

More sophisticated methods of water application are used when larger areas require irrigation. There are three commonly used methods: surface irrigation, sprinkler irrigation and drip irrigation.

Surface irrigation:	basin irrigation
	furrow irrigation
	border irrigation
Sprinkler irrigation	
Drip irrigation	

1.1 Surface Irrigation

Surface irrigation is the application of water by gravity flow to the surface of the field. Either the entire field is flooded (basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders).

BASIN IRRIGATION

Basins are flat areas of land, surrounded by low bunds (see section 2.2.2). The bunds prevent the water from flowing to the adjacent fields. Basin irrigation is commonly used for rice grown on flat lands or in terraces on hillsides (see Figure 2a). Trees can also be grown in basins, where one tree is usually located in the middle of a small basin (Figure 2b). In general, the basin method is suitable for crops that are unaffected by standing in water for long periods (e.g. 12-24 hours).

Figure 2 Basin irrigation on the hillside

Figure 2 Basin irrigation for trees

FURROW IRRIGATION

Furrows are small channels, which carry water down the land slope between the crop rows. Water infiltrates into the soil as it moves along the slope. The crop is usually grown on the ridges between the furrows (see Figure 3). This method is suitable for all row crops and for crops that cannot stand in water for long periods (e.g. 12-24 hours).

Figure 3 Furrow irrigation, using siphons

Irrigation water flows from the field channel into the furrows by opening up the bank of the channel, or by means of siphons or spiles (see Annex 1).

BORDER IRRIGATION

Borders are long, sloping strips of land separated by bunds. They are sometimes called border strips.

Irrigation water can be fed to the border in several ways: opening up the channel bank, using small outlets or gates or by means of siphons or spiles. A sheet of water flows down the slope of the border, guided by the bunds on either side. (see Figure 4).

Figure 4 Border irrigation, using siphons

1.2 Sprinkler Irrigation

Sprinkler irrigation is similar to natural rainfall. Water is pumped through a pipe system and then sprayed onto the crops through rotating sprinkler heads.

Figure 5 Sprinkler irrigation

1.3 Drip Irrigation

With drip irrigation, water is conveyed under pressure through a pipe system to the fields, where it drips slowly onto the soil through emitters or drippers which are located close to the plants. Only the immediate root zone of each plant is wetted. Therefore this can be a very efficient method of irrigation (Figure 6). Drip irrigation is sometimes called trickle irrigation.

Figure 6 Drip irrigation (A)

Figure 6 Drip irrigation (B)

1.4 Functioning of Irrigation Systems

Whatever irrigation method is being chosen, its purpose is always to attain a better crop and a higher yield. Therefore proper design, construction and irrigation practice are of utmost importance. Maintenance, the after-care of the system to keep it functioning as well as possible, is often neglected. This always results in a lower irrigation efficiency (see also Volume 4), and thus less benefit from the irrigation system.

It is recommended to give canals, structures and methods a regular check-up and to repair damage immediately. Maintenance of canals and structures is dealt with in the Volumes concerning these subjects; maintenance of surface methods is discussed in the appropriate sections (2.5, 3.6, 4.4). Maintenance of sprinkler and drip systems is usually described in handbooks supplied by the manufacturers of the systems.

CHAPTER 2. BASIN IRRIGATION

2.1 When to Use Basin Irrigation

This chapter indicates which crops can be grown in basins, which land slopes are acceptable and which soil types are most suitable. Chapter 7 discusses under which circumstances to choose basin irrigation.

2.1.1 Suitable crops

Basin irrigation is suitable for many field crops. Paddy rice grows best when its roots are submerged in water and so basin irrigation is the best method to use for this crop (Figure 7).

Figure 7 Basin irrigation; transplanting paddy rice

Other crops which are suited to basin irrigation include:

- pastures, e.g. alfalfa, clover;
- trees, e.g. citrus, banana;
- crops which are broadcast, such as cereals;
- to some extent row crops such as tobacco.

Basin irrigation is generally not suited to crops which cannot stand in wet or waterlogged conditions for periods longer than 24 hours. These are usually root and tuber crops such as potatoes, cassava, beet and carrots which require loose, well-drained soils.

2.1.2 Suitable land slopes

The flatter the land surface, the easier it is to construct basins. On flat land only minor levelling may be required to obtain level basins.

It is also possible to construct basins on sloping land, even when the slope is quite steep. Level basins can be constructed like the steps of a staircase and these are called terraces (Figure 8).

Figure 8 Terraces

2.1.3 Suitable soils

Which soils are suitable for basin irrigation depends on the crop grown. A distinction has to be made between rice and non-rice or other crops.

Paddy rice is best grown on clayey soils which are almost impermeable as percolation losses are low. Rice could also be grown on sandy soils but percolation losses will be high unless a high water table can be maintained. Such conditions sometimes occur in valley bottoms.

Although most other crops can be grown on clays, loamy soils are preferred for basin irrigation so that waterlogging (permanent saturation of the soil) can be avoided. Coarse sands are not recommended for basin irrigation as, due to the high infiltration rate, percolation losses can be high. (How to determine the infiltration rate of the soil is explained in detail in Annex 2.) Also soils which form a hard crust when dry (capping) are not suitable.

2.2 Basin Layout

Basin **layout** not only refers to the shape and size of basins but also to the shape and size of the bunds. What is the shape of the basin: square, rectangular or irregular? What is the size of the basin: 10, 100, 1000 or 10 000 m^2? How high should the bund be: 10, 50 or 100 cm? What is the shape of the bund? These aspects are discussed in the following sections.

2.2.1 Shape and size of basins

The shape and size of basins are mainly determined by the land slope, the soil type, the available stream size (the water flow to the basin), the required depth of the irrigation application and farming practices.

BASIN WIDTH

The main limitation on the width of a basin is the land slope. If the land slope is steep, the basin should be narrow, otherwise too much earth movement will be needed to obtain level basins. Table 1 provides some guidance on the maximum width of basins or terraces, depending on the land slope.

Three other factors which may affect basin width are:

- depth of fertile soil,
- method of basin construction,
- agricultural practices.

If the topsoil is shallow, there is a danger of exposing the infertile subsoil when the terraces are excavated. This can be avoided by reducing the width of basins and thus limiting the depth of excavation.

Table 1 APPROXIMATE VALUES FOR THE MAXIMUM BASIN OR TERRACE WIDTH (m)

Slope %	Maximum width (m)	
	average	range
0.2	45	35-55
0.3	37	30-45
0.4	32	25-40
0.5	28	20-35
0.6	25	20-30
0.8	22	15-30
1.0	20	15-25
1.2	17	10-20
1.5	13	10-20
2.0	10	5-15
3.0	7	5-10
4.0	5	3-8

Basins can be quite narrow if they are constructed by hand labour but will need to be wider if machines are used so that the machines can easily be moved around.

If hand or animal powered tillage is used then basins can be much narrower than if machines are used for cultivation. If machines are used then it is important to make sure that basin widths are some multiple of the width of the machines for efficient mechanization.

BASIN SIZE

The size of basins depends not only on the slope but also on the soil type and the available water flow to the basins. The relationship between soil type, stream size and size of the basin is given in Table 2. Values are based on practical experience, and have been adjusted in particular to suit small-scale irrigation conditions.

Table 2 SUGGESTED MAXIMUM BASIN AREAS (m^2) FOR VARIOUS SOIL TYPES AND AVAILABLE STREAM SIZES (l/sec)

Stream size (l/sec)	Sand	Sandy loam	Clay loam	Clay
5	35	100	200	350
10	65	200	400	650
15	100	300	600	1000

30	200	600	1200	2000
60	400	1200	2400	4000
90	600	1800	3600	6000

Example of how to estimate Basin Sizes

Question: Estimate the dimensions of basins, when the soil type is a deep clay loam and the land slope is 1%. As basin construction is mechanized, the terraces should be as wide as possible. The available stream size is 25 l/sec.

Answer: From Table 1 the maximum basin or terrace width for a slope of 1% is 25 m (range 15-25 m). From Table 2 the maximum basin size for a clay loam soil and an available stream size of 25 l/sec is 1000 m^2.

If the total basin area is 1000 m^2 and the width is 25 m, the maximum basin length is 1000/25 = 40 m.

Note: This example shows how to estimate the maximum basin dimensions. This basin can be made smaller than this if required and still be irrigated efficiently with the available stream size.

The size of the basin is also influenced by the depth (in mm) of the irrigation application. If the required irrigation depth is large, the basin can be large. Similarly, if the required irrigation depth is small, then the basin should be small to obtain good water distribution. This is further explained in Annex 3.

The size and shape of basins can often be limited by farming practice. Many farms in developing countries are very small and cultivation is by hand. In these circumstances basins are usually small as they are easy to level and efficient irrigation can be attained with relatively small stream sizes.

On the large mechanized farms, basins are generally made as large as possible to provide large uninterrupted areas for machine movements. Basin dimensions are chosen to be some multiple of the width of the machines so as to use the equipment as efficiently as possible. Other reasons to make basins as large as possible are that less land is wasted in this way (less bunds) and large stream sizes and a relatively large application depth can be used.

The shape of the basin can be square, rectangular or irregular. The shape is mainly determined by the slope. On steep and irregular sloping lands, the basins may be long and narrow. The long side of the basin is along the contour line. If the slope and thus the contour line is irregular, the shape of the basin will also be irregular.

IN SUMMARY

BASINS SHOULD BE SMALL IF THE:

1. slope of the land is steep
2. soil is sandy
3. stream size to the basin is small
4. required depth of the irrigation application is small
5. field preparation is done by hand or animal traction.

BASINS CAN BE LARGE IF THE:

1. slope of the land is gentle or flat
2. soil is clay
3. stream size to the basin is large
4. required depth of the irrigation application is large
5. field preparation is mechanized.

2.2.2 Shape and dimensions of bunds

Bunds are small earth embankments which contain irrigation water within basins. They are sometimes called ridges, dykes or levees. The height of bunds is determined by the irrigation depth and the freeboard. The freeboard is the height above the irrigation depth to be sure that water will not overtop the bund.

The width of bunds should be such that leakage will not occur, and that they are stable.

Temporary bunds are normally 60-120 cm wide at the base and have a height of 1.5-30 cm above the original ground surface, including a freeboard of 10 cm (which means an irrigation depth of 5-20 cm). Temporary bunds surround fields on which annual crops are grown; these bunds are rebuilt each season.

Figure 9 Shape and dimensions of permanent bunds

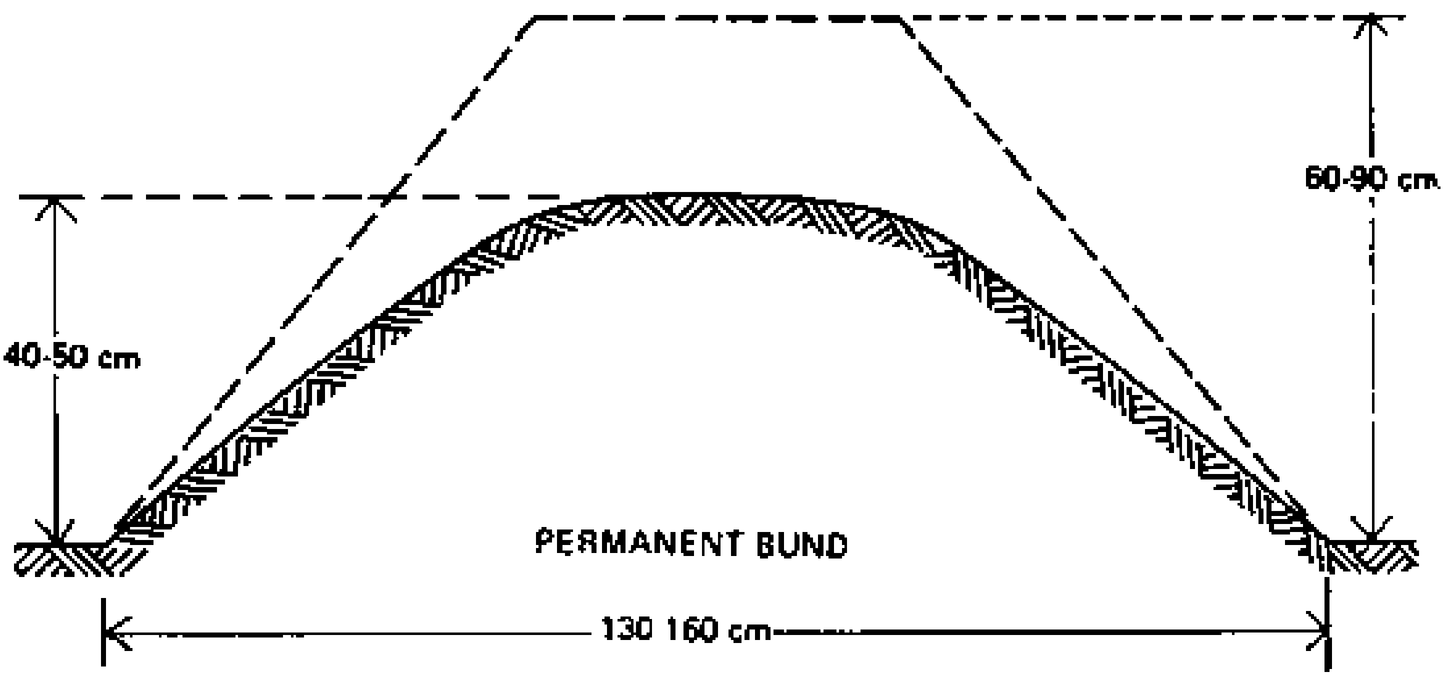
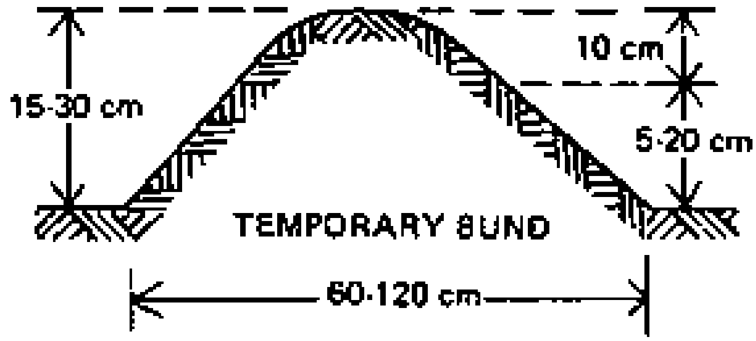


Figure 9 Shape and dimensions of temporary bunds



Permanent bunds usually have a base width of 130-160 cm and a height of 60-90 cm when constructed. The settled height will be 40-50 cm. This settling (compaction of the soil) will take several months.

Permanent bunds are mostly used in rice cultivation, where the same crop is planted on the same fields year after year. The bunds are used as paths in the rice fields as well. Temporary bunds may be used to subdivide the various fields further, for example as indicated in Figure 15.

2.3 Basin Construction

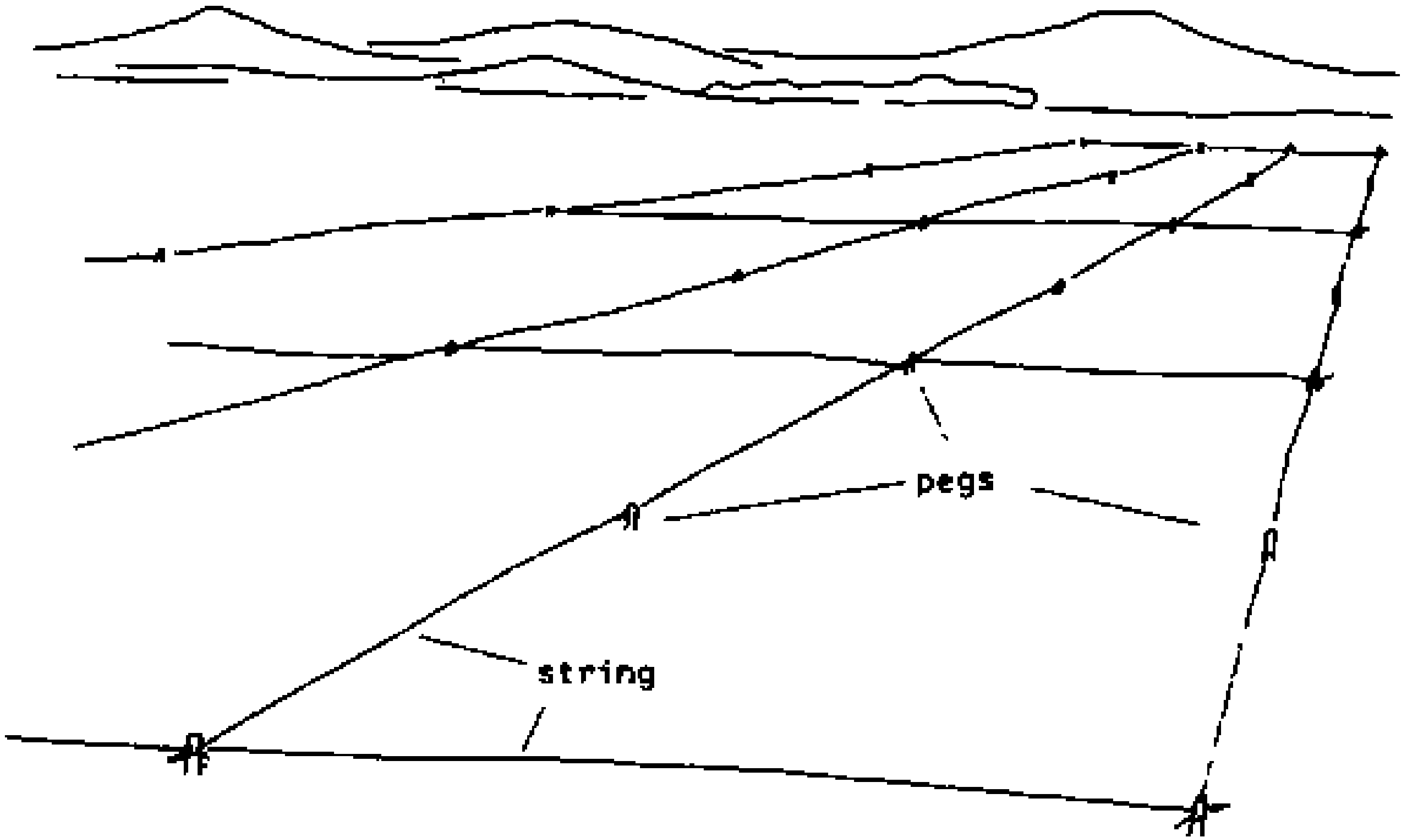
The following steps are involved in the construction of basins: setting out; forming the bunds; and smoothing the land within the basins.

Step 1: Setting Out

Before construction can begin the location of the basins and bunds must be set out on the ground. This can be done using pegs, string lines or chalk powder to mark the lines of the bunds.

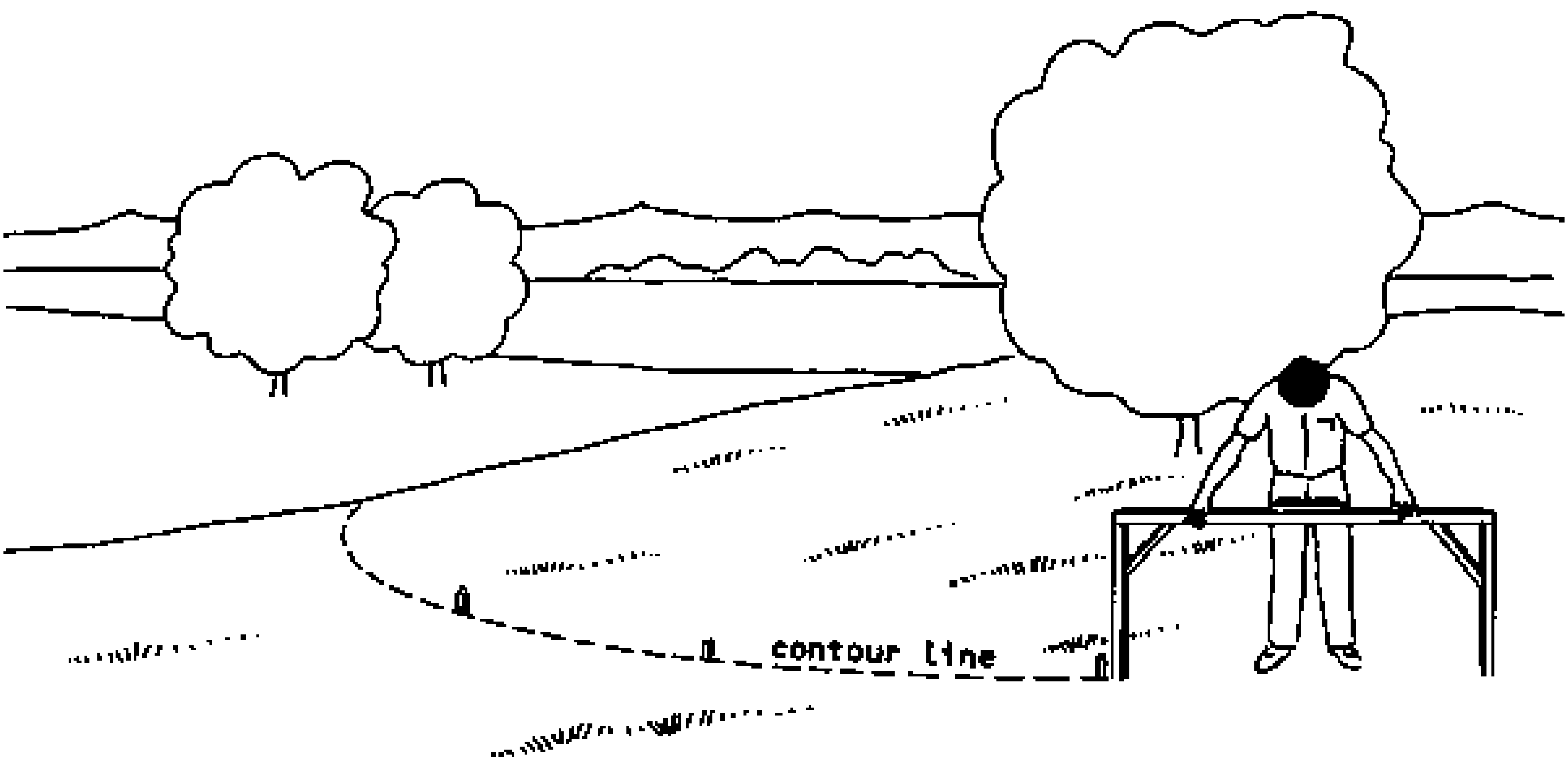
On flat land basins may be square or rectangular in shape (Figure 10). Setting out is relatively simple and involves only straight lines. On sloping or undulating land basins may be irregular in shape and terracing required. Terraces are set out so that the bunds are located along contour lines; the differences in elevation within each basin should not be excessive so that the amount of earth movement required to obtain a level land surface is small (see Table 1).

Figure 10 Setting out the markers



A terrace is set out by first locating a suitable contour line across the land slope (Figure 11; see also Volume 2). This is the line along which the first bund is constructed. A second line is then set out along a contour further up the slope to mark the location of the next bund.

Figure 11 Marking a contour line



Step 2: Forming the bunds

Both temporary and permanent bunds can be formed by hand labour or by animal or tractor powered equipment. When soil is gathered from an area close to the bund a 'borrow-furrow' is formed. This furrow can be smoothed out later or be used as a farm channel or drain. When forming bunds for terraces, soil should only be taken from the uphill side of the bund.

A useful piece of equipment for forming bunds is an A-frame (Figure 12). This consists of two boards set on edge and cross-braced, with a wide opening at the front and a narrow opening at the rear. The boards act as blades for cutting into the soil and crowding it into a ridge or bund (Figure 13). A typical A-frame suitable for drawing by animals has blades 20 cm deep and 2 m long spaced 1.5 m apart at the front and 30 cm apart at the rear.

Figure 12 Wooden A-frame

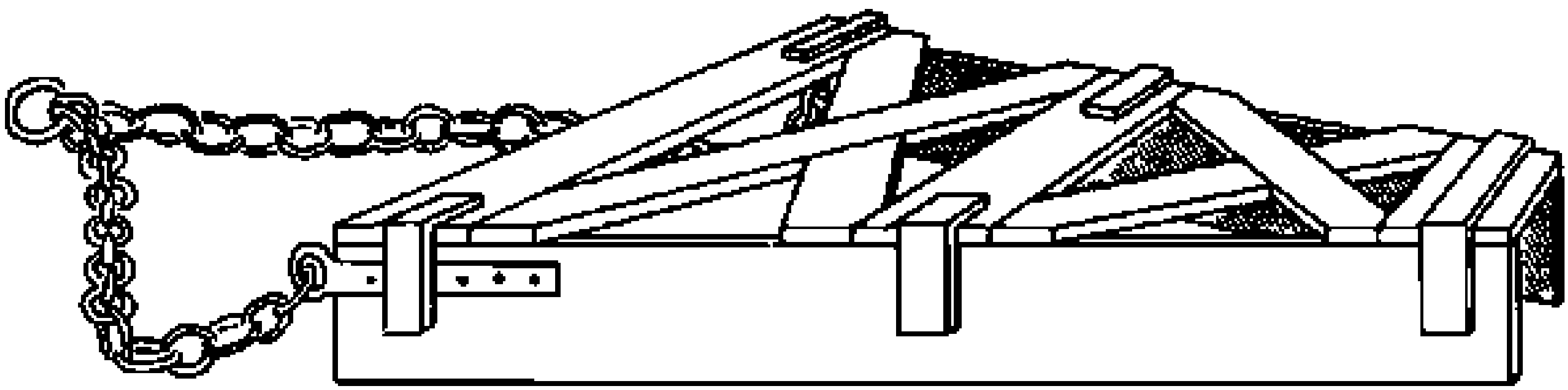
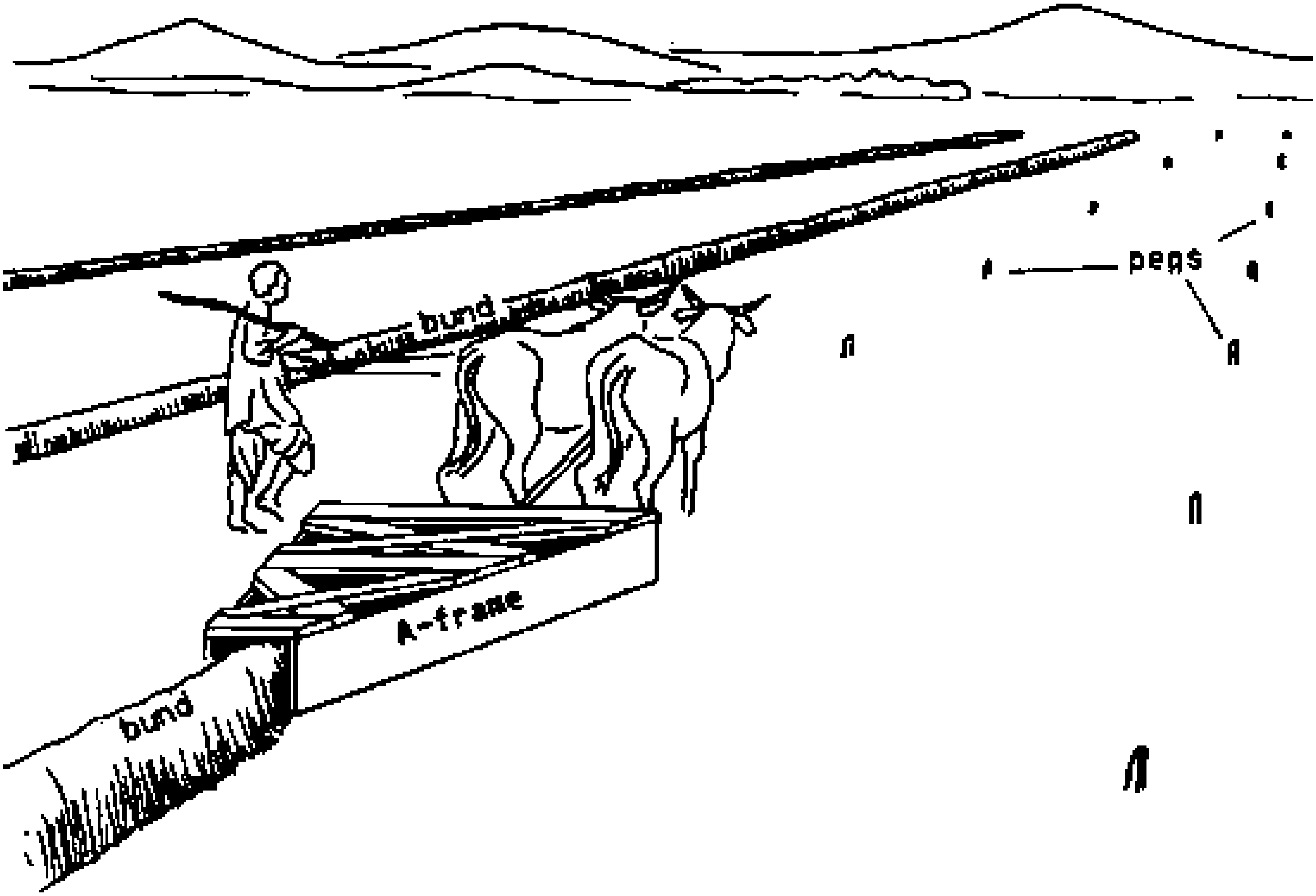


Figure 13 Making the bunds



Before forming bunds with an A-frame it is useful to loosen the top soil to a depth of 10-15 cm so that the blades can easily collect sufficient soil.

Whichever method is used it is important that the bunds are properly compacted so that leakage cannot occur.

Step 3: Smoothing the land

This can be the most difficult part of basin construction and involves very careful levelling of the land within each basin.

On flat land this involves smoothing out the minor high and low spots so that the differences in level are less than 3 cm. This can be done by hand or by a tractor-drawn land plane depending on the size of the basin. However, 3 cm level differences are almost impossible to judge by eye and only when applying water will it become obvious where high and low spots still exist. Thus several attempts may be required to correct the levelling.

Levelling rice basins can be much simpler. These are first cultivated and then filled with water. As the water surface is level, it will be obvious where the high spots are. These can be smoothed put and the water in the basin gradually lowered to reveal other high areas. The smoothing is usually done by an animal or tractor drawn float. This method of smoothing usually destroys the soil structure. This is not a problem when growing rice, but it is not a recommended procedure for other crops.

On sloping land, where terraces are constructed, levelling is achieved by moving soil from the upper part of the slope to the lower part (Figure 14). Care is needed when filling in the borrow furrow to ensure the bund height is maintained so that overtopping is avoided.

Figure 14 Construction terraces (Construction first bund)

Figure 14 Construction terraces (Levelling 1st field)

Figure 14 Construction terraces (Construction 2nd bund)

2.4 Irrigating Basins

There are two methods to supply irrigation water to basins: the direct method and the cascade method.

The direct method

Irrigation water is led directly from the field channel into the basin through siphons, spiles or bundbreaks (see also Annex 1).

Figure 15 shows that "Basin a" is irrigated first, then "Basin b" is irrigated and so on. This method can be used for most crop types and is suitable for most soils.

Figure 15 Direct method of water supply

The cascade method

On sloping land, where terraces are used, the irrigation water is supplied to the highest terrace, and then allowed to flow to a lower terrace and so on. In Figure 16 the water is supplied to the highest terrace (a.1) and is allowed to flow through terrace a.2 until the lowest terrace (a.3) is filled. The intake of terrace a.1 is then closed and the irrigation water is diverted to terrace b.1 until b.1, b.2 and b.3 are filled, and so on.

Figure 16 Cascade method of water supply

This is a good method to use for paddy rice on clay soils where percolation and seepage losses are low. However, for other crops on sandy or loamy soils, percolation losses can be excessive while water is flowing through the upper terraces to irrigate the lower ones. This problem can be overcome by using the borrow-furrow as a small channel to take water to the lower terrace. The lower terrace is irrigated first and when complete the bund is closed and water is diverted into the next terrace. Thus the terrace nearest the supply channel is the last to be irrigated.

When long cascades are used for growing rice it is common practice to allow water to flow continuously into the terraces at low discharge rates. The water demand in the cascade can easily be monitored by observing the drainage flow. If there is no drainage then more water may be required at the top of the cascade. If there is a drainage flow then it is possible to reduce the inflow.

2.4.1 Wetting patterns

For good crop growth it is very important that the right quantity of water is supplied to the root zone (see also Volume 3: Irrigation Water Needs) and that the root zone is wetted uniformly.

If crops receive too little water, they will suffer from drought stress, and yield may be reduced. If they receive too much water, then water is lost through deep percolation and, especially on clay soils, permanent pools may form, causing the plants to drown. How much irrigation water should be supplied to the root zone - in other words "the net irrigation depth" - has been discussed in Volume 3. How the irrigation water can be evenly distributed in the root zone is explained below, and an example of the evaluation of basin irrigation performance is given in Annex 4.

Ideal wetting pattern

To obtain a uniformly wetted root zone, the surface of the basin must be level and the irrigation water must be applied quickly. Figure 17 shows an ideal wetting pattern: the basin is level and the right quantity of water has been supplied with the correct scream size. As can be seen from Figure 17, it is not possible to have the wetting pattern and root zone coincide completely. The part of the basin near the field channel is always in contact with the irrigation water longer than the opposite side of the basin. Therefore percolation losses will occur near the field channel, if sufficient water is supplied to the opposite side of the basin.

Figure 17 Ideal wetting pattern

Poor wetting patterns

Poor wetting patterns can be caused by:

- unfavourable natural conditions, e.g. a compacted subsoil layer, or different soil types within one basin;
- poor layout, e.g. a poorly levelled surface;
- poor management, e.g. supplying incorrect stream size, applying too little or too much water.

i. Unfavourable natural conditions

A compacted sub-soil layer can sometimes occur in a basin some 30-50 cm below the soil surface. Infiltration through this layer may be very slow and so water tends to accumulate above this layer: a "perched" water table is formed (Figure 18). This may result in waterlogging.

Figure 18 A nearly impermeable layer above which a perched water table is formed

This situation may be very helpful for growing rice but will be harmful for other crops. The compacted layer can be removed by using deep ploughs or rippers which break up the subsoil.

Different soil types within a basin can cause very uneven water distribution. This problem can be solved by re-aligning basin boundaries so that each basin contains only one soil type.

ii. Poor layout

Figure 19 shows what happens to the wetting pattern if the soil surface is not level. Some parts of the root zone receive too little water and in the lower parts water may pond or be lost through deep percolation. Plants suffer in the drier parts because they receive too little water and wilt. Plants may also suffer in the wet parts; plant nutrients are carried away from the rootzone to the subsoil and, especially on clay soils, the plants may drown. These faults can easily be corrected by careful land levelling.

Figure 19 Wetting pattern of a poorly levelled basin

iii. Poor management

Figure 20 shows what happens if the basin is irrigated too slowly, by using a stream size which is too small. The part of the basin which receives irrigation water first (near the supply channel) and thus the longest, receives too much water. Percolation losses occur, nutrients are washed away and the plants may drown. The other end of the basin remains too dry. The plants there do not receive enough water and wilt.

Figure 20 Wetting pattern when the flow rate is insufficient

The solution to the problem is to:

- increase the stream size so that the basin will be flooded more rapidly, or

- subdivide the basin into smaller basins; smaller basins need a smaller stream size than larger basins.

Figure 21 shows what happens If insufficient water is applied to fill the root zone. This is called "under-irrigation" and is caused by under-estimating the time needed to fill the root zone.

Figure 21 Under-irrigation

There are no percolation losses during under-irrigation. Although water may be used efficiently by this approach, frequent irrigation will be necessary to meet crop water needs. However, continual under-irrigation will eventually restrict root development and the crop may suffer when there are delays in irrigating, e.g. when water is in short supply or the supply system breaks down.

Figure 22 shows what happens if too much water is supplied to a basin. This is called "over-irrigation". The percolation losses are high, the plant nutrients are washed away and, on clay soils, the plants may even drown. The obvious solution is to apply less water.

Figure 22 Over-irrigation

2.5 Maintenance of Basins

Bunds are susceptible to erosion which may be caused by, for example, rainfall, flooding or the passing of people when used as footpaths. Rats may dig holes in the sides of the bunds. It is therefore important to check the bunds regularly, notice defects and repair them instantly, before greater damage is done. Before each growing season, the basins should be checked to see that they remain level. During pre-irrigation it can easily be seen where higher and lower spots are; there should be smoothed out. Also, the field channels should be kept free from weeds and silt deposits.

CHAPTER 3. FURROW IRRIGATION

Furrows are small, parallel channels, made to carry water in order to irrigate the crop. The crop is usually grown on the ridges between the furrows (Figures 23 and 24).

Figure 23 Furrow irrigation

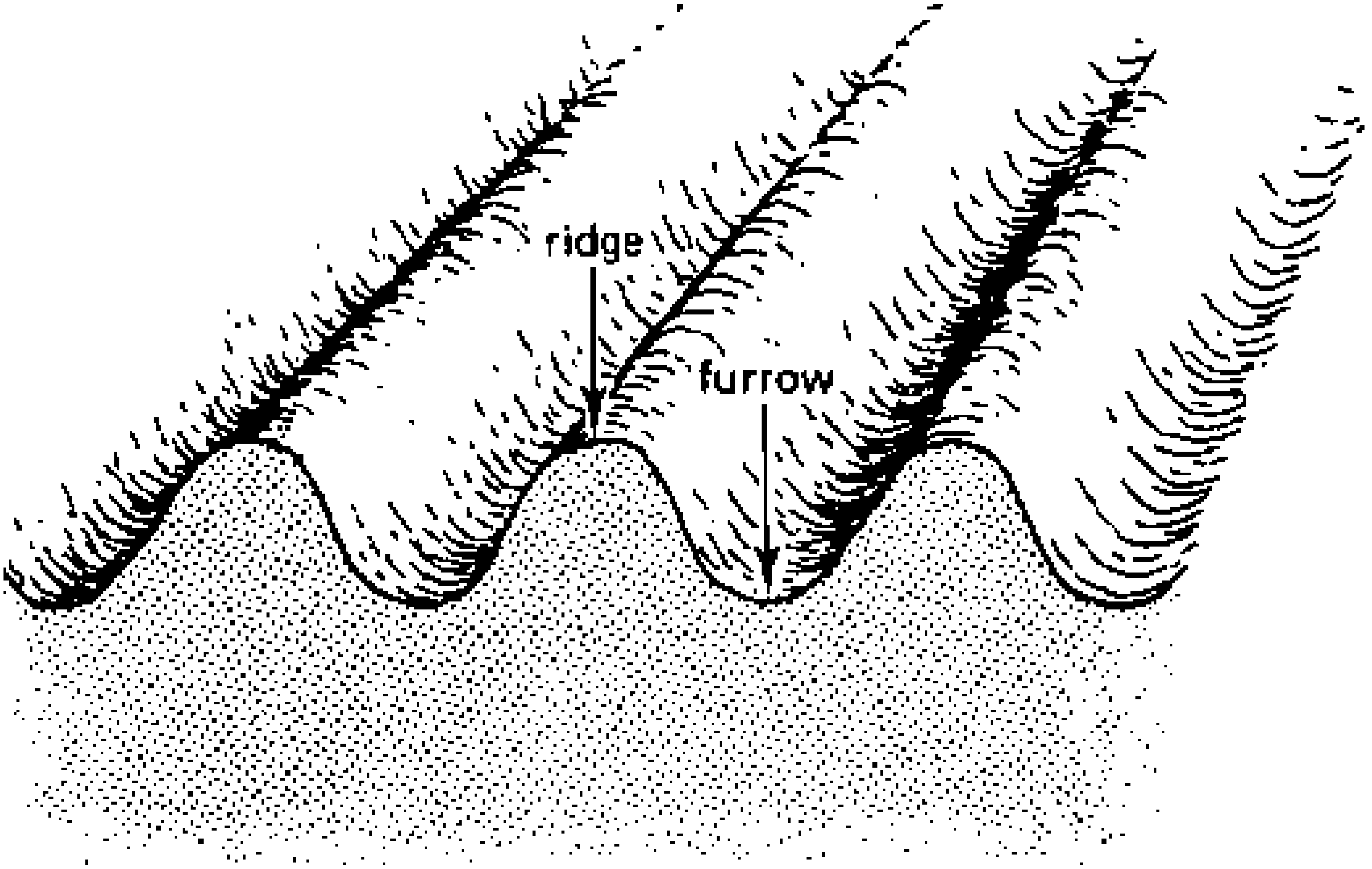
3.1 When to Use Furrow Irrigation

Furrow irrigation is suitable for a wide range of soil types, crops and land slopes, as indicated below. Under which circumstances to choose furrow irrigation is further discussed in Chapter 7.

3.1.1 Suitable crops

Furrow irrigation is suitable for many crops, especially row crops. Crops that would be damaged if water covered their stem or crown should be irrigated by furrows.

Figure 24 Top view and cross-section of furrows and ridges



Furrow irrigation is also suited to the growing of tree crops. In the early stages of tree planting, one furrow alongside the tree row may be sufficient but as the trees develop then two or more furrows can be constructed to provide sufficient water. Sometimes a special zig-zag system is used to improve the spread of water (Figure 25).

Corrugation irrigation, frequently mentioned in literature, is a special type of furrow irrigation, used for broadcast crops. Corrugations are small hills pressed into the soil surface. The application of this method is limited and is not included in this manual.

In summary, the following crops can be Irrigated by furrow irrigation:

- row crops such as maize, sunflower, sugarcane, soybean;
- crops that would be damaged by inundation, such as tomatoes, vegetables, potatoes, beans;
- fruit trees such as citrus, grape;
- broadcast crops (corrugation method) such as wheat.

Figure 25 Zig-zag furrows - A: Zig-zag furrows used for irrigating trees on land with a moderate slope (0.5-1.5%)

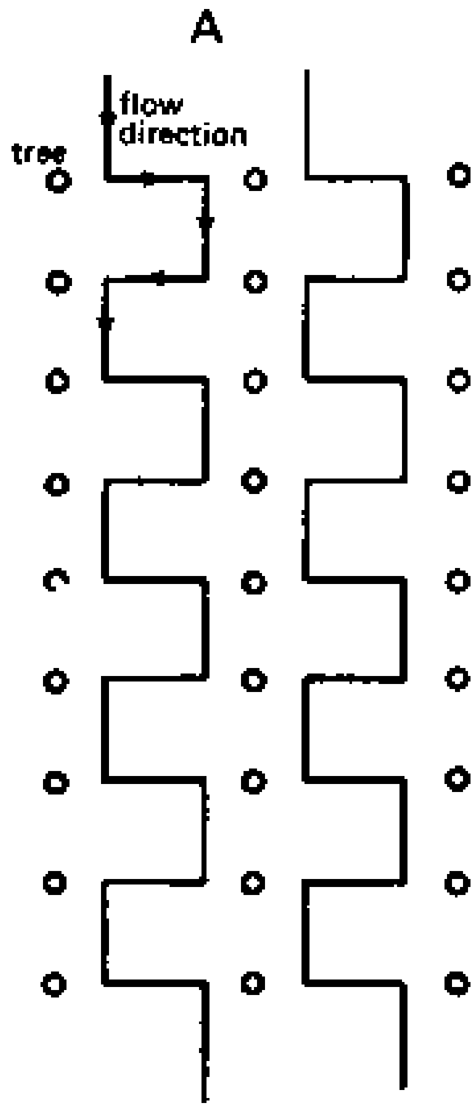
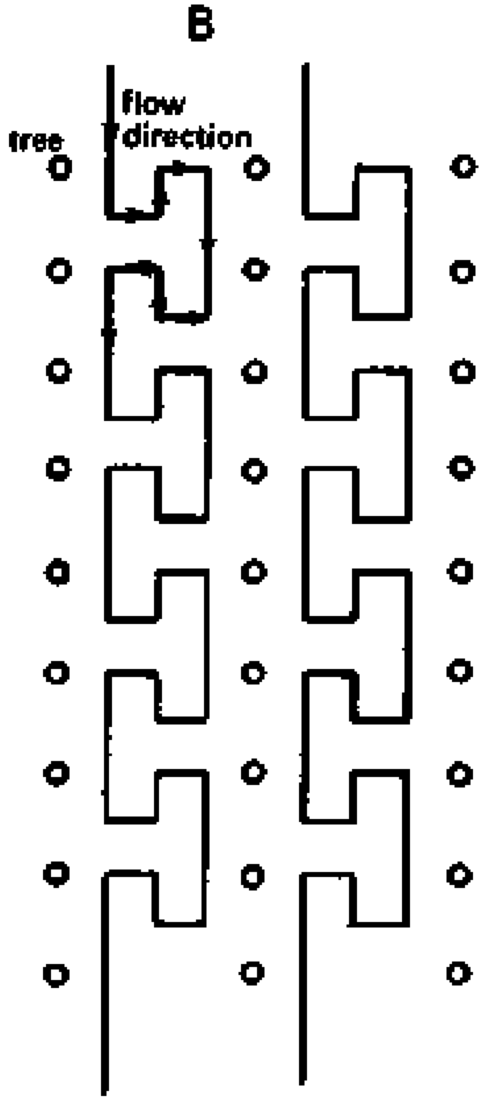


Figure 25 Zig-zag furrows - B: Another zig-zag pattern for furrow irrigation on fairly flat slopes (under 0.5%)



3.1.2 Suitable slopes

Uniform flat or gentle slopes are preferred for furrow irrigation. These should not exceed 0.5%. Usually a gentle furrow slope is provided up to 0.05% to assist drainage following irrigation or excessive rainfall with high intensity.

On undulating land furrows should follow the land contours (see Figure 26). However, this can be a difficult operation requiring very careful setting out of the contours before cutting the furrows (see section 3.3 Furrow Construction).

Figure 26 Contour furrows

3.1.3 Suitable soils

Furrows can be used on most soil types. However, as with all surface irrigation methods, very coarse sands are not recommended as percolation losses can be high. Soils that crust easily are especially suited to furrow irrigation because the water does not flow over the ridge, and so the soil in which the plants grow remains friable.

3.2 Furrow Layout

This section deals with the shape, length and spacing of furrows. Generally, the shape, length and spacing are determined by the natural circumstances, i.e. slope, soil type and available stream size. However, other factors may influence the design of a furrow system, such as the irrigation depth, farming practice and the field length.

3.2.1 Furrow length

Furrows must be on consonance with the slope, the soil type, the stream size, the irrigation depth, the cultivation practice and the field length. The impact of these factors on the furrow length is discussed below.

Slope

Although furrows can be longer when the land slope is steeper, the maximum recommended furrow slope is 0.5% to avoid soil erosion. Furrows can also be level and are thus very similar to long narrow basins. However a minimum grade of 0.05% is recommended so that effective drainage can occur following irrigation or excessive rainfall. If the land slope is steeper than 0.5% then furrows can be set at an angle to the main slope or even along the contour to keep furrow slopes within the recommended limits. Furrows can be set in this way when the main land slope does not exceed 3%. Beyond this there is a major risk of soil erosion following a breach in the furrow system. On steep land, terraces can also be constructed (see Basin Irrigation) and furrows cultivated along the terraces.

Soil type

In sandy soils water infiltrates rapidly. Furrows should be short (less than 110 a), so that water will reach the downstream end without excessive percolation losses.

In clay soils, the infiltration rate is much lower than in sandy soils. Furrows can be much longer on clayey than on sandy soils. The determination of the infiltration rate is explained in Annex 2.

Stream size

Normally stream sizes up to 0.5 l/sec will provide an adequate irrigation provided the furrows are not too long. When larger stream sizes are available, water will move rapidly down the furrows and so generally furrows can be longer. The maximum stream size that will not cause erosion will obviously depend on the furrow slope; in any case, it is advised not to use stream sizes larger than 3.0 l/sec (see Table 3).

Irrigation depth

Applying larger irrigation depths usually means that furrows can be longer as there is more time available for water to flow down the furrows and infiltrate.

Cultivation practice

When the farming is mechanized, furrows should be made as long as possible to facilitate the work. Short furrows require a lot of attention as the flow must be changed frequently from one furrow to the next. However, short furrows can usually be irrigated more efficiently than long ones as it is much easier to keep the percolation losses low.

Field length

It may be more practical to make the furrow length equal to the length of the field, instead of the ideal length, when this would result In a small piece of land left over (Figure 27). Equally the length of field may be much less than the maximum furrow length. This is not usually a problem and furrow lengths are made to fit the field boundaries.

Figure 27 Field length and furrow length

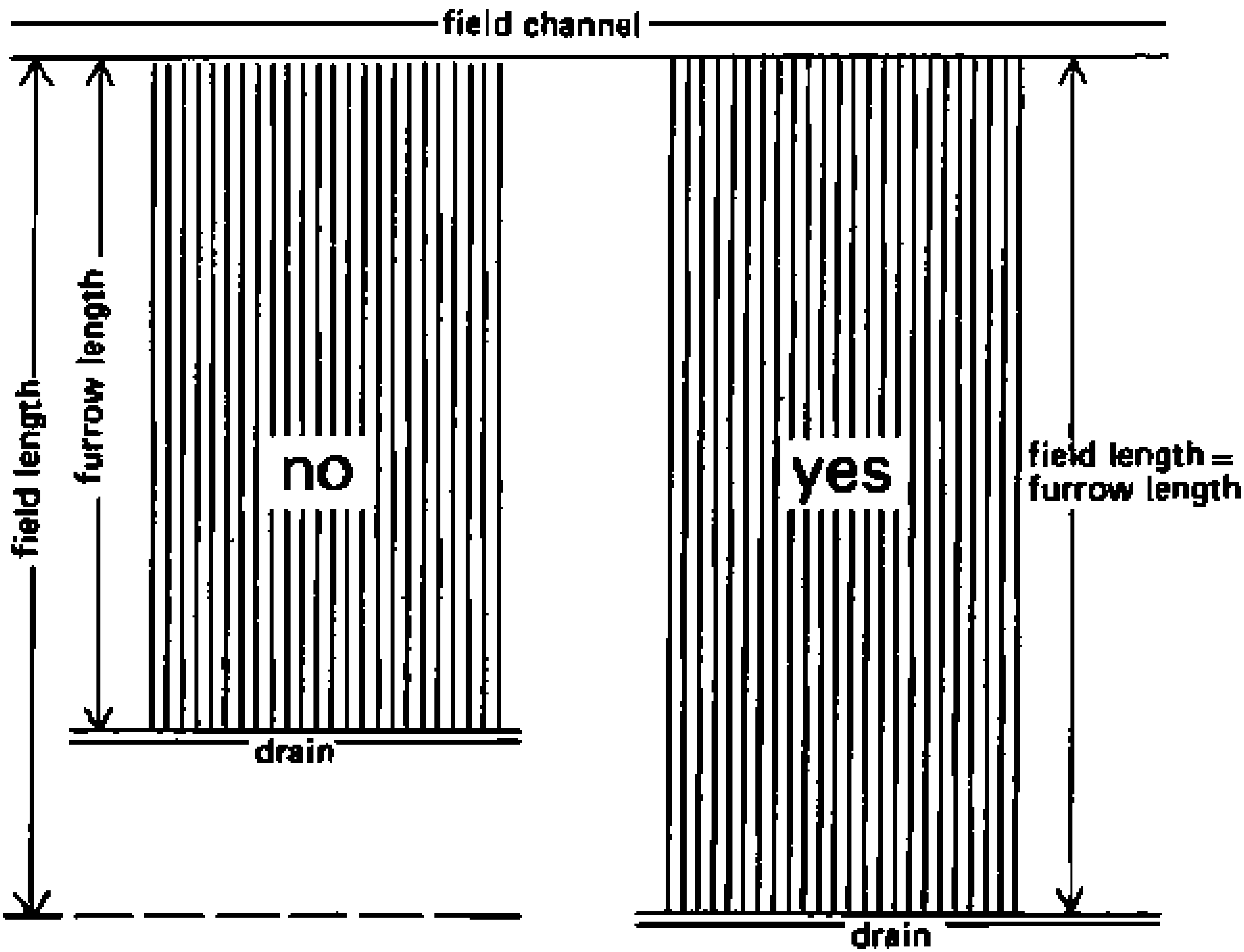


Table 3 gives some practical values of maximum furrow lengths under small-scale irrigation conditions. The values shown in Table 3 are lower than those generally given in irrigation handbooks. These higher values are appropriate under larger scale, fully mechanized conditions.

Table 3 PRACTICAL VALUES OF MAXIMUM FURROW LENGTHS (m) DEPENDING ON SLOPE, SOIL TYPE, STREAM SIZE AND NET IRRIGATION DEPTH

Furrow slope (%)	Maximum stream size (l/s) per furrow	Clay		Loam		Sand	
		Net irrigation depth (mm)					
		50	75	50	75	50	75
0.0	3.0	100	150	60	90	30	45
0.1	3.0	120	170	90	125	45	60
0.2	2.5	130	180	110	150	60	95
0.3	2.0	150	200	130	170	75	110
0.5	1.2	150	200	130	170	75	110

Important:

This table only provides approximate Information relating furrow slope, soil type, stream size and irrigation depth to furrow lengths. This should only be used as a guide as the data are based primarily on field experience and not on any scientific relationships. Maximum values of furrow length are given for reasonably efficient irrigation. However, furrow lengths can be even shorter than those given in the table and in general this will help to improve irrigation efficiency. Only by Installing a furrow system, following the guidelines, and then evaluating its performance can an appropriate system be developed for a given locality.

3.2.2 Furrow shape

The shape of furrows is influenced by the soil type and the stream size.

Soil type

In sandy soils, water moves faster vertically than sideways (= lateral). Narrow, deep V-shaped furrows are desirable to reduce the soil area through which water percolates (Figure 28). However, sandy soils are less stable, and tend to collapse, which may reduce the irrigation efficiency.

In clay soils, there is much more lateral movement of water and the infiltration rate is much less than for sandy soils. Thus a wide, shallow furrow is desirable to obtain a large wetted area (Figure 29) to encourage infiltration.

Figure 28 A deep, narrow furrow on a sandy soil

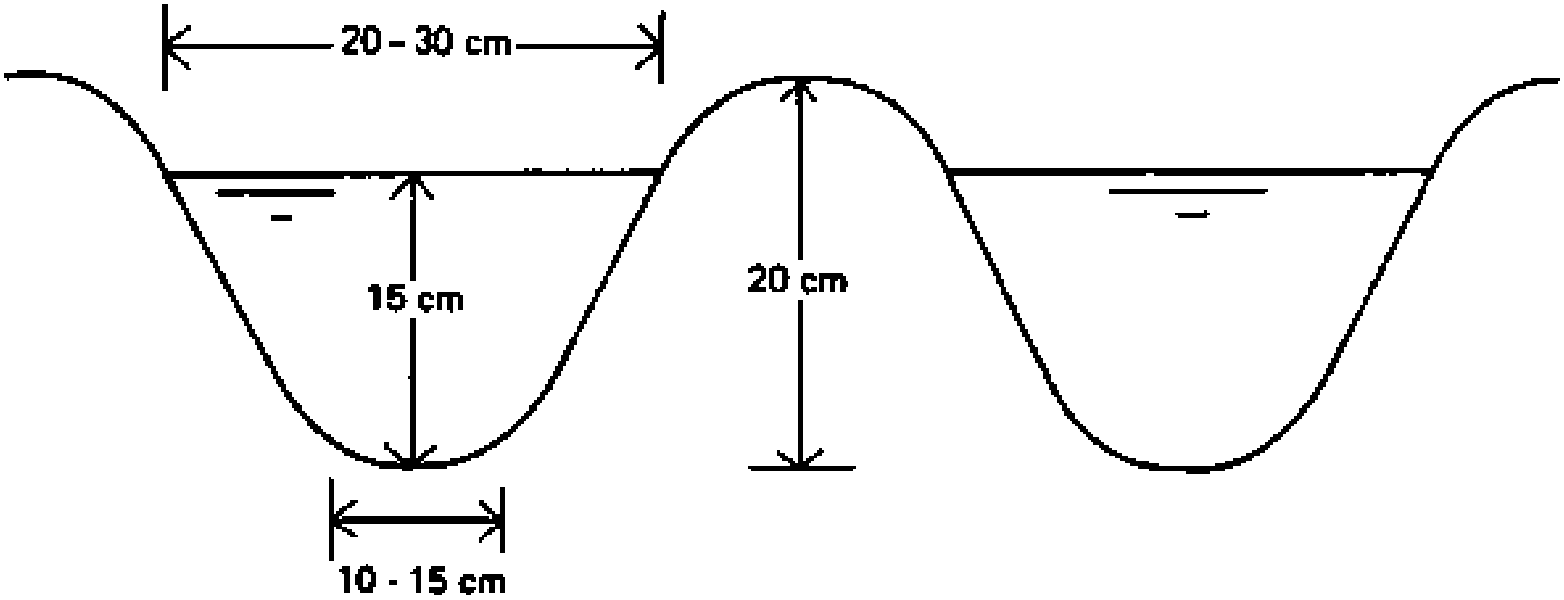
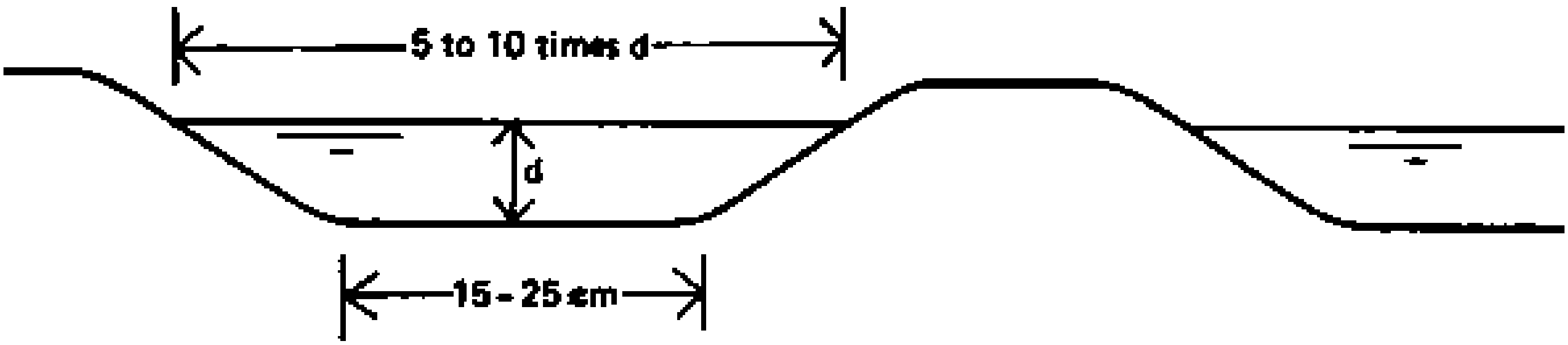


Figure 29 A wide, shallow furrow on a clay soil



Stream size

In general, the larger the stream size the larger the furrow must be to contain the flow.

3.2.3 Furrow spacing

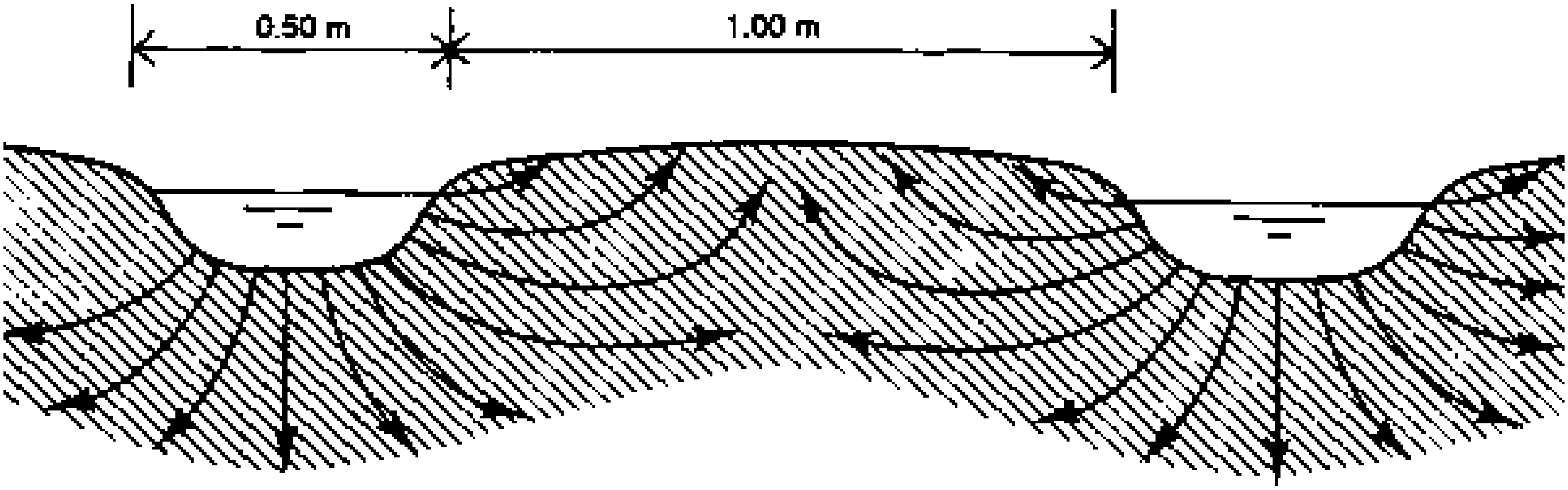
The spacing of furrows is influenced by the soil type and the cultivation practice.

Soil type

As a rule, for sandy soils the spacing should be between 30 and 60 cm, i.e. 30 cm for coarse sand and 60 cm for fine sand.

On clay soils, the spacing between two adjacent furrows should be 75-150 cm. On clay soils, double-ridged furrows - sometimes called beds - can also be used. Their advantage is that more plant rows are possible on each ridge, facilitating manual weeding. The ridge can be slightly rounded at the top to drain off water that would otherwise tend to pond on the ridge surface during heavy rainfall (Figure 30).

Figure 30 A double-ridged furrow



Cultivation practice

In mechanized farming a compromise is required between the machinery available to cut furrows and the ideal spacings for crops. Mechanical equipment will result in less work if a standard width between the furrows is maintained, even when the crops grown normally require a different planting distance. This way the spacing of the tool attachment does not need to be changed when the equipment is moved from one crop to another. However, care is needed to ensure that the standard spacings provide adequate lateral wetting on all soil types.

3.3 Furrow Construction

The most common way to construct furrows is with a ridger. Figure 31 shows animal- and hand-drawn ridgers.

Figure 31 Ridger plough: (a) wooden body, animal-drawn

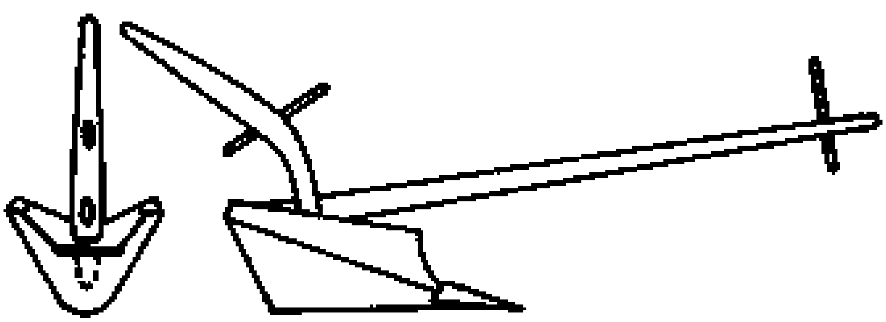


Figure 31 Ridger plough: (b) iron type, animal-drawn

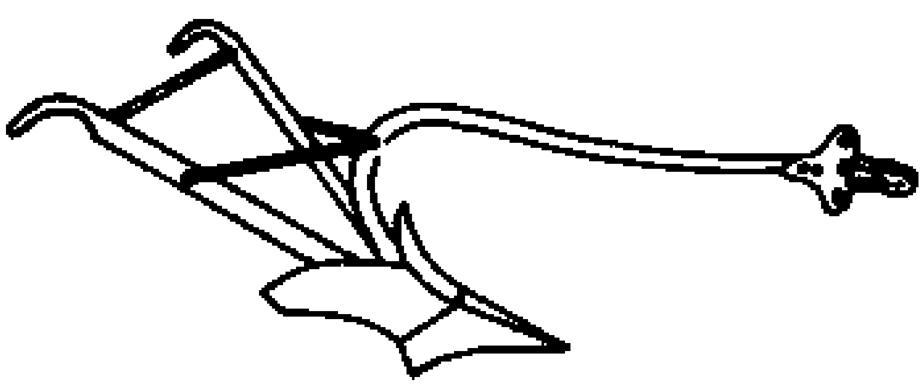
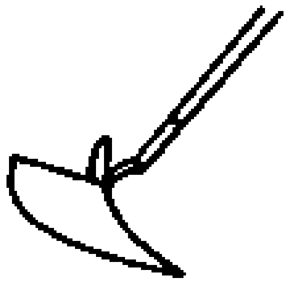


Figure 31 Ridger plough: (c) hand-drawn version



CONSTRUCTION OF FURROWS ON FLAT OR MILDLY SLOPING LAND

The following steps are taken to construct furrows: setting out; forming one (or more) ridge(s); forming one (or more) parallel ridge(s).

Step 1

A straight line is set out in the field along the proposed line of furrows. This can be done by setting up ranging poles or marking a line on the ground with chalk powder or small mounds of earth. An experienced ploughman should be able to plough along the line by aligning the poles or earth mounds by eye (Figure 32).

Figure 32 Markers are put along a straight line

Step 2

The ridger is moved along the line. The resulting furrow should be straight. If not, the area should be ploughed again and the procedure repeated.

Step 3

About every five (5) metres, a new straight line should be set out.

If a ridger-drawbar connected with a tractor is used, four furrows can be drawn simultaneously. On the track back the left ridger is put in the last furrow track to make sure the new furrows arc parallel to the previous ones (Figure 33). Also here it should be checked that straight lines are followed: for every track a centre line is set out (see Figure 33).

Attention: It should always be kept in mind that a new straight line has to be set out before a new furrow track is made.

Figure 33 A ridger-drawbar behind a tractor makes four ridges simultaneously

CONSTRUCTION OF FURROWS ON SLOPING OR UNDULATING LAND

Special care is needed to construct furrows along the contour on sloping or undulating land. The following steps are taken to construct furrows along the contour:

Step 1

A guide furrow must first be set out along the upper edge of the field close to the farm channel using a levelling device to locate the contour line. Further guide furrows are set out every 5 metres on undulating ground and every 10 metres on uniformly sloping land (Figure 34).

Figure 34 Making guide furrows

Step 2

Working from each guide furrow, furrows are made to halfway along the next guide furrow (Figure 35).

Figure 35 Making furrows

3.4 Irrigating Furrows

Water is supplied to each furrow from the field canal, using siphons or spiles (see Annex 1). Sometimes, instead of the field canal with siphons or spiles, a gated pipe is used (Figure 36).

Figure 36 Gated pipe

Depending on the available flow in the farm channel, several furrows can be irrigated at the same time.

When there is a water shortage, it is possible to limit the amount of irrigation water applied by using 'alternate furrow irrigation'. This involves irrigating alternate furrows rather than every furrow. Figure 37 is an example of this procedure. Instead of irrigating every furrow after 10 days, furrows 1, 3, 5, etc. are irrigated after 5 days and furrows 2, 4 and 6, etc. are irrigated after 10 days. Thus the crop receives some water every 5 days instead of a large amount every 10 days. Small amounts applied frequently in this way are usually better for the crop than large amounts applied after longer intervals of time.

Figure 37 Alternate furrow irrigation

Runoff at the ends of furrows can be a problem on sloping land. This can be as much as 30 percent of the inflow, even under good conditions. Therefore a shallow **drain** should always be made at the end of the field, to remove excess water. When no drain is made, plants may be damaged by waterlogging. Light vegetation allowed to grown in the drain can prevent erosion. Excessive runoff can be prevented by reducing the inflow once the irrigation water has reached the end of the furrows. This is called **cut-back** irrigation. It may also be possible to reuse runoff water further down the farm.

3.4.1 Wetting patterns

In order to obtain a uniformly wetted rootzone, furrows should be properly spaced, have a uniform slope and the irrigation water should be applied rapidly.

As the root zone in the ridge must be wetted from the furrows, the downward movement of water in the soil is less important than the lateral (or sideways) water movement. Both lateral and downward movement of water depends on soil type as can be seen in Figure 38.

Figure 38 Different wetting patterns in furrows, depending on the soil type (A - SAND)

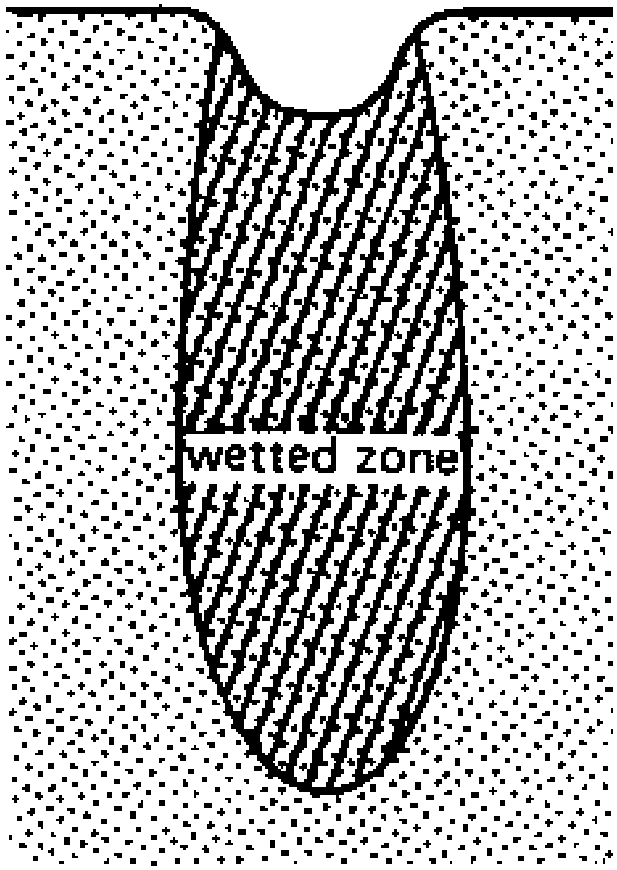


Figure 38 Different wetting patterns in furrows, depending on the soil type (B - LOAM)

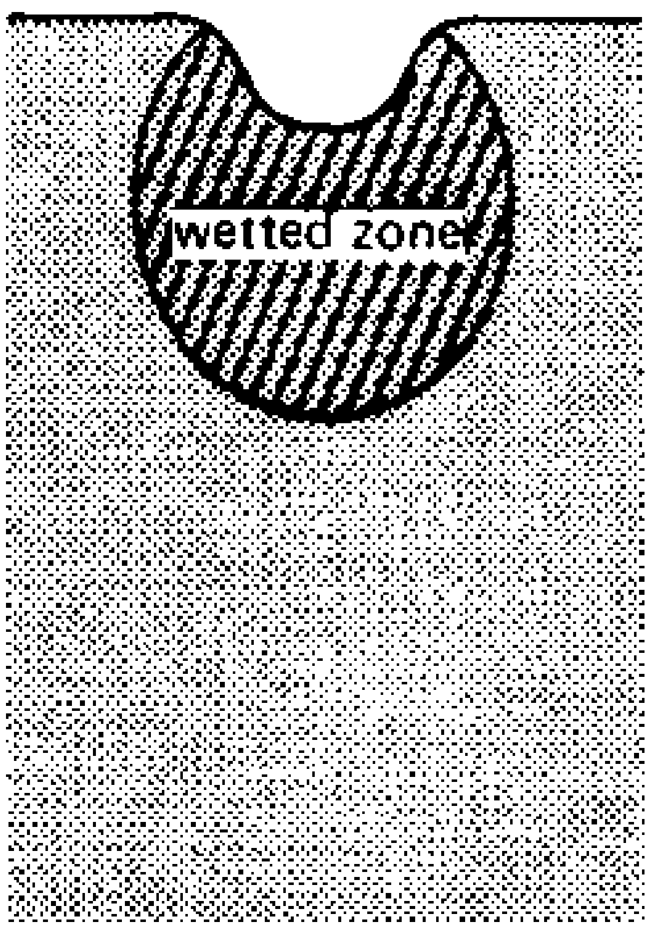
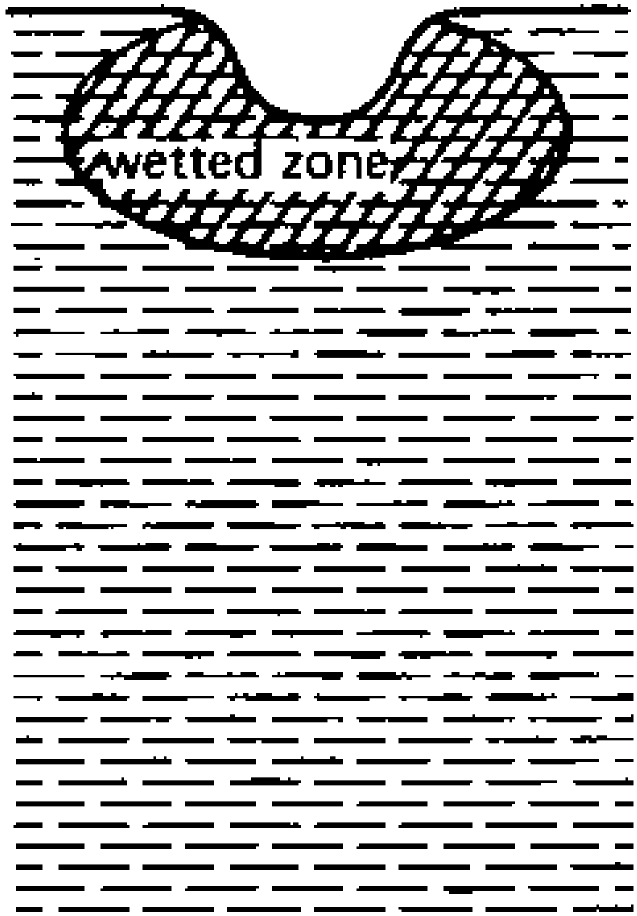


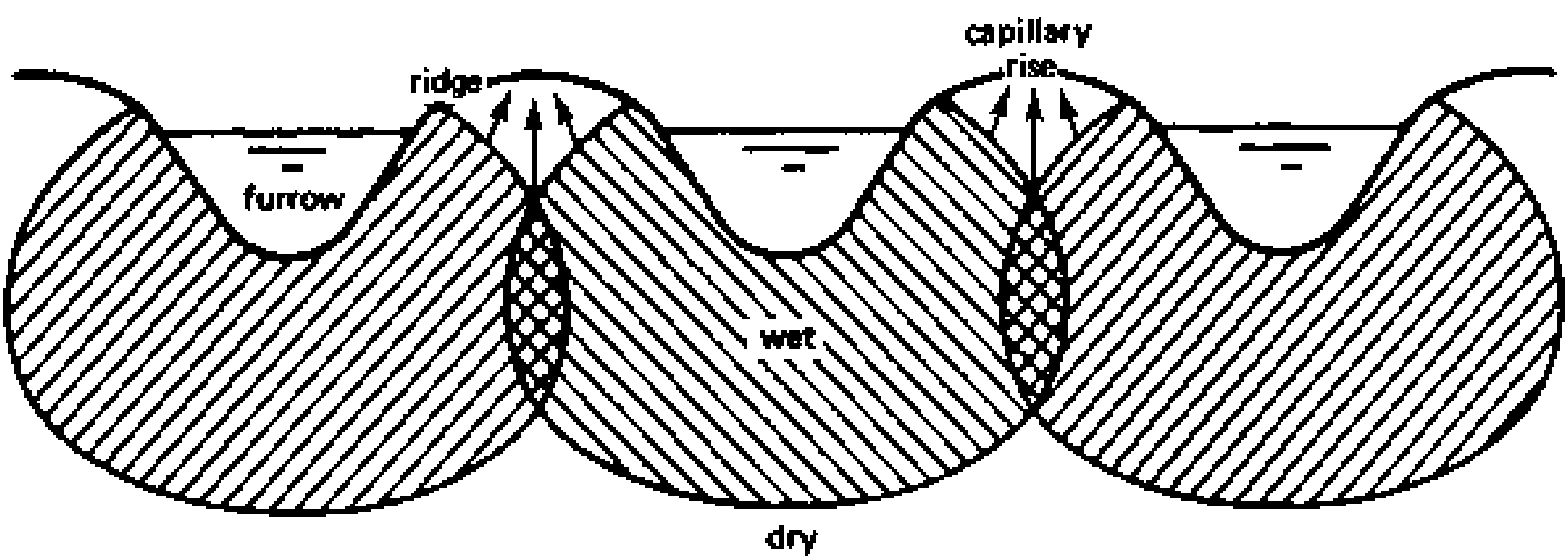
Figure 38 Different wetting patterns in furrows, depending on the soil type (C - CLAY)



Ideal wetting pattern

In an ideal situation adjacent wetting patterns overlap each other, and there is an upward movement of water (capillary rise) that wets the entire ridge (see Figure 39), thus supplying the root zone with water.

Figure 39 Ideal wetting pattern



To obtain a uniform water distribution along the furrow length, it is very important to have a uniform slope and a large enough stream size so that water advances rapidly down the furrow. In this way large percolation losses at the head of the furrow can be avoided. The quarter time rule is used to determine the time required for water to travel from the farm channel to the end of the furrow, in order to minimize precolation losses. The quarter time rule is further discussed in Annex 3.

Poor wetting patterns

Poor wetting patterns can be caused by:

- unfavourable natural conditions, e.g. a compacted layer, different soil types, uneven slope;
- poor layout, e.g. a furrow spacing too wide;
- poor management: supplying a stream size that is too large or too small, stopping the Inflow too soon.

i. Unfavourable natural conditions

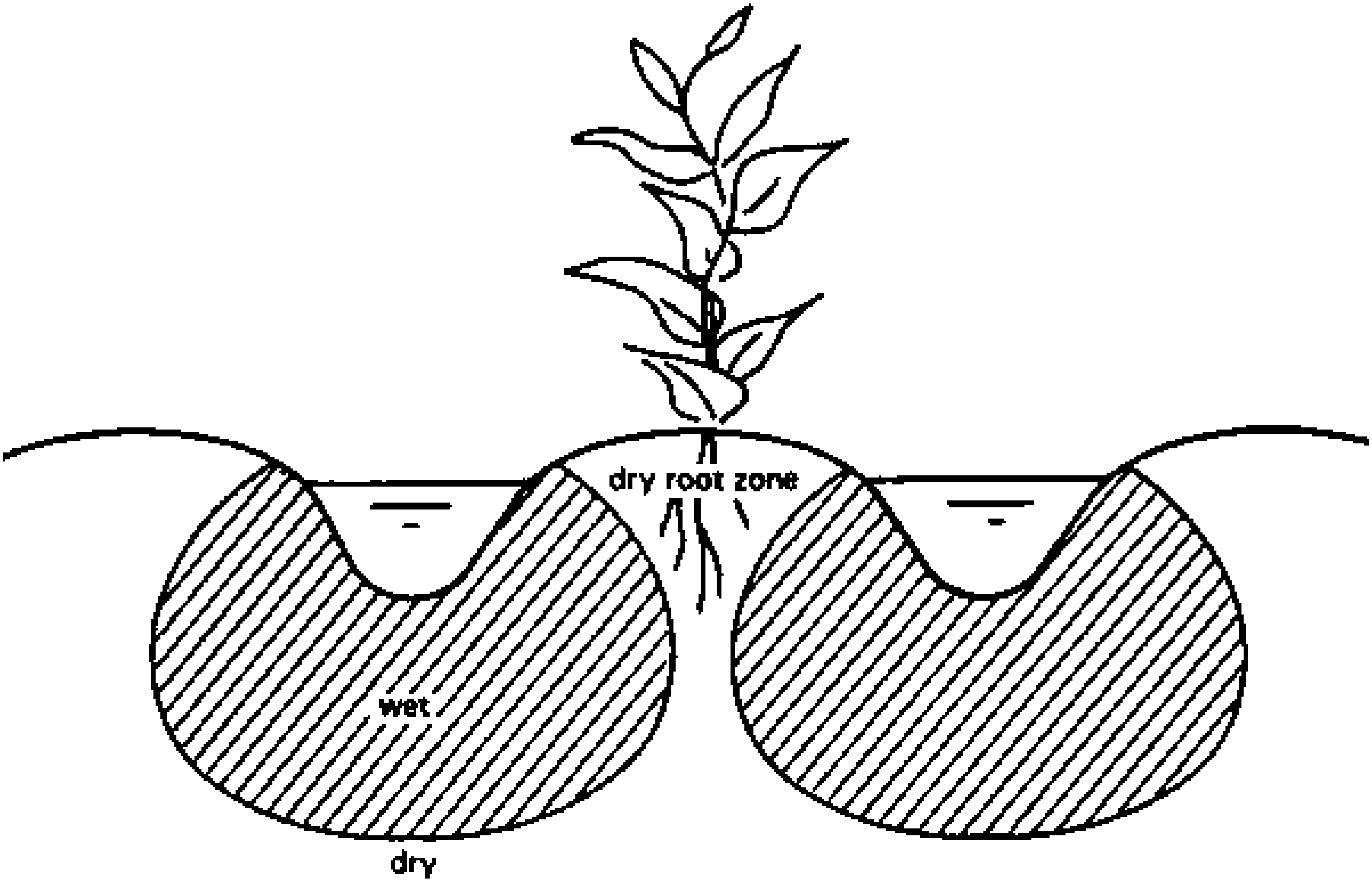
Compacted soil layers or different soil types have the same effect on furrow irrigation as they have on basin irrigation - see section 2.4.1. The solution to the problem is also similar.

An uneven slope can result in uneven wetting along the furrow. Water flows fast down the steep slopes and slowly down the flatter slopes. This affects the time available for infiltration and results in poor water distribution. The problem can be overcome by regrading the land to a uniform slope.

ii. Poor layout

If the furrow spacing is too wide (Figure 40) then the root zone will not be adequately wetted. The spacing of furrows needs careful selection to ensure adequate wetting of the entire root zone (Figure 40).

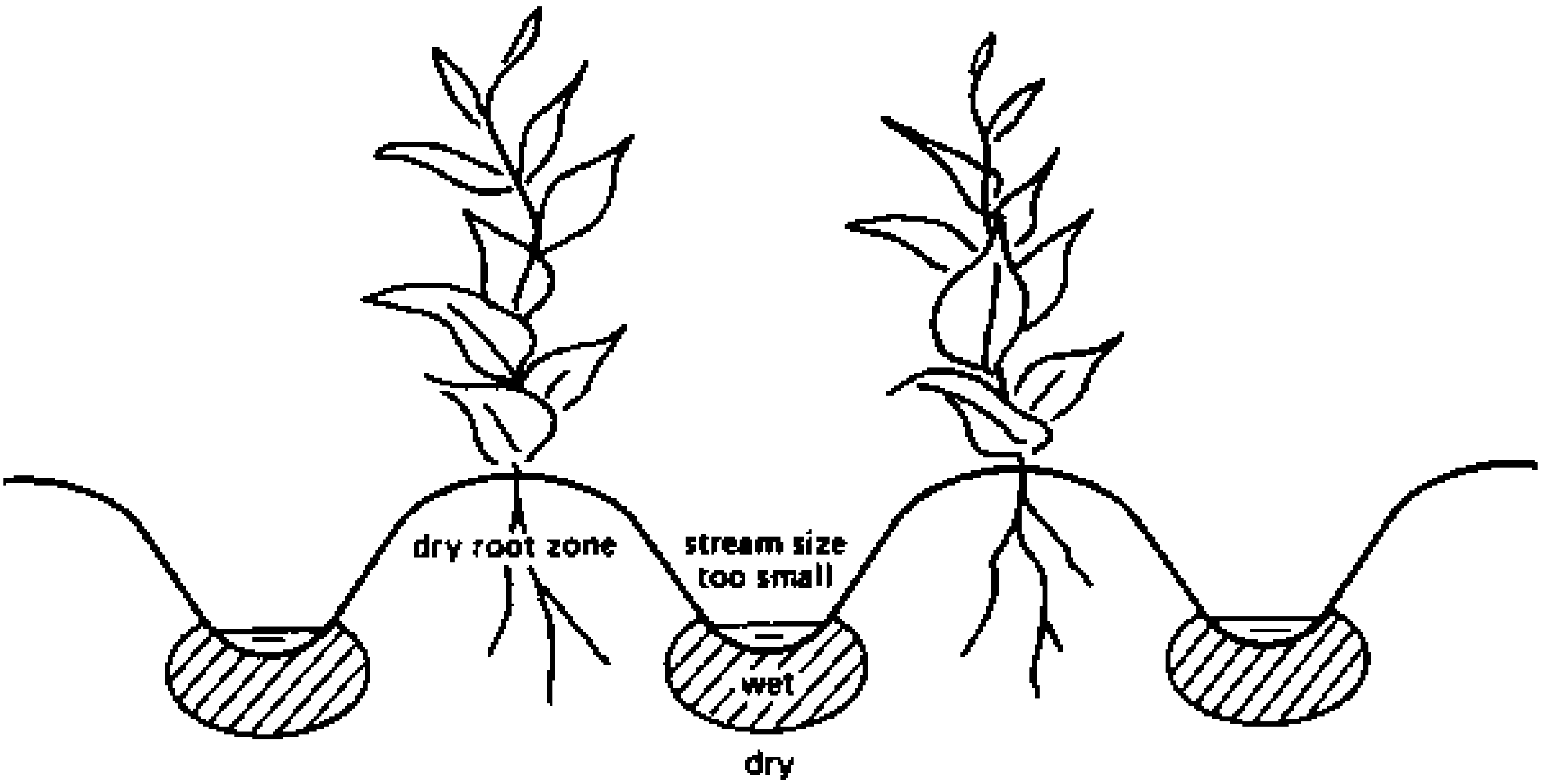
Figure 40 The spacing between two adjacent furrows is too wide



iii. Poor management

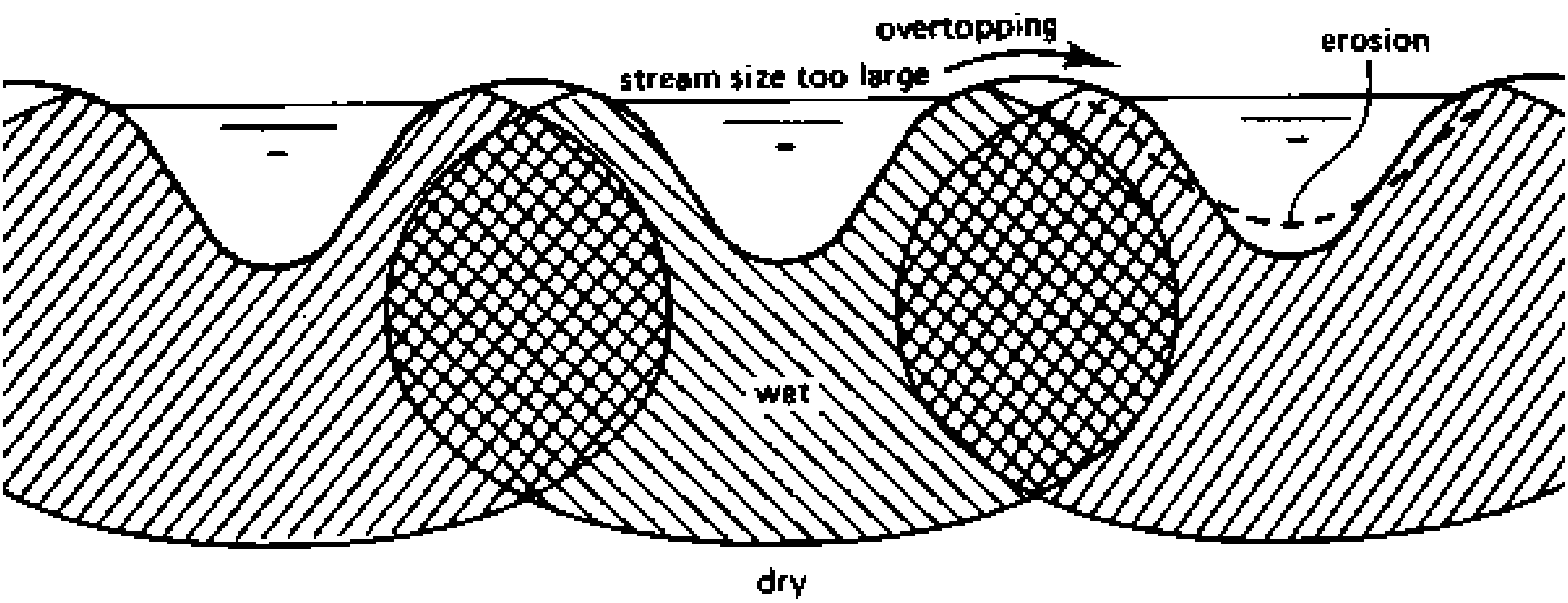
A stream size that is too small (Figure 41) will result in inadequate wetting of the ridges. Even if the plants are located at the sides of the ridge, not enough water will be available. A small stream size will also result in poor water distribution along the length of the furrow. The advance will be slow and too much water will be lost through deep percolation at the head of the furrow.

Figure 41 Stream size is too small to wet the ridge



If the stream size is too large on flat slopes, overtopping of the ridge may occur (Figure 42). On steeper slopes with too large a stream size, erosion of the bed and sides of the furrow may take place (Figure 42).

Figure 42 Stream size too large causing overtopping or erosion



A common management fault is to stop the inflow too soon. This is usually done to reduce runoff, but it results in a poor water distribution and the plants in particular at the end of the furrow do not get enough water. If the Inflow of irrigation water is not stopped soon enough, the runoff is excessive and plants at the end of the furrow may drown when an adequate drainage system to evacuate excess water is not provided (see also Annex 3).

3.5 Planting Techniques

The location of plants In a furrow system is not fixed but depends on the natural circumstances. A few examples will be mentioned.

- In areas with heavy rainfall, the plants should stand on top of the ridge in order to prevent damage as a result of waterlogging (Figure 43).

- If water is scarce, the plants may he put in the furrow itself, to benefit more from the limited water (Figure 44).

- As salts tend to accumulate in the highest point, a crop on saline soils should be planted away from the top of the ridge. Usually it is planted in two rows at the sides (Figure 45). However, it is important to make sure there is no danger of waterlogging.

- For winter and early spring crops in colder areas, the seeds may be planted on the sunny side of the ridge (Figure 46). In hotter areas, seeds may be planted on the shady side of the ridge, to protect them from the sun.

Figure 43 Protection against waterlogging

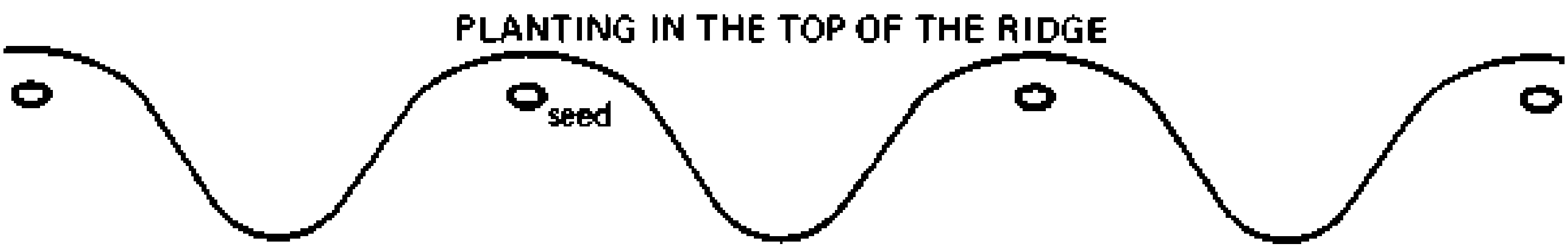


Figure 44 Protection against water scarcity

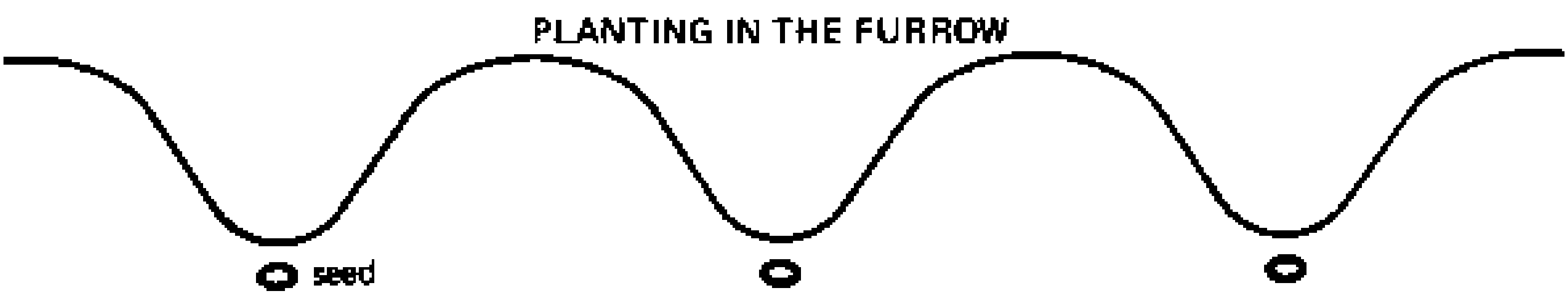


Figure 45 Protection against accumulation of salt

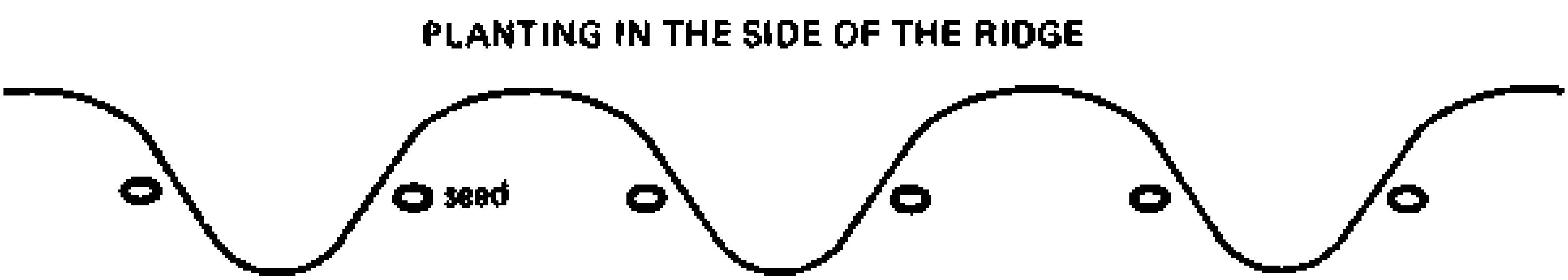
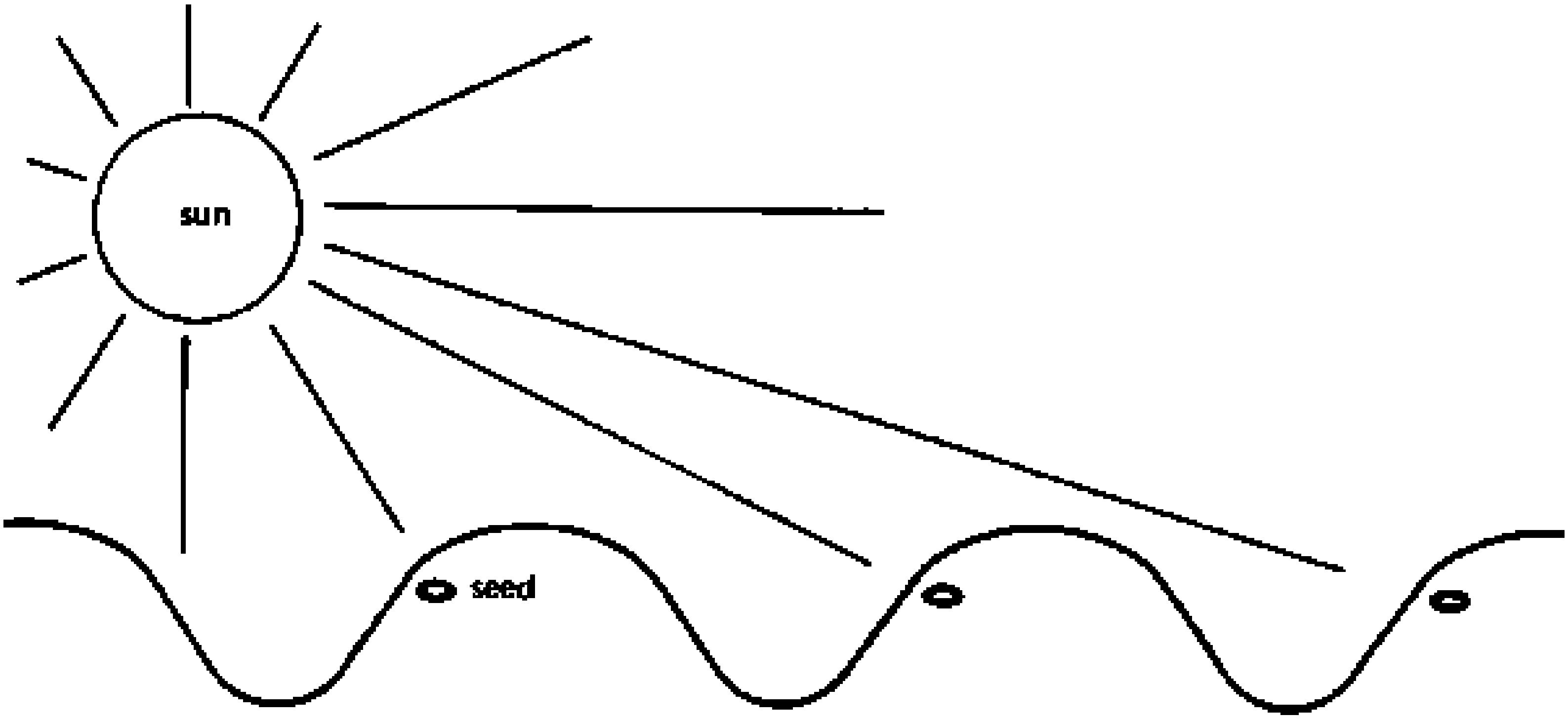


Figure 46 Winter and early spring crops: seeds planted on the sunny side of the ridge



3.6 Maintenance of Furrows

After construction the furrow system should be maintained regularly; during irrigation it should be checked if water reaches the downstream end of all furrows. There should be no dry spots or places where water stays ponding. Overtopping of ridges should not occur. The field channels and drains should be kept free from weeds.

CHAPTER 4. BORDER IRRIGATION

Borders are usually long, uniformly graded strips of land, separated by earth bunds. In Contrast to basin irrigation these bunds are not to contain the water for ponding but to guide it as it flows down the field (Figures 47 and 48).

Figure 47 Border irrigation

Figure 48 Border irrigation, field not properly levelled

4.1 When to Use Border Irrigation

Border irrigation is generally best suited to the larger mechanized farms as it is designed to produce long uninterrupted field lengths for ease of machine operations. Borders can be up to 800 m or more in length and 3-30 m wide depending on a variety of factors. It is less suited to small-scale farms involving hand labour or animal-powered cultivation methods.

Suitable slopes: Border slopes should be uniform, with a minimum slope of 0.05% to provide adequate drainage and a maximum slope of 2% to limit problems of soil erosion.

Suitable soils: Deep homogenous loam or clay soils with medium infiltration rates are preferred. Heavy, clay soils can be difficult to irrigate with border irrigation because of the time needed to infiltrate sufficient water into the soil. Basin irrigation is preferable in such circumstances.

Suitable crops: Close growing crops such as pasture or alfalfa are preferred.

4.2 Border Layout

The dimensions and shape of borders are influenced in much the same way as basins and furrows by the soil type, stream size, slope, irrigation depth and other factors such as farming practices and field or farm size.

Many of the comments made about basins and furrows are generally applicable to borders also and so do not require repetition here. Table 4 provides a guideline to determine maximum border dimensions. It must, however, be stressed that this table is for general guidance only as the values are based on field experience and not on any scientific relationships.

Table 4 SUGGESTED MAXIMUM BORDER LENGTHS AND WIDTHS

Soil type	Border Slope (%)	Unit flow per metre width (l/sec)	Border Width (m)	Border Length (m)
SAND	0.2-0.4	10-15	12-30	60-90
Infiltration rate greater than 25 mm/h	0.4-0.6	8-10	9-12	60-90
	0.6-1.0	5-8	6-9	75
LOAM	0.2-0.4	5-7	12-30	90-250
Infiltration rate of 10 to 25 mm/h	0.4-0.6	4-6	6-12	90-180
	0.6-1.0	2-4	6	90
CLAY	0.2-0.4	3-4	12-30	180-300
Infiltration rate less than 10 mm/h	0.4-0.6	2-3	6-12	90-180
	0.6-1.0	1-2	6	90

Note: The flow is given per metre width of the border. Thus the total flow into a border is equal to the unit flow multiplied by border width (in metres).

4.3 Irrigating Borders

Borders are irrigated by diverting a stream of water from the channel to the upper end of the border. The water flows down the slope. When the desired amount of water has been delivered to the border, the stream is turned off. This may occur before the water has reached the end of the border. There are no specific rules controlling this decision. However, if the flow is stopped too soon there may not be enough water in the border to complete the irrigation at the far end. If it is left running for too long, then water may run off the end of the border and be lost in the drainage system.

As a guideline, the inflow to the border can be stopped as follows:

- On **clay soils**, the inflow is stopped when the irrigation water covers 60% of the border. If, for example, the border is 100 m long a stick is placed 60 m from the farm channel. When the water front reaches the stick, the inflow is stopped.

- On **loamy soils** it is stopped when 70 to 80% of the border is covered with water.

- On **sandy soils** the irrigation water must cover the entire border before the flow is stopped.

However, these are only guidelines. Realistic rules can only be established locally when testing the system.

4.3.1 Wetting patterns

As with the other irrigation methods it is important to ensure that adequate irrigation water is supplied to the borders so that it fills the root zone uniformly. However, there are many common problems which result in poor water distribution. These include:

- poor land grading;
- wrong stream size;
- stopping the inflow at the wrong time.

i. Poor land grading

If the land is not graded properly and there is a cross-slope, the irrigation water will not spread evenly over the field. It will flow down the slope always seeking the lowest side of the border (Figure 49). This can be corrected by regrading the border to eliminate the cross-slope or by constructing guide bunds in the border to prevent the cross flow of water.

Figure 49 Effect of a cross-slope on the water movement in a border

ii. Wrong stream size

A stream size which is too small will result in deep percolation losses near the field channel (Figure 50), especially on sandy soils.

Figure 50. Stream size too small

If the stream size is too large the water will flow too quickly down the border and the point where the flow should be stopped is reached before sufficient water has been applied to fill the root zone (Figure 51). In this situation the flow will need to be left running until the root zone has been adequately filled and this results in considerable losses from surface runoff. Large stream sizes may also cause soil erosion.

Figure 51 Stream size too large

iii. Inflow stopped at the wrong time

If the inflow is stopped too soon, the water may not even reach the end of the border. In contrast, if the flow is left running too long, water will run off the border at the downstream end and be lost in the drainage system.

4.4 Maintenance of Borders

Maintenance of borders consists of keeping the border free from weeds and uniformly sloping. Whatever damage occurs to the bunds must be repaired and the field channel and drains are to be weeded regularly. By checking frequently and carrying out immediate repairs where necessary, further damage is prevented.

Figure 52 Irrigating a border

CHAPTER 5. SPRINKLER IRRIGATION

5.1 When to Use Sprinkler Irrigation

Sprinkler irrigation is a method of applying irrigation water which is similar to natural rainfall. Water is distributed through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground. The pump supply system, sprinklers and operating conditions must be designed to enable a uniform application of water.

5.1.1 Suitable crops

Sprinkler irrigation is suited for most row, field and tree crops and water can be sprayed over or under the crop canopy. However, large sprinklers are not recommended for irrigation of delicate crops such as lettuce because the large water drops produced by the sprinklers may damage the crop.

5.1.2 Suitable slopes

Sprinkler irrigation is adaptable to any farmable slope, whether uniform or undulating. The lateral pipes supplying water to the sprinklers should always be laid out along the land contour whenever possible. This will minimize the pressure changes at the sprinklers and provide a uniform irrigation.

5.1.3 Suitable soils

Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils. The average application rate from the sprinklers (in mm/hour) is always chosen to be less than the basic infiltration rate of the soil (see Annex 2) so that surface ponding and runoff can be avoided.

Sprinklers are not suitable for soils which easily form a crust. If sprinkler irrigation is the only method available, then light fine sprays should be used. The larger sprinklers producing larger water droplets are to be avoided.

5.1.4 Suitable irrigation water

A good clean supply of water, free of suspended sediments, is required to avoid problems of sprinkler nozzle blockage and spoiling the crop by coating it with sediment.

5.2 Sprinkler System Layout

A typical sprinkler irrigation system consists of the following components:

- Pump unit
- Mainline and sometimes submainlines
- Laterals
- Sprinklers

Figure 53 shows the mainline In the foreground, to which the laterals, with the sprinklers, are connected.

The **pump unit** is usually a centrifugal pump which takes water from the source and provides adequate pressure for delivery into the pipe system.

Figure 53 An example of a sprinkler irrigation system layout

Figure 54 Hand-moved sprinkler system using two laterals (Laterals 1 and 2 in position 1)

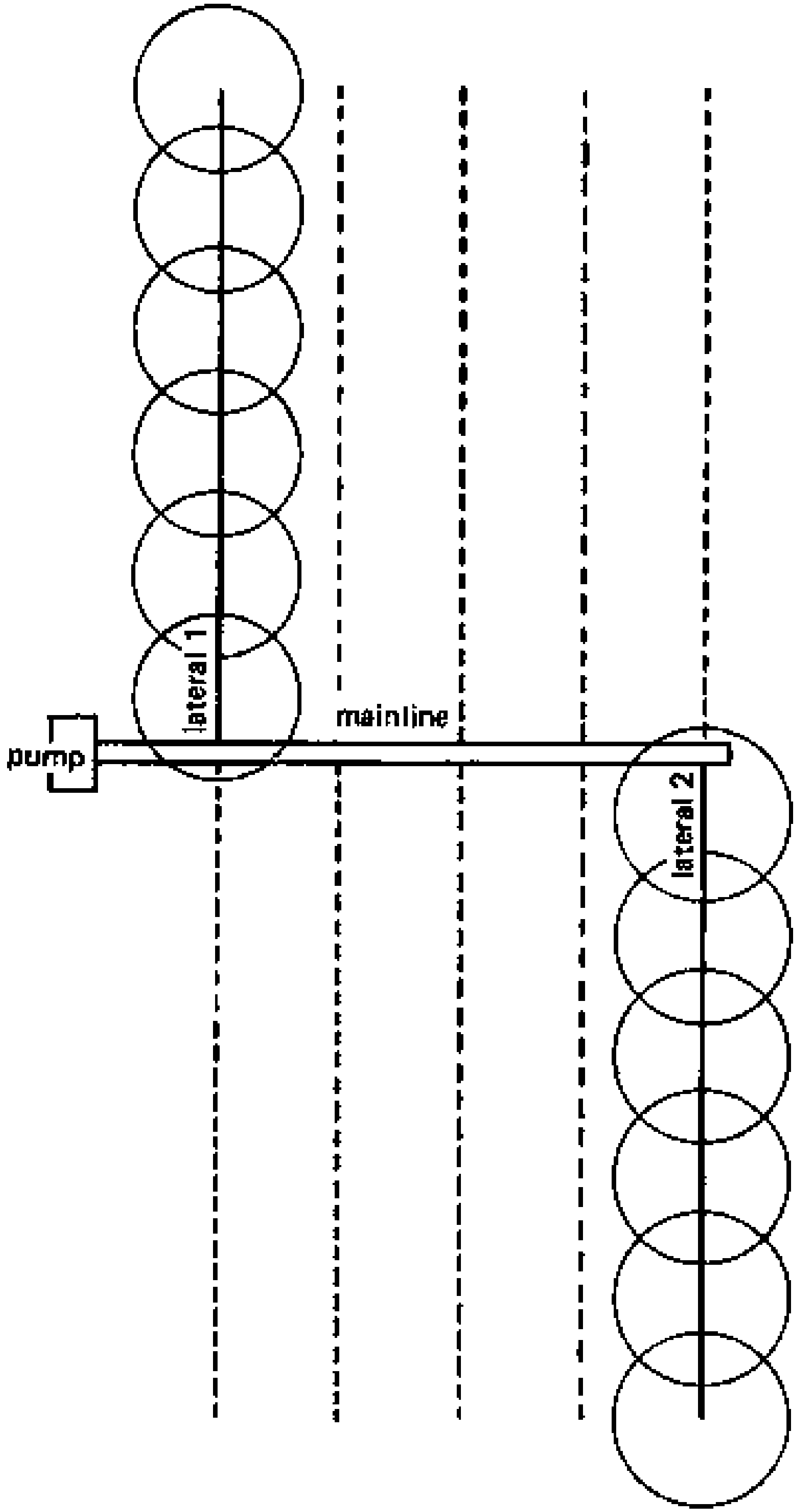
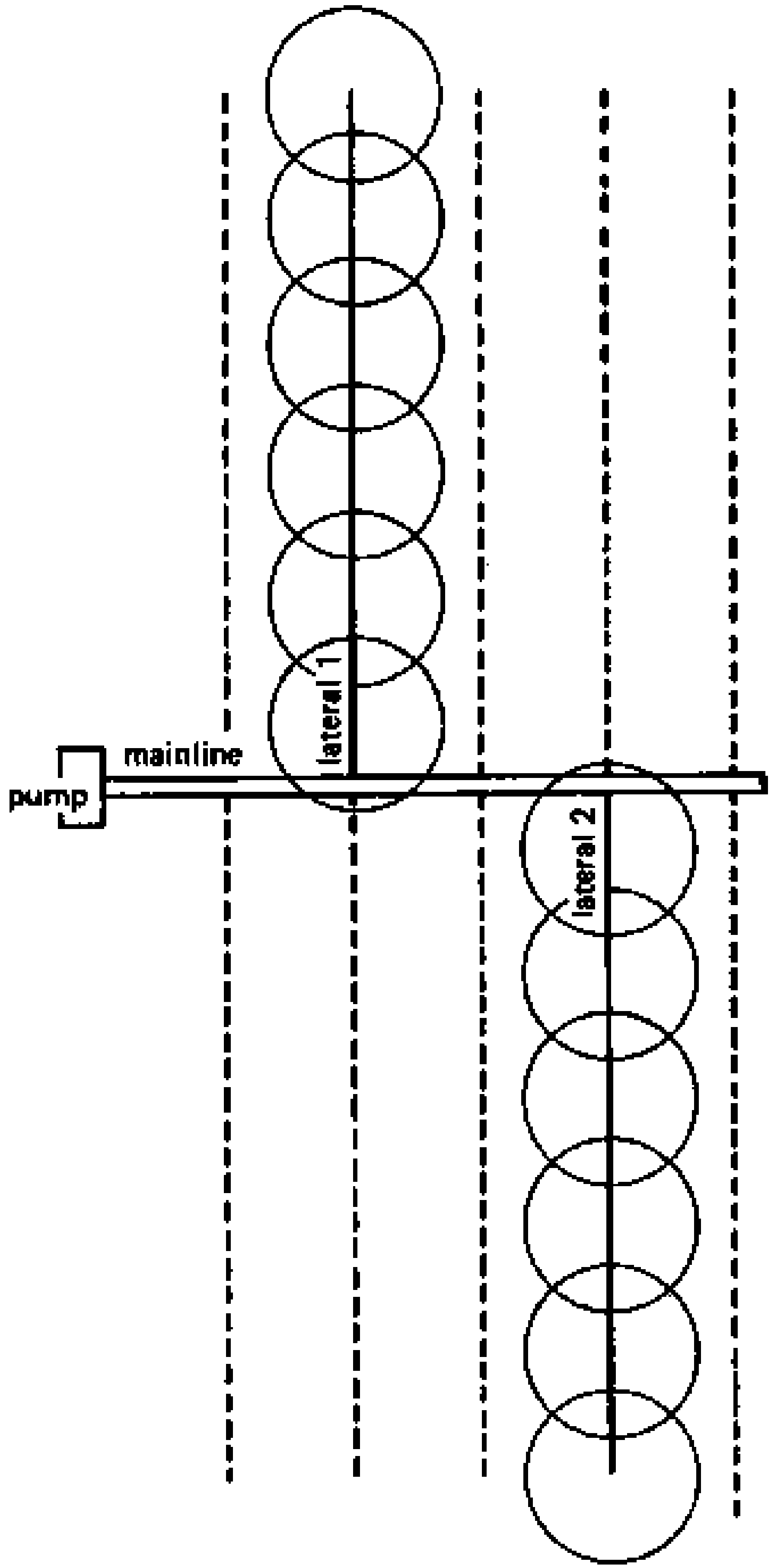

lateral 1
mainline
pump
lateral 2

Figure 54 Hand-moved sprinkler system using two laterals (Laterals 1 and 2 in position 2)



The **mainline** - and **submainlines** - are pipes which deliver water from the pump to the laterals. In some cases these pipelines are permanent and are laid on the soil surface or buried below ground. In other cases they are temporary, and can be moved from field to field. The main pipe materials used include asbestos cement, plastic or aluminium alloy.

The **laterals** deliver water from the mainlines or submainlines to the sprinklers. They can be permanent but more often they are portable and made of aluminium alloy or plastic so that they can be moved easily.

The most common type of sprinkler system layout is shown in Figure 54. It consists of a system of lightweight aluminium or plastic pipes which are moved by hand. The rotary sprinklers are usually spaced 9-24 m apart along the lateral which is normally 5-12.5 cm in diameter. This is so it can be carried easily. The lateral pipe is located in the field until the irrigation is complete. The pump is then switched off and the lateral is disconnected from the mainline and moved to the next location (Figure 55). It is re-assembled and connected to the mainline and the irrigation begins again. The lateral can be moved one to four times a day. It is gradually moved around the field until the whole field is irrigated. This is the simplest of all systems. Some use more than one lateral to irrigate larger areas (see Figure 54).

Figure 55 Moving a lateral

A common problem with sprinkler irrigation is the large labour force needed to move the pipes and sprinklers around the field (Figure 55). In some places such labour may not be available and may also be costly. To overcome this problem many mobile systems have been developed such as the hose reel raingun and the centre pivot.

However, these systems go beyond the scope of this introduction to sprinkler systems. An example of such a complex system is shown in Figure 56.

Figure 56 An example of a sophisticated sprinkler irrigation system

Another system which does not need a large labour force is the drag-hose sprinkler system. Main and laterals are buried PVC pipes: one lateral covers three positions. For example, in the sprinkler system of Figure 53, only four buried laterals would be needed, in positions 2, and 5. Sprinklers on risers carried by skids are attached to the laterals through hoses (similar to garden sprinklers). Only the skid with the sprinkler has to be moved from one position to another, which is an easy task.

5.3 Operating Sprinkler Systems

The main objective of a sprinkler system is to apply water as uniformly as possible to fill the root zone of the crop with water.

5.3.1 Wetting patterns

The wetting pattern from a single rotary sprinkler is not very uniform (Figure 57). Normally the area wetted is circular (see topview). The heaviest wetting is close to the sprinkler (see sideview). For good uniformity several sprinklers must be operated close together so that their patterns overlap (Figure 58). For good uniformity the overlap should be at least 65% of the wetted diameter. This determines the maximum spacing between sprinklers.

Figure 57 Wetting pattern for a single sprinkler (TOP VIEW)

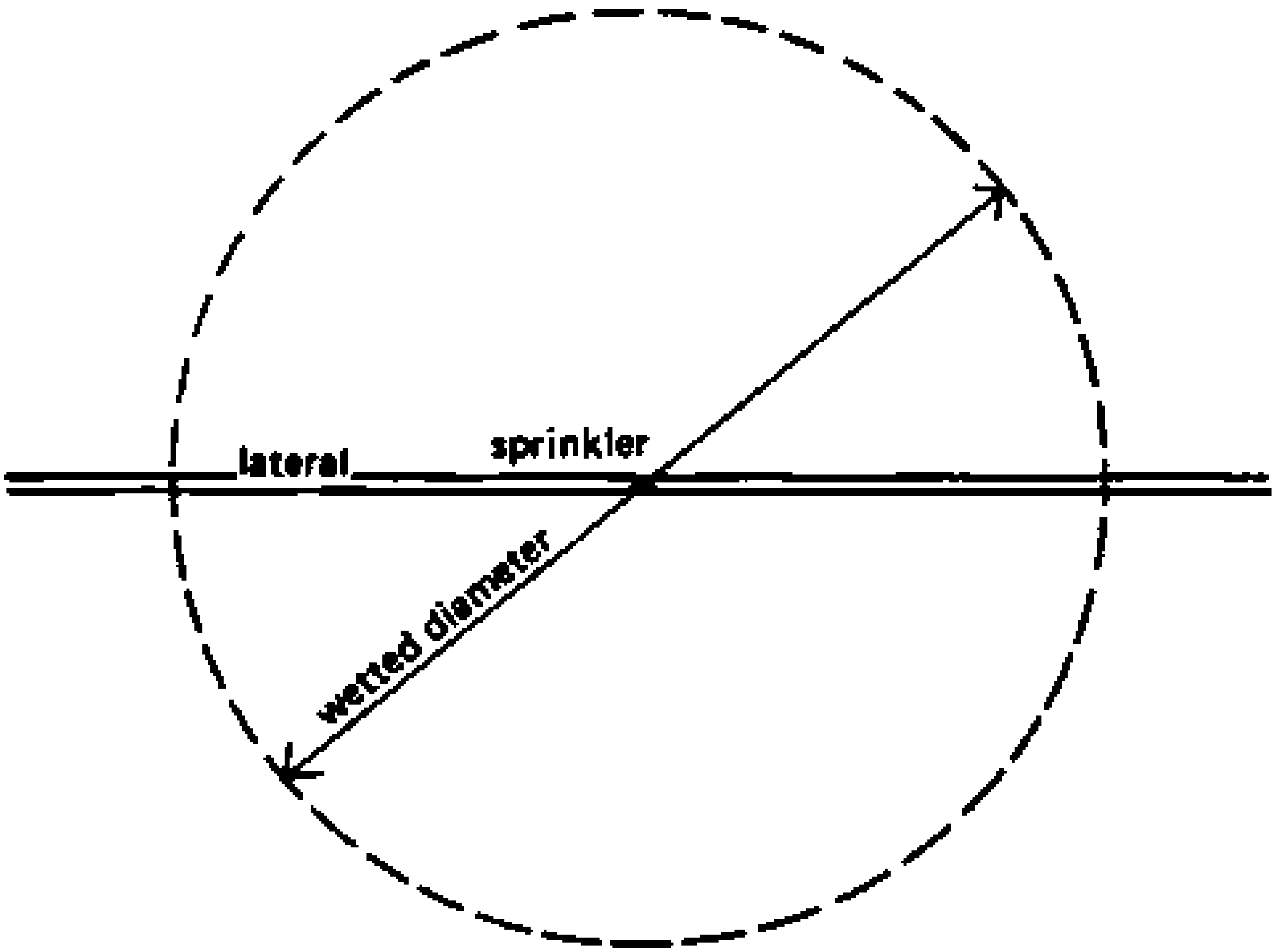


Figure 57 Wetting pattern for a single sprinkler (SIDE VIEW)

Figure 58 Wetting patterns for several sprinklers (TOP VIEW)

Figure 58 Wetting patterns for several sprinklers (SIDE VIEW)

The uniformity of sprinkler applications can be affected by wind and water pressure.

Spray from sprinklers is easily blown about by even a gentle breeze and this can seriously reduce uniformity. To reduce the effects of wind the sprinklers can be positioned more closely together.

Sprinklers will only work well at the right operating pressure recommended by the manufacturer. If the pressure is above or below this then the distribution will be affected. The most common problem is when the pressure is too low. This happens when pumps and pipes wear. Friction increases and so pressure at the sprinkler reduces. The result is that the water jet does not break up and all the water tends to fall in one area towards the outside of the wetted circle. If the pressure is too high then the distribution will also be poor. A fine spray develops which falls close to the sprinkler.

5.3.2 Application rate

This is the average rate at which water is sprayed onto the crops and is measured in mm/hour. The application rate depends on the size of sprinkler nozzles, the operating pressure and the distance between sprinklers. When selecting a sprinkler system it is important to make sure that the average application rate is less than the basic infiltration rate of the soil (see Annex 2). In this way all the water applied will be readily absorbed by the soil and there should be no runoff.

5.3.3 Sprinkler drop sizes

As water sprays from a sprinkler it breaks up into small drops between 0.5 and 4.0 mm in size. The small drops fall close to the sprinkler whereas the larger ones fall close to the edge of the wetted circle. Large drops can damage delicate crops and soils and so in such conditions it is best to use the smaller sprinklers.

Drop size is also controlled by pressure and nozzle size. When the pressure is low, drops tend to be much larger as the water jet does not break up easily. So to avoid crop and soil damage use small diameter nozzles operating at or above the normal recommended operating pressure.

Figure 59 Sprinkler irrigation

CHAPTER 6. DRIP IRRIGATION

6.1 When to Use Drip Irrigation

Drip irrigation is sometimes called trickle irrigation and involves dripping water onto the soil at very low rates (2-20 litres/hour) from a system of small diameter plastic pipes fitted with outlets called **emitters** or drippers. Water is applied close to plants so that only part of the soil in which the roots grow is wetted (Figure 60), unlike surface and sprinkler irrigation, which involves wetting the whole soil profile. With drip irrigation water, applications are more frequent (usually every 1-3 days) than with other methods and this provides a very favourable high moisture level in the soil in which plants can flourish.

Figure 60 With drip irrigation, only the part of the soil in which the roots grow is wetted

6.1.1 Suitable crops

Drip irrigation is most suitable for row crops (vegetables, soft fruit), tree and vine crops where one or more emitters can be provided for each plant. Generally only high value crops are considered because of the high capital costs of installing a drip system.

6.1.2 Suitable slopes

Drip irrigation is adaptable to any farmable slope. Normally the crop would be planted along contour lines and the water supply pipes (laterals) would be laid along the contour also. This is done to minimize changes in emitter discharge as a result of land elevation changes.

6.1.3 Suitable soils

Drip irrigation is suitable for most soils. On clay soils water must be applied slowly to avoid surface water ponding and runoff. On sandy soils higher emitter discharge rates will be needed to ensure adequate lateral wetting of the soil.

6.1.4 Suitable irrigation water

One of the main problems with drip irrigation is blockage of the emitters. All emitters have very small waterways ranging from 0.2-2.0 mm in diameter and these can become blocked if the water is not clean. Thus it is essential for irrigation water to be free of sediments. If this is not so then filtration of the irrigation water will be needed.

Blockage may also occur if the water contains algae, fertilizer deposits and dissolved chemicals which precipitate such as calcium and iron. Filtration may remove some of the materials but the problem may be complex to solve and requires an experienced engineer or consultation with the equipment dealer.

Drip irrigation is particularly suitable for water of poor quality (saline water). Dripping water to individual plants also means that the method can be very efficient in water use. For this reason it is most suitable when water is scarce.

6.2 Drip System Layout

A typical drip irrigation system is shown in Figure 61 and consists of the following components:

Pump unit
Control head
Main and submain lines
Laterals
Emitters or drippers.

Figure 61 An example of a drip irrigation system layout

The **pump unit** takes water from the source and provides the right pressure for delivery into the pipe system.

The **control head** consists of valves to control the discharge and pressure In the entire system. It may also have filters to clear the water. Common types of filter include screen filters and graded sand filters which remove fine material suspended in the water. Some control head units contain a fertilizer or nutrient tank. These slowly add a measured dose of fertilizer into the water during irrigation. This is one of the major advantages of drip irrigation over other methods.

Mainlines, submains and laterals supply water from the control head into the fields. They are usually made from PVC or polyethylene hose and should be buried below ground because they easily degrade when exposed to direct solar radiation. Lateral pipes are usually 13-32 mm diameter.

Emitters or drippers are devices used to control the discharge of water from the lateral to the plants. They are usually spaced more than 1 metre apart with one or more emitters used for a single plant such as a tree. For row crops more closely spaced emitters may be used to wet a strip of soil. Many different emitter designs have been produced in recent years. The basis of design is to produce an emitter which will provide a specified constant discharge which does not vary much with pressure changes, and does not block easily. Various types of emitters are shown in Figure 61 and Figure 62. Figure 63 gives an example of sublateral loops.

Figure 62 Types of emitters

Figure 63 Sublateral loops

6.3 Operating Drip Systems

A drip system is usually permanent. When remaining In place during more than one season, a system is considered permanent. Thus it can easily be automated. This is very useful when labour is scarce or expensive to hire. However, automation requires specialist skills and so this approach is unsuitable if such skills are not available.

Water can be applied frequently (every day if required) with drip irrigation and this provides very favourable conditions for crop growth. However, if crops are used to being watered each day they may only develop shallow roots and If the system breaks down, the crop may begin to suffer very quickly.

6.3.1 Wetting patterns

Unlike surface and sprinkler irrigation, drip irrigation only wets part of the soil root zone. This may be as, low as 30% of the volume of soil wetted by the other methods. The wetting patterns which develop from dripping water onto the soil depend on discharge and soil type. Figure 64 shows the effect of changes in discharge on two different soil types, namely sand and clay.

Figure 64 Wetting patterns for sand and clay soils with high and low discharge rates (SAND)

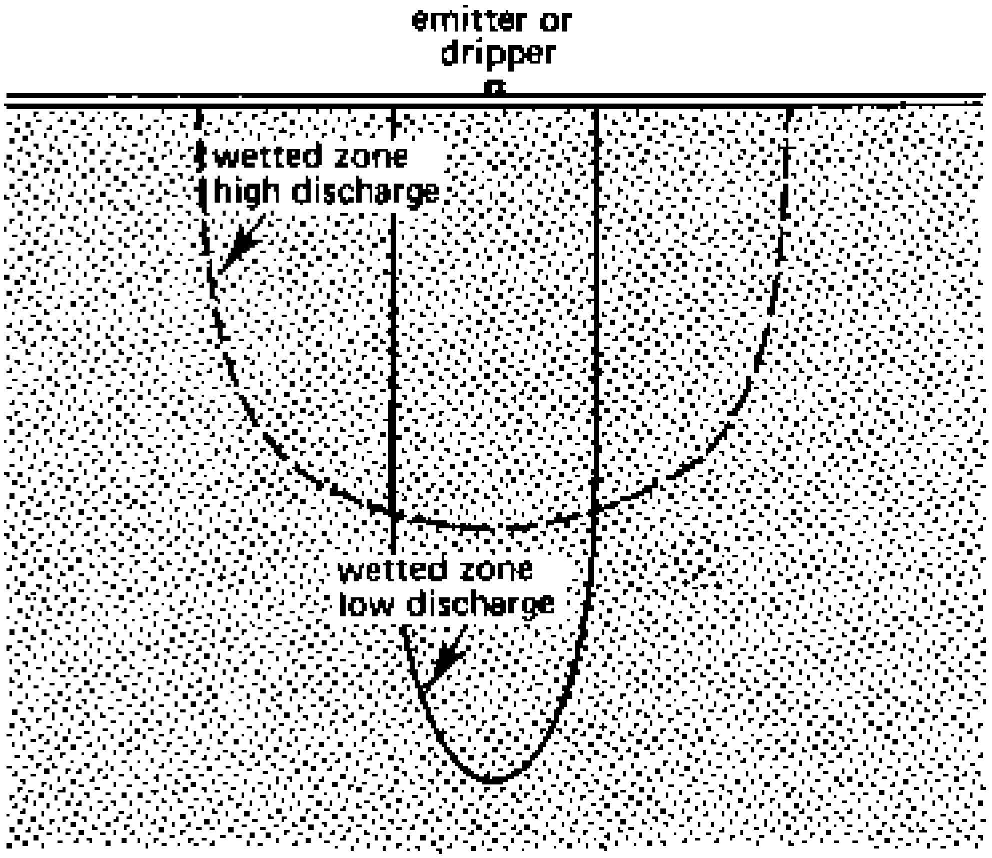
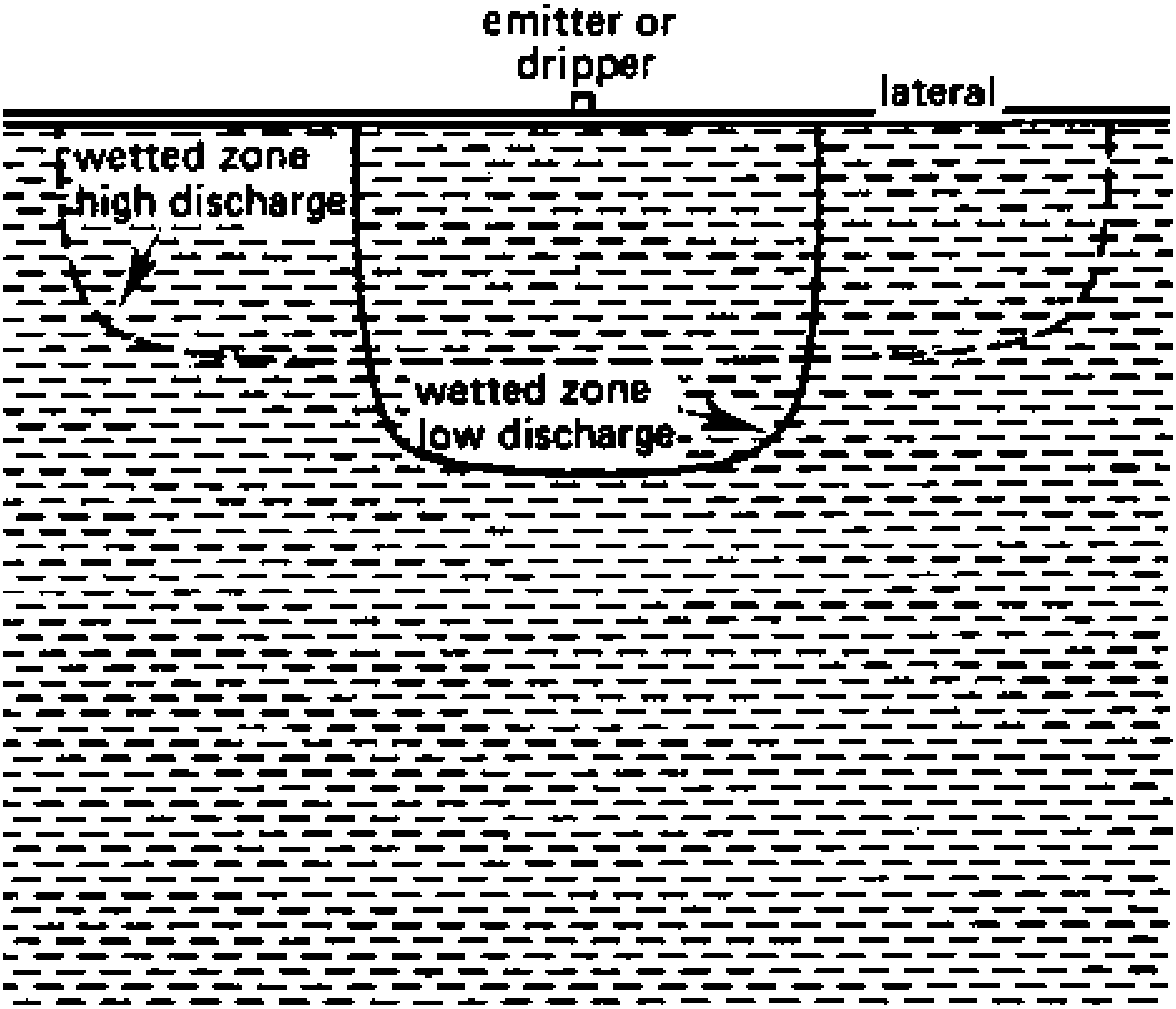


Figure 64 Wetting patterns for sand and clay soils with high and low discharge rates (CLAY)



Although only part of the root zone is wetted it is still important to meet the full water needs of the crop. It is sometimes thought that drip irrigation saves water by reducing the amount used by the crop. This is not true. Crop water use is not changed by the method of applying water. Crops just require the right amount for good growth.

The water savings that can be made using drip irrigation are the reductions in deep percolation, in surface runoff and in evaporation from the soil. These savings, it must be remembered, depend as much on the user of the equipment as on the equipment itself.

Drip irrigation is not a substitute for other proven methods of irrigation. It is just another way of applying water. It is best suited to areas where water quality is marginal, land is steeply sloping or undulating and of poor quality, where water or labour are expensive, or where high value crops require frequent water applications.

CHAPTER 7. CHOOSING AN IRRIGATION METHOD

To choose an irrigation method, the farmer must know the advantages and disadvantages of the various methods. He or she must know which method suits the local conditions best. Unfortunately, in many cases there is no single best solution: all methods have their advantages and disadvantages. Testing of the various methods - under the prevailing local conditions - provides the best basis for a sound choice of irrigation method. This chapter gives some very broad guidance and indicates several important criteria in the selection of a suitable irrigation method.

7.1 Surface, Sprinkler or Drip Irrigation

The suitability of the various irrigation methods, i.e. surface, sprinkler or drip irrigation, depends mainly on the following factors:

- natural conditions
- type of crop
- type of technology
- previous experience with irrigation
- required labour inputs
- costs and benefits.

NATURAL CONDITIONS

The natural conditions such as soil type, slope, climate, water quality and availability, have the following impact on the choice of an irrigation method:

Soil type:	Sandy soils have a low water storage capacity and a high infiltration rate. They therefore need frequent but small irrigation applications, in particular when the sandy soil is also shallow. Under these circumstances, sprinkler or drip irrigation are more suitable than surface irrigation. On loam or clay soils all three irrigation methods can be used, but surface irrigation is more commonly found. Clay soils with low infiltration rates are ideally suited to surface irrigation.

	When a variety of different soil types is found within one irrigation scheme, sprinkler or drip irrigation are recommended as they will ensure a more even water distribution.
Slope:	Sprinkler or drip irrigation are preferred above surface irrigation on steeper or unevenly sloping lands as they require little or no land levelling. An exception is rice grown on terraces on sloping lands.
Climate:	Strong wind can disturb the spraying of water from sprinklers. Under very windy conditions, drip or surface irrigation methods are preferred. In areas of supplementary irrigation, sprinkler or drip irrigation may be more suitable than surface irrigation because of their flexibility and adaptability to varying irrigation demands on the farm.
Water availability:	Water application efficiency (see Annex 4, step 8) is generally higher with sprinkler and drip irrigation than surface irrigation and so these methods are preferred when water is in short supply. However, it must be remembered that efficiency is just as much a function of the irrigator as the method used.
Water quality:	Surface irrigation is preferred if the irrigation water contains much sediment. The sediments may clog the drip or sprinkler irrigation systems.
	If the irrigation water contains dissolved salts, drip irrigation is particularly suitable, as less water is applied to the soil than with surface methods.
	Sprinkler systems are more efficient that surface irrigation methods in leaching out salts.

TYPE OF CROP

Surface irrigation can be used for all types of crops. Sprinkler and drip irrigation, because of their high capital investment per hectare, are mostly used for high value cash crops, such as vegetables and fruit trees. They are seldom used for the lower value staple crops.

Drip irrigation is suited to irrigating individual plants or trees or row crops such as vegetables and sugarcane. It is not suitable for close growing crops (e.g. rice).

TYPE OF TECHNOLOGY

The type of technology affects the choice of irrigation method. In general, drip and sprinkler irrigation are technically more complicated methods. The purchase of equipment requires high capital investment per hectare. To maintain the equipment a high level of 'know-how' has to be available,. Also, a regular supply of fuel and spare parts must be maintained which - together with the purchase of equipment - may require foreign currency.

Surface irrigation systems - in particular small-scale schemes - usually require less sophisticated equipment for both construction and maintenance (unless pumps are used). The equipment needed is often easier to maintain and less dependent on the availability of foreign currency.

PREVIOUS EXPERIENCE WITH IRRIGATION

The choice of an irrigation method also depends on the irrigation tradition within the region or country. Introducing a previously unknown method may lead to unexpected complications. It is not certain that the farmers will accept the new method. The servicing of the equipment may be problematic and the costs may be high compared to the benefits.

Figure 65 Surface irrigation requires a high labour input

Often it will be easier to improve the traditional irrigation method than to introduce a totally new method.

REQUIRED LABOUR INPUTS

Surface irrigation often requires a much higher labour input - for construction, operation and maintenance - than sprinkler or drip irrigation (Figure 65). Surface irrigation requires accurate land levelling, regular maintenance and a high level of farmers' organization to operate the system. Sprinkler and drip irrigation require little land levelling; system operation and maintenance are less labour-intensive.

COSTS AND BENEFITS

Before choosing an irrigation method, an estimate must be made of the costs and benefits of the available options. On the cost side not only the construction and installation, but also the operation and maintenance (per hectare) should be taken into account. These costs should then be compared with the expected benefits (yields). It is obvious that farmers will only be interested in implementing a certain method if they consider this economically attractive. Cost/benefit analysis is, however, beyond the scope of this manual.

> **In conclusion:** surface irrigation is by far the most widespread irrigation method. It is normally used when conditions are favourable: mild and regular slopes, soil type with medium to low infiltration rate, and a sufficient supply of surface or groundwater. In the case of steep or irregular slopes, soils with a very high infiltration rate or scarcity of water, sprinkler and drip irrigation may be more appropriate. When introducing sprinkler and drip irrigation it must be ensured that the equipment can be maintained.

7.2 Basin, Furrow or Border Irrigation

This section discusses some of the important factors which should be taken into account when determining which surface irrigation method is most suitable: basin, furrow or border irrigation. Again, it is not possible to give specific guidelines leading to a single best solution; each option has its advantages and disadvantages.

Factors to be taken into account include:

- natural circumstances (slope, soil type)
- type of crop
- required depth of irrigation application
- level of technology

- previous experience with irrigation
- required labour inputs.

NATURAL CIRCUMSTANCES

Flat lands, with a slope of 0.1% or less, are best suited for basin irrigation: little land levelling will be required. If the slope is more than 1%, terraces can be constructed. However, the amount of land levelling can be considerable.

Furrow irrigation can be used on flat land (short, near horizontal furrows), and on mildly sloping land with a slope of maximum 0.5%. On steeper sloping land, contour furrows can be used up to a maximum land slope of 3%. A minimum slope of 0.05% is recommended to assist drainage.

Border irrigation can be used on sloping land up to 2% on sandy soil and 5% on clay soil. A minimum slope of 0.05% is recommended to ensure adequate drainage.

Surface irrigation may be difficult to use on irregular slopes as considerable land levelling may be required to achieve the required land gradients.

All soil types, except coarse sand with an infiltration rate of more than 30 mm/hour, can be used for surface irrigation. If the infiltration rate is higher than 30 mm/hour, sprinkler or drip irrigation should be used.

TYPE Of CROP

Paddy rice is always grown in basins. Many other crops can also be grown in basins: e.g. maize, sorghum, trees, etc. Those crops that cannot stand a very wet soil for more than 12-24 hours should not be grown in basins.

Furrow irrigation is best used for irrigating row crops such as maize, vegetables and trees.

Border irrigation is particularly suitable for close growing crops such as alfalfa, but border irrigation can also be used for row crops and trees.

REQUIRED DEPTH OF IRRIGATION APPLICATION

When the irrigation schedule has been determined (see Volume 4) it is known how much water (in mm) has to be given per irrigation application. It must be checked that this amount can indeed be given, with the irrigation method under consideration.

Field experience has shown that most water can be applied per irrigation application when using basin irrigation, less with border irrigation and least with furrow irrigation. In practice, in small-scale irrigation projects, usually 40-70 mm of water are applied in basin irrigation, 30-60 mm in border irrigation and 20-50 mm in furrow irrigation. (In large-scale irrigation projects, the amounts of water applied may be much higher.)

This means that if only little water is to be applied per application, e.g. on sandy soils and a shallow rooting crop, furrow irrigation would be most appropriate. (However, none of the surface irrigation methods can be used if the sand is very coarse, i.e. if the infiltration rate is more than 30 mm/hour.)

If, on the other hand, a large amount of irrigation water is to be applied per application, e.g. on a clay soil and with a deep rooting crop, border or basin irrigation would be more appropriate.

The above considerations have been summarized in Table 5. The net irrigation application values used are only a rough guide. They result from a combination of soil type and rooting depth. For example: if the soil is sandy and the rooting depth of the crop is medium, it is estimated that the net depth of each irrigation application will be in the order of 35 mm. The last column indicates which irrigation method is most suitable. In this case medium furrows or short borders.

The sizes of the furrows, borders and basins have been discussed in the previous chapters. The approximate rooting depths of the most Important field crops are given in Volume 4.

LEVEL OF TECHNOLOGY

Basin irrigation is the simplest of the surface irrigation methods. Especially if the basins are small, they can be constructed by hand or animal traction. Their operation and maintenance is simple (see Figure 66).

Furrow irrigation - with the possible exception of short, level furrows -requires accurate field grading. This is often done by machines. The maintenance - ploughing and furrowing - is also often done by machines. This requires skill, organization and frequently the use of foreign currency for fuel, equipment and spare parts.

Table 5 SELECTION OF AN IRRIGATION METHOD BASED ON THE DEPTH OF THE NET IRRIGATION APPLICATION

Soil type	Rooting depth of the crop	Net irrigation depth per application (mm)	Irrigation method
Sand	shallow	20-30	short furrows
	medium	30-40	medium furrows, short borders
	deep	40-50	long furrows, medium borders, small basins
Loam	shallow	30-40	medium furrows, short borders
	medium	40-50	long furrows, medium borders, small basins
	deep	50-60	long borders, medium basins
Clay	shallow	40-50	long furrows, medium borders, small basins
	medium	50-60	long borders, medium basins
	deep	60-70	large basins

Figure 66 Land levelling using animal traction

Short, level furrows - also called furrow basins - can, like basins, be constructed and maintained by hand.

Borders require the highest level of sophistication. They are constructed and maintained by machines. The grading needs to be accurate. Machine operation requires a high level of skill, organization and usually foreign currency.

PREVIOUS EXPERIENCE WITH IRRIGATION

If there is no tradition in irrigation, the most simple irrigation method to introduce is basin irrigation. The smaller the basins, the easier their construction, operation and maintenance.

If irrigation is used traditionally, it is usually simpler to improve the traditional irrigation method than it is to introduce a previously unknown method.

REQUIRED LABOUR INPUTS

The required labour inputs for construction and maintenance depend heavily on the extent to which machinery is used.

In general it can be stated that to operate the system, basin irrigation requires the least labour and the least skill. For the operation of furrow and border irrigation systems more labour is required combined with more skill.

Figure 67 Basin irrigation is relatively easy

Annex 1 Field intakes and measuring siphon discharge

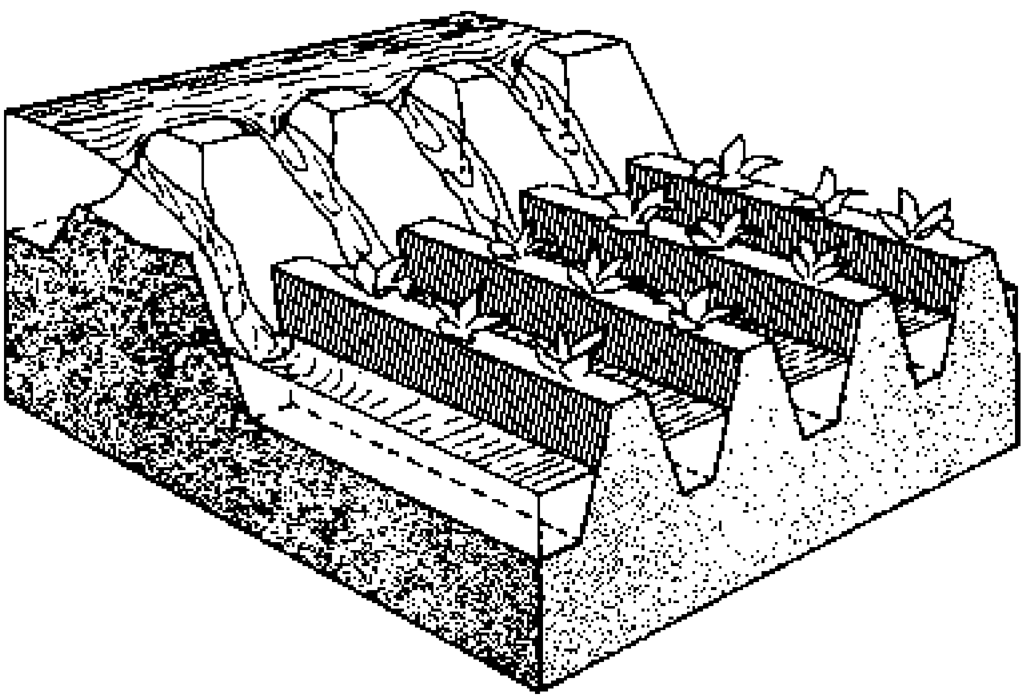
FIELD INTAKES

Irrigation water can be supplied from the farm channel into the field through:

- a breach in the channel bank
- siphons
- spiles.

A **breach** (Figure 68) is a cut in the channel embankment to allow water to flow into the field.

Figure 68 Breaches

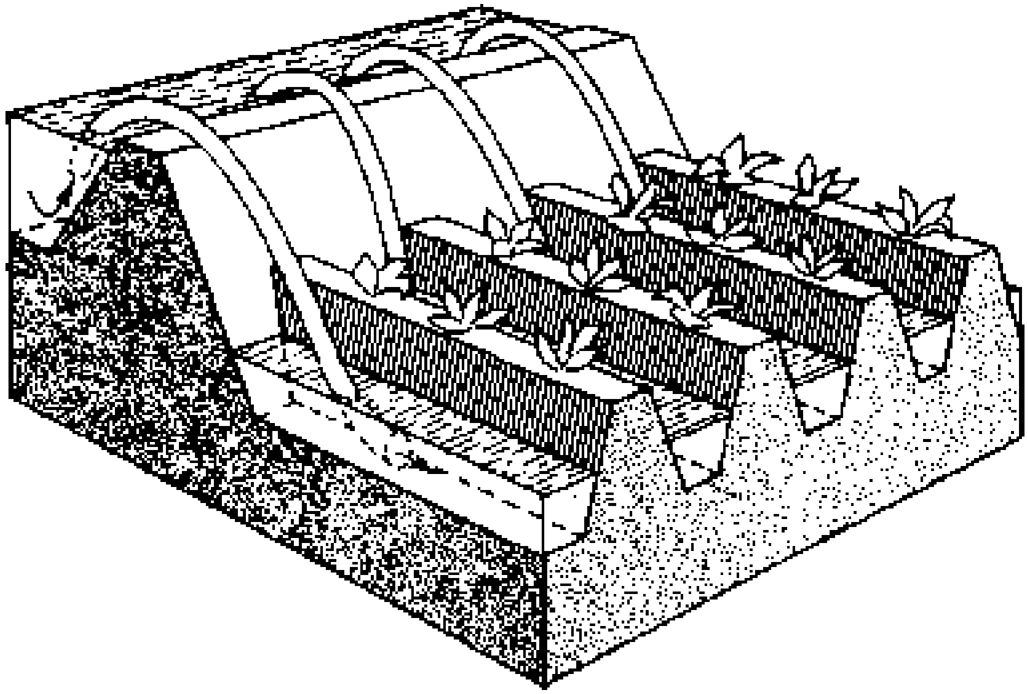


After completing the irrigation, the farmer closes the embankment again. This has to be done carefully to prevent leakage. This is the most common method of releasing water from a channel, but it can also be the most damaging. Not only is it difficult to control the discharge, but there can be serious erosion of the channel embankment which is difficult to repair. If other more controllable methods are available then these should be used in preference to this. Breaches can be most easily controlled on clay soils which do not erode easily.

On sandy and loamy soils cutting a breach may cause serious erosion and leakage problems. In this case it is better to use siphons or spiles.

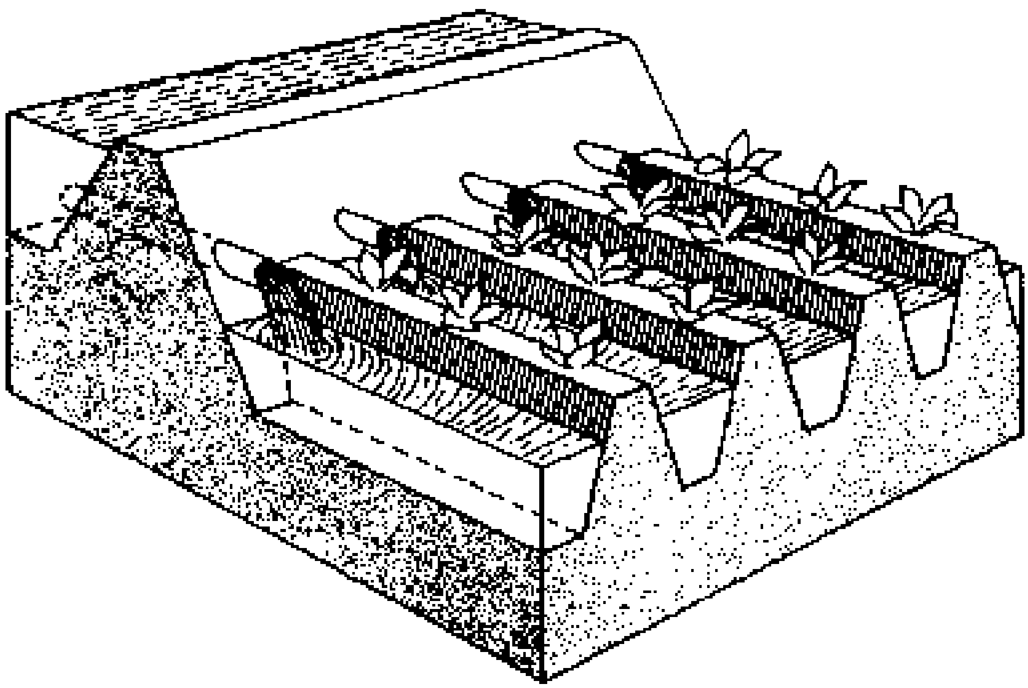
Siphons are small diameter pipes used to convey water over the channel embankment (Figure 69).

Figure 69 Siphons



Spiles are small pipes buried in the ditch bank (Figure 70).

Figure 70 Spiles



For siphons and spiles to work properly, the water level in the farm channel must be higher than in the field. When the water level in the farm channel is much higher than in the field, the outlet from the siphon or spile may be above the water level in the field. This is known as free discharge (Figure 70). When the water level in the farm channel is lower, then the outlet may be below the field water level. This is known as **drowned** discharge (Figure 69). Both modes of operation are acceptable.

The discharge through siphons and spiles depends on the diameter of the pipe and the head. For **free** discharge, the head is the difference between the water level in the farm channel and the outlet from the pipe (Figure 71b). For drowned or **submerged** discharge, the head is the difference between the water level in the farm channel and in the field (Figure 71a). Discharge can be changed by a change in pipe diameter or a change in the head (see Table 6).

Table 6 DISCHARGES FOR SIPHONS AND SPILES (l/s)

Diameter	Head (cm)			
(cm)	5	10	15	20
2	0.19	0.26	0.32	0.73
3	0.42	0.59	0.73	0.84
4	0.75	1.06	1.29	1.49
5	1.17	1.65	2.02	2.33

MEASURING SIPHON OR SPILE DISCHARGE

The most common method used to measure siphon or spile discharge is the volume method.

Figure 71 Determining the head (a) Submerged discharge

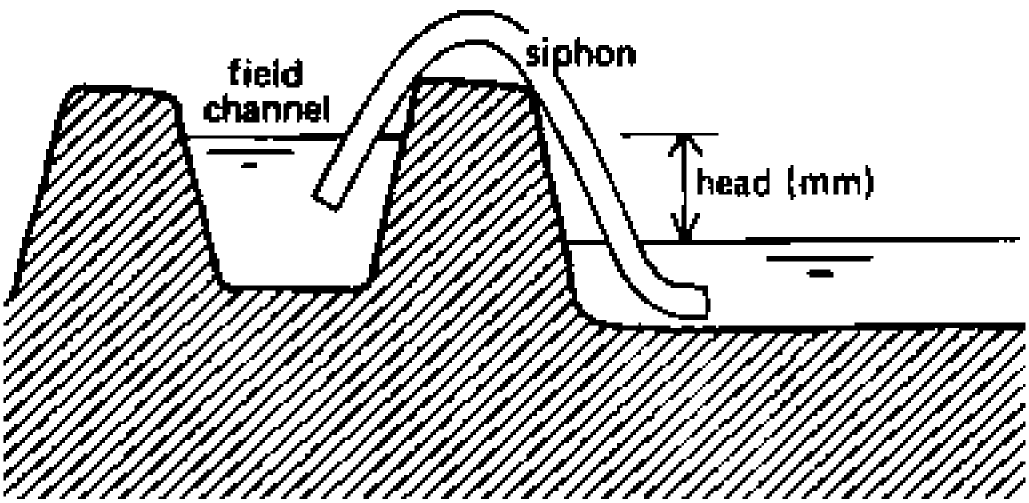
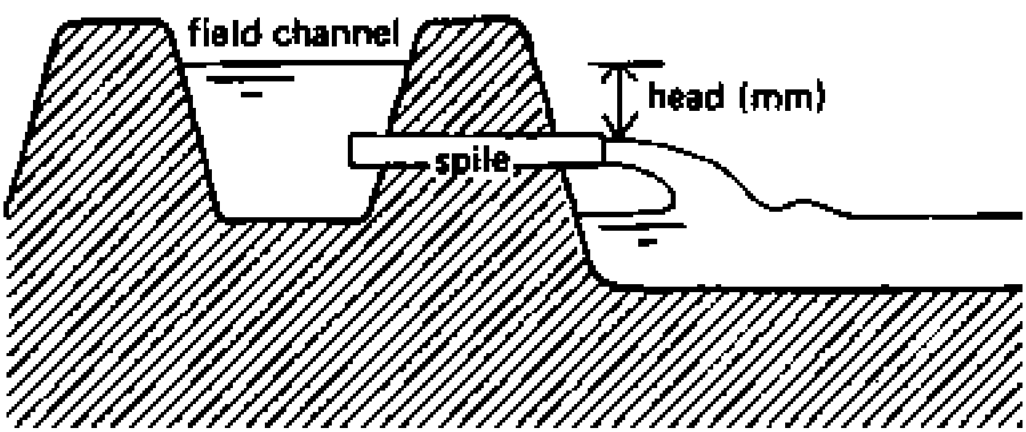


Figure 71 Determining the head (b) Free discharge



Equipment

Bucket of a known volume, a siphon or a spile, a (stop) watch, two people.

Set-up

Just behind the bund of the field channel a hole is made in the soil, in which a bucket is placed (Figure 72).

Figure 72 Measuring the siphon discharge (a) Free discharge

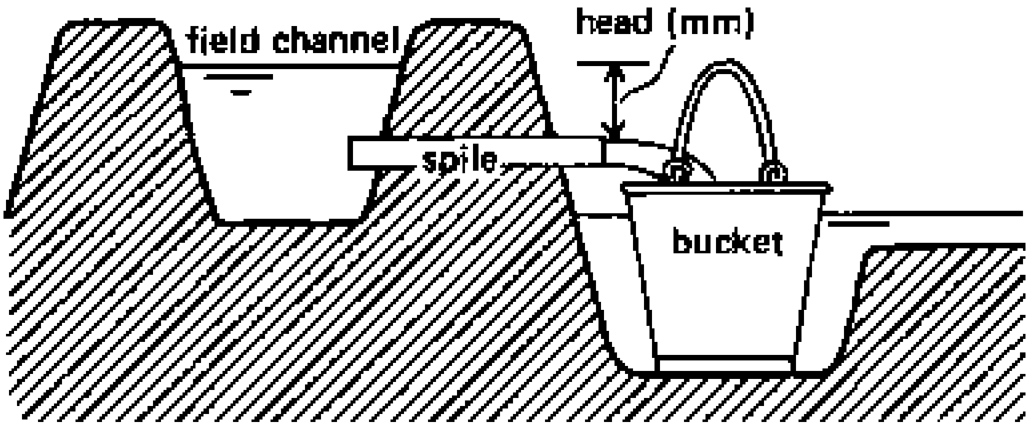
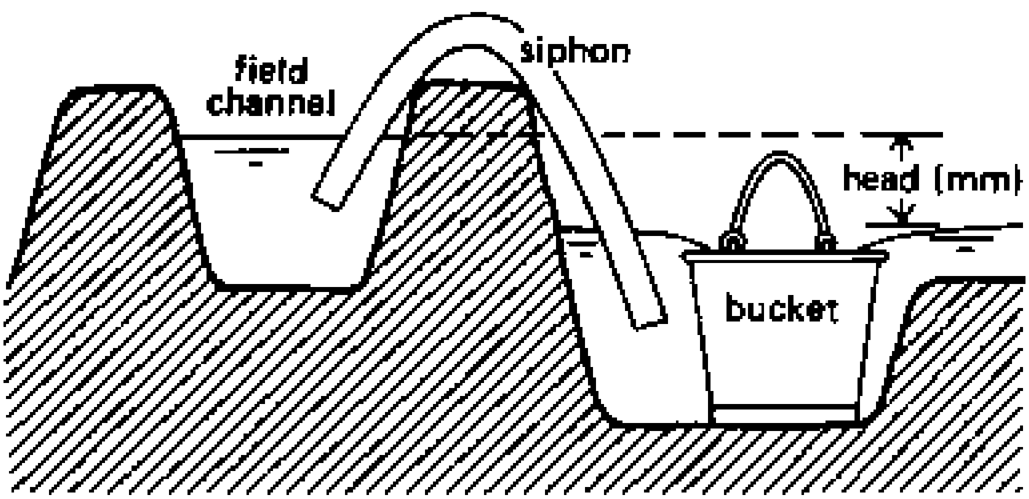


Figure 72 Measuring the siphon discharge (b) Drowned or submerged discharge



If the siphon or spile is **freely** discharging then the pipe can discharge directly into the bucket (Figure 72a). However, if the siphon discharge is **drowned**, then the bucket must be held firmly with the bucket lip at the same level as the normal water level in the field (Figure 72b). Water is discharged into the hole alongside the bucket, where the water level rises and overflows into the bucket. This procedure is important in order to measure the discharge under the normal operating head. If the siphon was allowed to discharge directly into the bucket the head would be changing as the bucket fills and this would affect the siphon discharge.

Procedure

The siphon is first filled with water to take out all the air. This is called **priming** (Figure 73). One end is kept under water and the other end is covered with the hand to prevent air from re-entering (Figure 73). The siphon is placed over the embankment with one end in the channel and the other in the hole beside the bucket.

Figure 73 "Priming" of a siphon

As the water level rises it flows over into the bucket. The time taken to fill the bucket is then recorded.

For free siphon flow the water can be discharged directly from the siphon into the bucket.

The siphon discharge is then calculated as follows:

$$\text{Siphon discharge (l/s)} = \frac{\text{Volume of bucket (litres)}}{\text{Time to fill bucket (seconds)}}$$

Example:

A 5-litre bucket is filled by a siphon according to the volume method.

The time to fill the bucket is 12 seconds. Hence 5 litres/12 seconds is the discharge of the siphon, i.e. 0.42 l/s.

Annex 2 Infiltration rate and infiltration test

INFILTRATION RATE

The **infiltration rate** is the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour. An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the soil surface, will take one hour to infiltrate.

In dry soil, water infiltrates rapidly. This is called the **initial infiltration** rate. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the basic **infiltration rate** (Table 7).

The infiltration rate depends on soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles: see Volume 1) and is a useful way of categorizing soils from an irrigation point of view (see Table 8).

The most common method to measure the infiltration rate is by a field test using a cylinder or ring infiltrometer.

Table 7 BASIC INFILTRATION RATES FOR VARIOUS SOIL TYPES

Soil type	Basic infiltration rate (mm/hour)
sand	less than 30
sandy loam	20 - 30
loam	10 - 20
clay loam	5 - 10
clay	1 - 5

FIELD INFILTRATION TEST

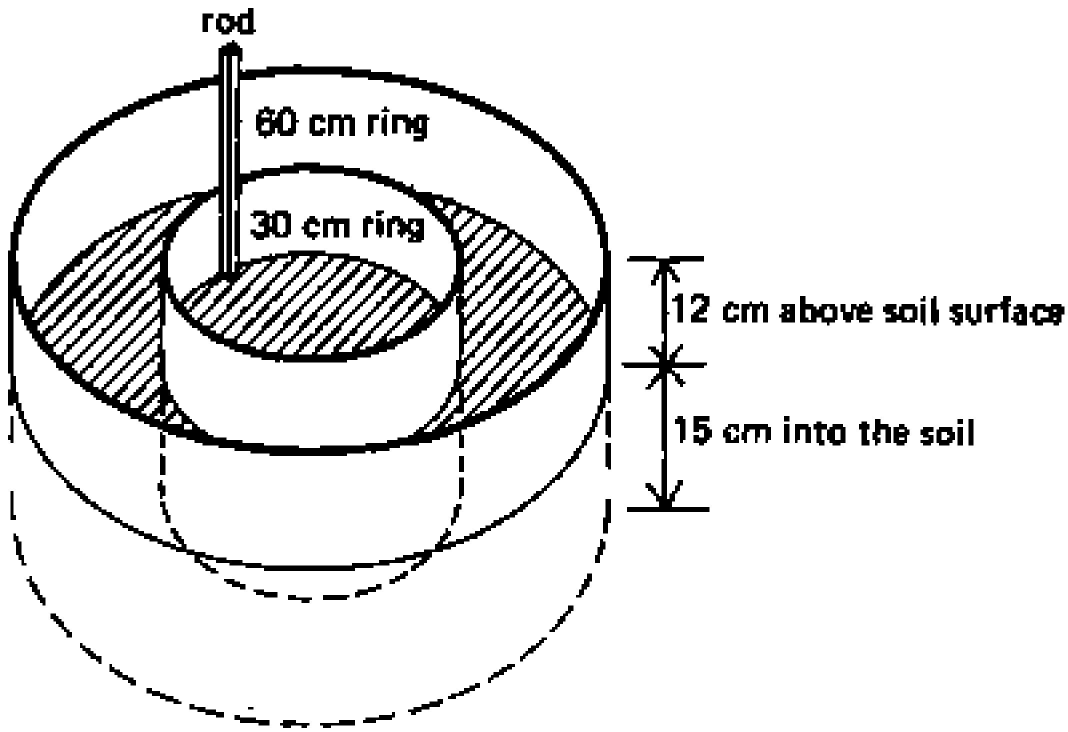
Equipment required

Shovel/hoe
Hammer (2 kg)
Watch or clock
5 litre bucket
Timber (75 x 75 x 400)
Hessian (300 x 300) or jute cloth
At least 100 litres of water

Ring infiltrometer of 30 cm diameter and 60 cm diameter. Instead of the outer cylinder a bund could be made to prevent lateral water flow.

Measuring rod graduated in mm (e.g. 300 mm ruler)

Figure 74 Set-up of field test



Method

Step 1: Hammer the 30 cm diameter ring at least 15 cm into the soil. Use the timber to protect the ring from damage during hammering. Keep the side of the ring vertical and drive the measuring rod into the soil so that approximately 12 cm is left above the ground.

Step 2: Hammer the 60 cm ring into the soil or construct an earth bund around the 30 cm ring to the same height as the ring and place the hessian inside the infiltrometer to protect the soil surface when pouring in the water (Figure 75).

Step 3: Start the test by pouring water into the ring until the depth is approximately 70-100 mm. At the same time, add water to the space between the two rings or the ring and the bund to the same depth. Do this quickly.

The water in the bund or within the two rings is to prevent a lateral spread of water from the infiltrometer.

Step 4: Record the clock time when the test begins and note the water level on the measuring rod.

Step 5: After 1-2 minutes, record the drop in water level in the inner ring on the measuring rod and add water to bring the level back to approximately the original level at the start of the test. Record the water level. Maintain the water level outside the ring similar to that inside.

Step 6: Continue the test until the drop in water level is the same over the same time interval. Take readings frequently (e.g. every 1-2 minutes) at the beginning of the test, but extend the interval between readings as the time goes on (e.g. every 20-30 minutes).

Note that at least two infiltration tests should be carried out at a site to make sure that the correct results are obtained.

Figure 75 Cylinder infiltrometers with second ring or bund

Table 8 and Figure 76 show how to record these measured data.

Table 8:

- Column 1 indicates the readings on the clock in hours, minutes and seconds.

- Column 2 indicates the difference in time (in minutes) between two readings.

- Column 3 indicates the cumulative time (in minutes); this is the time (in minutes) since the test started.

- Column 4 indicates the water level readings (in mm) on the measuring rod: before and after filling (see step 5).

- Column 5 indicates the infiltration (in mm) between two readings; this is the difference in the measured water levels between two readings. How the infiltration is calculated is indicated in brackets.

- Column 6 indicates the infiltration rate (in mm/minute); this is the infiltration (in mm; column 5) divided by the difference in time (in minutes, column 2).

- Column 7 indicates the infiltration rate (in mm/hour); this is the infiltration rate (in mm/minute, column 6) multiplied by 60 (60 minutes in 1 hour).

- Column 8 indicates the cumulative infiltration (in mm); this is the infiltration (in mm) since the test started. How the cumulative infiltration is calculated is indicated in brackets.

DATA SHEET: INFILTRATION RATE

Figure 76:

In Figure 76, the cumulative time (in minutes, column 2) is set out against the cumulative infiltration (in mm, column 8) and a curve is formed. From Figure 73 it can, for example, be observed that for the soil type used in the example it takes 70 minutes to infiltrate approximately 74 mm of irrigation water.

The basic infiltration rate can be determined from Table 8, column 7: the infiltration rate in am/hour. Once the values of the Infiltration rate are constant, the basic infiltration rate has been reached. In this example the basic infiltration rate is 27 mm/hour and was reached after 60 minutes. After 60 minutes the cumulative infiltration was 69 mm. After the first 60 minutes the infiltration rate is constant: 27 mm/hour. So after 120 minutes (2 hours) the cumulative infiltration will be 69 + 27 = 96 mm (indicated on the graph with a dotted line). After 3 hours the cumulative Infiltration will be (96 + 27 =) 123 mm, etc. Once the curve has been established it is possible to determine how long it will take to infiltrate a certain amount of water. This is of course important to know when determining the irrigation time.

Figure 76 Example of an infiltration curve

> Note: The infiltration curve should be determined for normal soil moisture conditions **before** irrigation takes place, i.e. usually when the top soil is dry.

DATA SHEET: INFILTRATION RATE

INFILTRATION TEST

Annex 3 Quarter time rule and irrigation time

QUARTER TIME RULE

In surface irrigation water is supplied to the field from the supply channel. From the side of the supply channel the water flows to the opposite side of the field; this is called the **advance** of the water front (Figure 77).

Figure 77 Advance of the water front

When the water supply is stopped, the water on the field gradually infiltrates into the soil and moves away from the field channel; this is called the **recession** of the water front (Figure 78).

Figure 78 Recession of the water front

Ideally the advance of the water front should be the same as the recession; this would result in a uniform infiltration of water over the entire field. Usually, however, the advance and recession are not the same: the advance is often slower than the recession. The result is that the side of the field near the supply channel receives more water than the opposite side of the field. This is especially true if the water supply to the field is too small.

When for example on a sandy soil a small stream size is applied to a large field, it will take a long time before the water reaches the far end of the field; the water infiltrates rapidly into the sandy soil. The side of the field near the supply channel receives too much water and the opposite side of the field receives too little water. This is shown in Figure 79.

Figure 79 Water distribution with too small stream size

When the stream size is increased, the distribution of the water will improve. The water, of course, infiltrates at the same rate, but the water front will reach the opposite side of the field sooner. So also this side will receive a fair share of the water, albeit always less than the side near the supply channel (see Figure 80).

Figure 80 Water distribution with adequate stream size

In order to choose an appropriate stream size, the following "rule of thumb" called **quarter time rule** is used. The quarter time rule says that the stream size should be large enough for the water to reach the end of the field (furrow irrigation) or for the water to cover the entire field (basin irrigation) in a quarter of the time needed to fill the root zone with sufficient water (the contact time). The contact time is the time needed to infiltrate the required amount of water. The contact time can be determined from the infiltration curve, as explained in Annex 2.

Example:

In this example the infiltration curve of Annex 2 is used (Figure 76). Suppose it has been determined that 70 mm of water has to be supplied to a basin. From Figure 76 it can be observed that to Infiltrate 70 mm would take approximately 74 minutes. This means that when applying the quarter time rule, the basin must be covered with water in 74/4 - 18 to 19 minutes. So the stream size must be chosen in such a way that indeed the field is covered with water within some 18 or 19 minutes. If it takes longer, the distribution of water in the root zone is poor. If it is for some reason not possible to Increase the stream size and it takes longer than 18 or 19 minutes to cover the field, then it will be necessary to reduce the size of the basin such that it is possible to cover the field within 18 or 19 minutes.

IRRIGATION TIME

The irrigation time (in minutes or hours) is the time needed to supply the required irrigation depth (in mm). The irrigation time depends on: the stream size (l/sec), the required irrigation depth (mm) and the size of the field to be Irrigated (ha). The following formula is used to determine the irrigation time:

$$\text{Irrigation time (hours)} = \frac{2.78 \times \text{irrigation depth (mm)} \times \text{field size (ha)}}{\text{stream size (l/sec)}}$$

Example:

If for example the required irrigation depth is 50 mm, the available stream size is 20 l/sec and the size of the field is 75 x 50 m, the irrigation time is calculated as follows:

Step 1: Determine the field size in hectares.

The size is 75 m x 50 m = 3 750 m^2 = 3750/10 000 = 0.375 ha

Step 2: Determine the irrigation time

$$\text{Irrigation time (hours)} = \frac{2.78 \times \text{irrigation depth (mm)} \times \text{field size (ha)}}{\text{stream size (l/sec)}}$$

$$\text{Irrigation time (hours)} = \frac{2.78 \times 50 \times 0.375}{20}$$

Irrigation time (hours) = 2.6 hours = 156 minutes

Applying the quarter time rule it would mean that the water has to reach the end of the furrow or cover the basin in 156/4 39 minutes. If it takes longer the stream size per furrow or basin has to be increased or the furrow length or basin size reduced.

Annex 4 Evaluation of irrigation performance

This section describes how to determine the performance of basin/furrow irrigation. It is assumed that the net irrigation water need of the crop is known (i.e. the net irrigation depth). This is compared with what happens during the actual irrigation practice. The field application efficiency thus obtained is a good measure for the evaluation of the performance.

Figure 81 Place wooden posts at 5 a intervals

Equipment needed

- Measuring tape (30 m)
- Infiltrometer
- Wooden posts or lathes
- Stopwatch or clock
- Data sheet

Method

Step 1: Identify a typical basin or furrow, which can be considered representative of the local situation in terms of size, soil type and crop. Measure the basin size or furrow length with the tape. Record the site data on the data sheet:

Example:

Date of test: 4 December 1987	Basin size: 24 (m) x 15 (m) - 360 (m^2)
Crop: Groundnuts	Required net irrigation depth: 45 mm

Step 2: Place wooden posts at 5 to 10 m intervals as shown in Figure 81. Record position of the posts on the data sheet (column 2).

Step 3: Carry out several infiltration tests (see Annex 3) and make an (average) infiltration curve. In this example, the curve of Annex 3 (Figure 76) is used.

Step 4: Now the irrigation starts. Use the same stream size and the same irrigation time as the irrigator normally uses. Record the time it takes for the water front to reach each wooden post (1 to 6). This is called the advance time: column 3.

Step 5: Record the time it takes the water to infiltrate at each wooden post (1 to 6). This is called recession time: column 4.

Step 6: Calculate the contact time at each of the wooden posts. The contact time is the difference between the advance and recession time: column 5.

Step 7: Calculate at each of the wooden posts the amount of water applied, using the infiltration curve: in this case Figure 76: column 6. All data are recorded on the data sheet as indicated in the example below.

Step 8: Determine the field application efficiency.

The field application efficiency is the fraction of the applied water that is used by the crop. Provided there are no runoff losses, the field application efficiency (%) is the required irrigation depth (mm), divided by the average applied irrigation depth (mm), multiplied by 100%.
Or:

$$\text{Field application efficiency (\%)} = \frac{\text{Required irrigation depth (mm)}}{\text{Ave. applied irrigation depth (mm)}} \times 100\%$$

The average irrigation depth applied (column 6) is:

(65 + 63 + 61 + 60 + 56 + 46):6 = 59 mm

The required net irrigation depth is 45 mm.
Thus the field application efficiency (%) = 45/59 x 100% = 76%
It means that the (average) deep percolation losses are 59 - 45 = 14 mm. This is shown in Figure 82.

1	2	3			4			5	6
Post No.	**Distance from field channel**	**Advance time**			**Recession time**			**Contact time**	**Water applied**
		clock reading		**time elapsed since start**	**clock reading**		**time elapsed since start**		
	m	**hr**	**min**	**min**	**hr**	**min**	**min**	**min**	**mm**
1	0	11	00	0	11	50	50	50	65
2	5	11	04	4	11	50	50	46	63
3	10	11	08	8	11	50	50	42	61
4	15	11	11	11	11	51	51	40	60
5	20	11	20	20	11	52	52	32	56
6	24	11	30	30	11	54	54	24	46
								Average	59 mm

Figure 82 Deep percolation losses

DATA SHEET IRRIGATION PERFORMANCE

INFILTRATION TEST (A)

INFILTRATION TEST (B)

Suggested further reading

General

Jensen M.E. 1983 (ed). Design and operation of farm irrigation systems. Revised Printing. Amer. Soc. Agr. Engr. Mono. No. 3. St. Joseph, Michigan. 840 p.

Stern P.H. 1979 Small Scale Irrigation: A Manual of Low Cost Water Technology. Intermediate Technology Publications, London.

Withers B. and Vipond S. 1974 Irrigation: Design and Practice. (1st ed.). Batsford, London.

Surface Irrigation

Booher L.J. 1974 Surface Irrigation. Land and Water Development Division, FAO, Rome.

Kay M. 1986 Surface Irrigation: Systems and Practice. Cranfield Press, Bedford, UK.

Sprinkler Irrigation

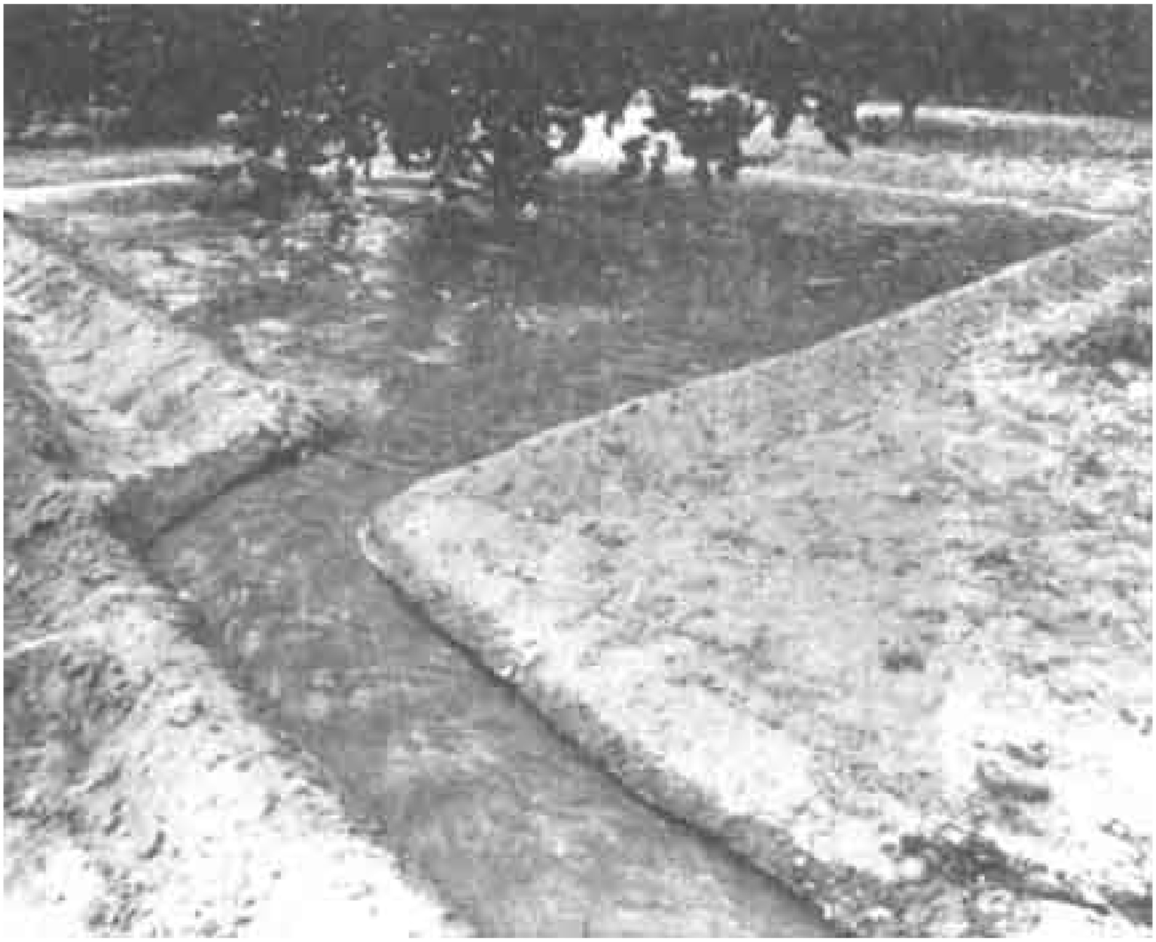
Kay M. 1983 Sprinkler Irrigation: Equipment and Practice. Batsford, London.

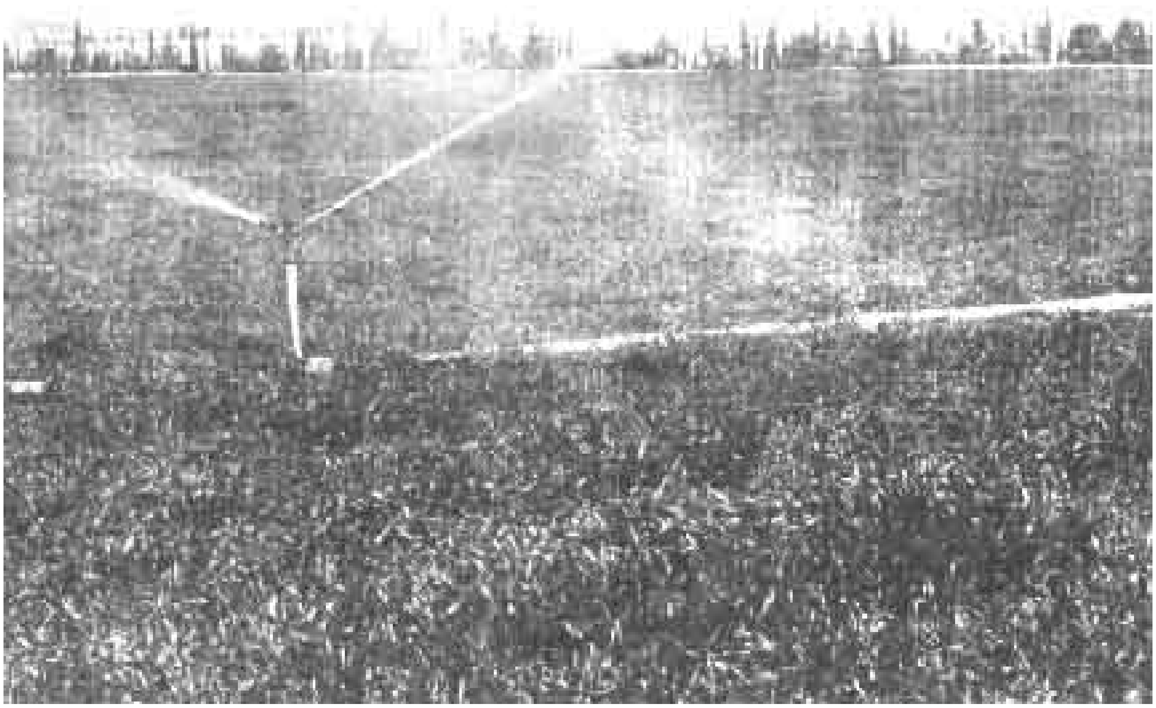
Drip Irrigation

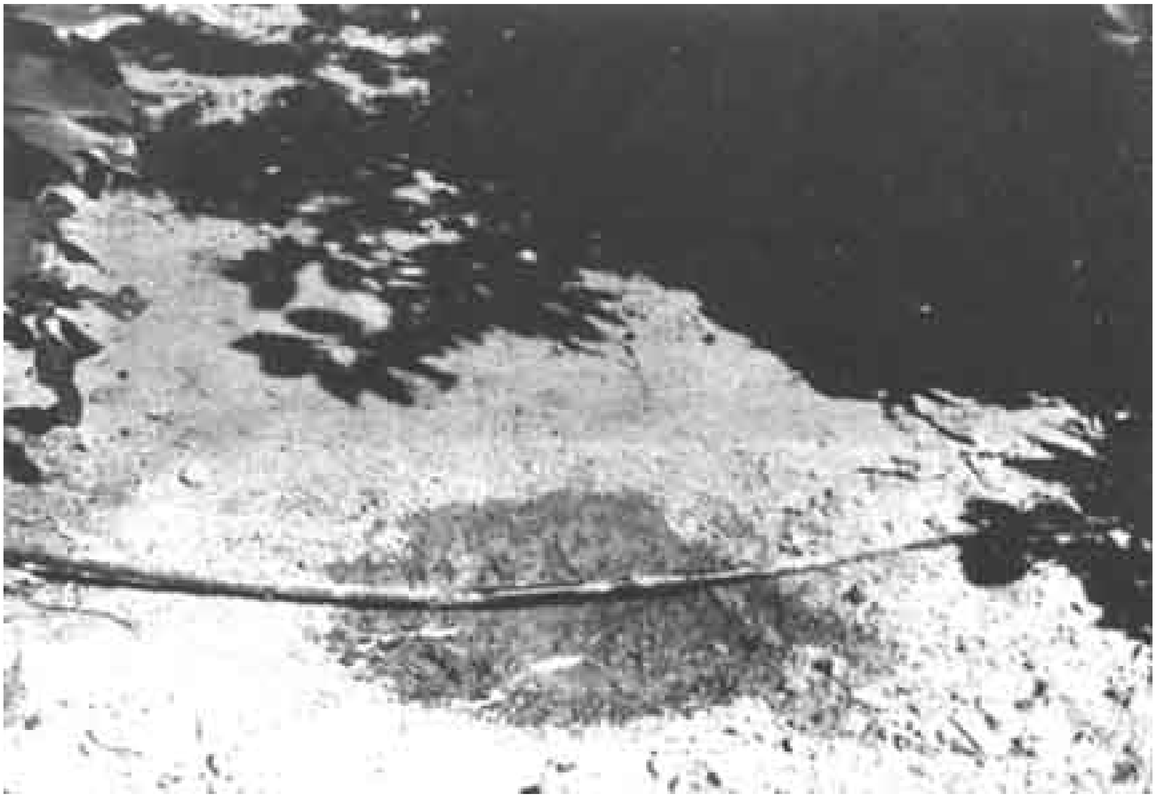
Nakayoma F.S. and Bucks D.A. 1986 (eds). Trickle Irrigation for Crop Production: Design, Operation and Management. Elsevier, New York. 393 p.

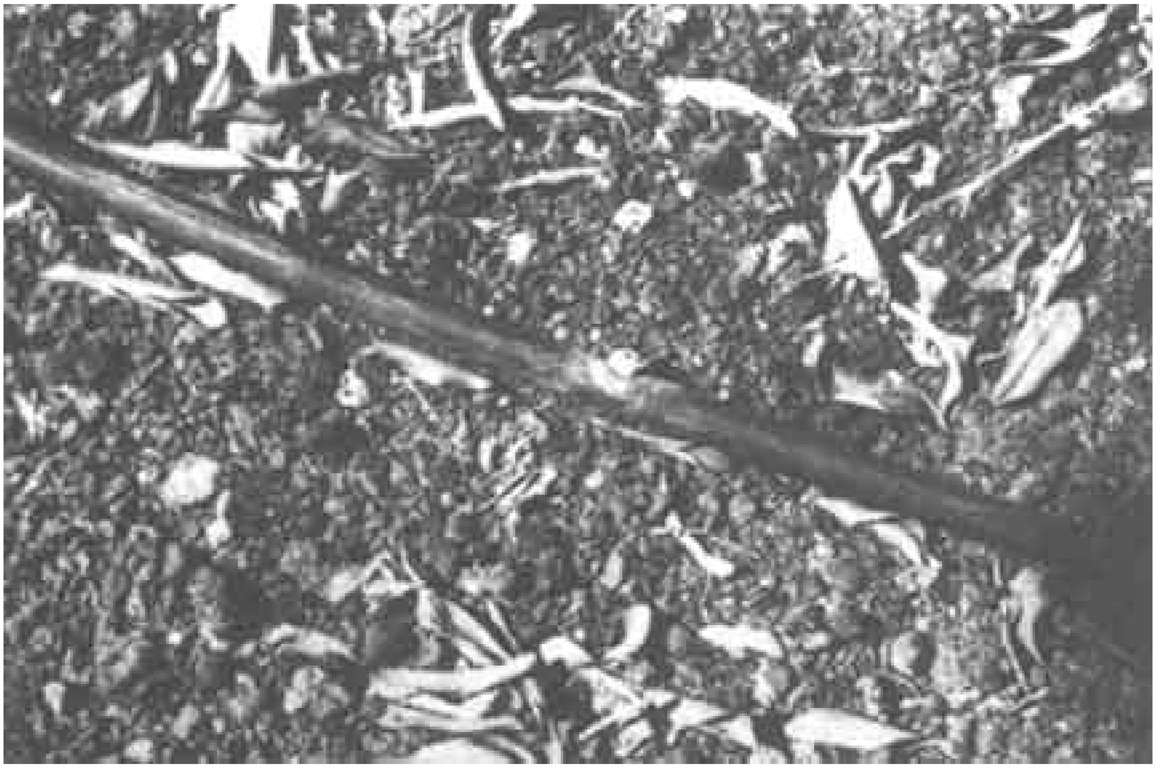
Vermeiren L. and Jobling G.A. 1980 Localized irrigation: design, installation, operation and evaluation. Irrigation and Drainage Paper 36, FAO, Rome.

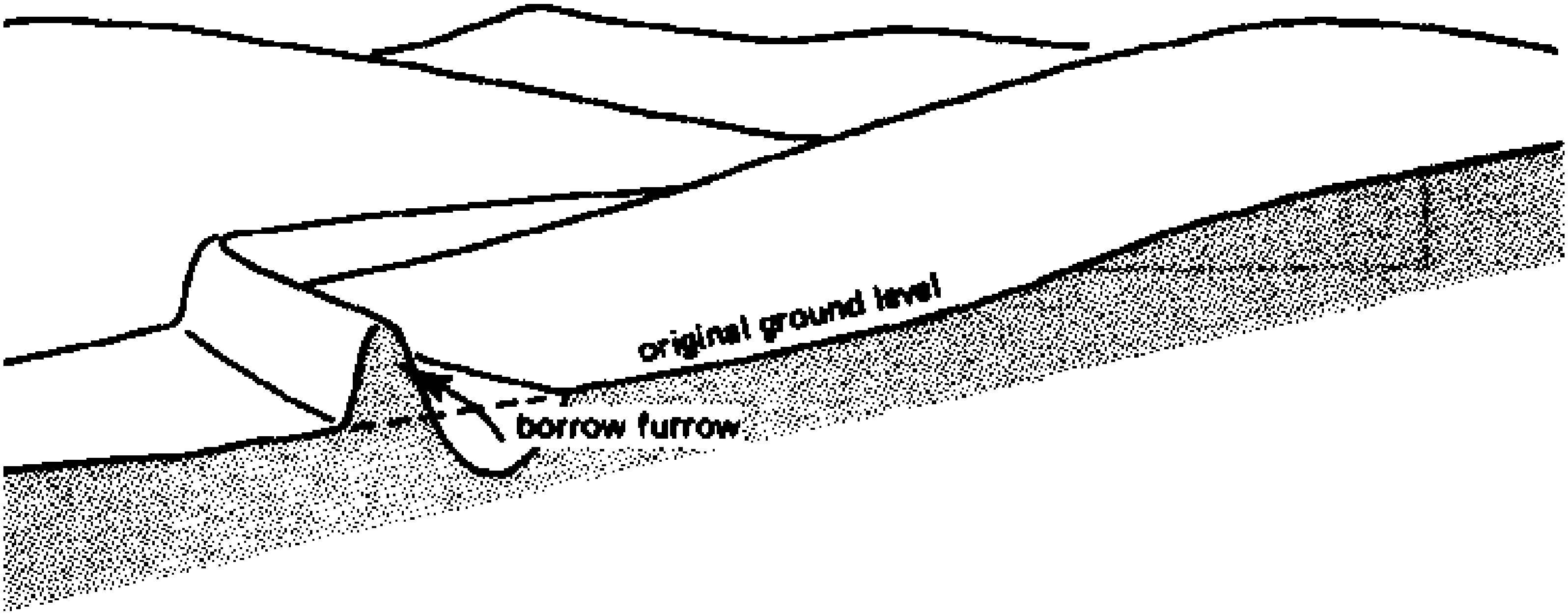
M/S8684E/1/11.88/3500

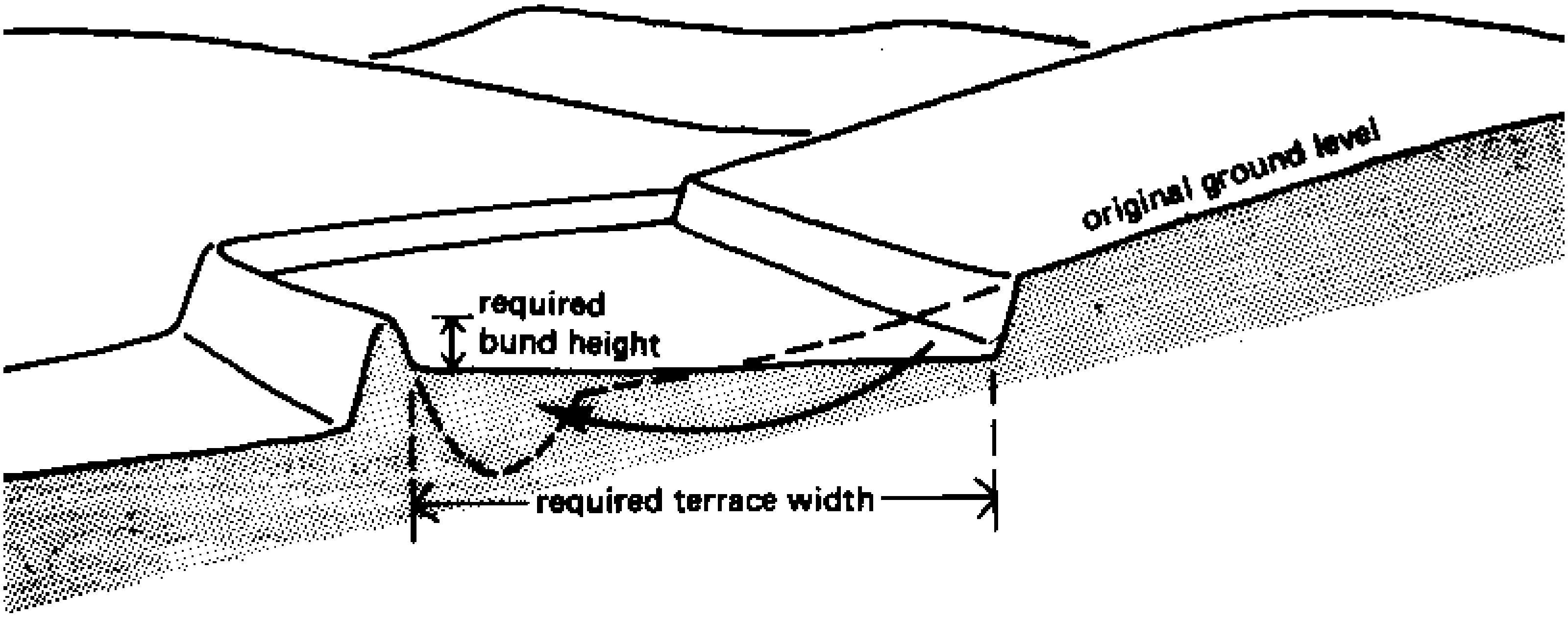


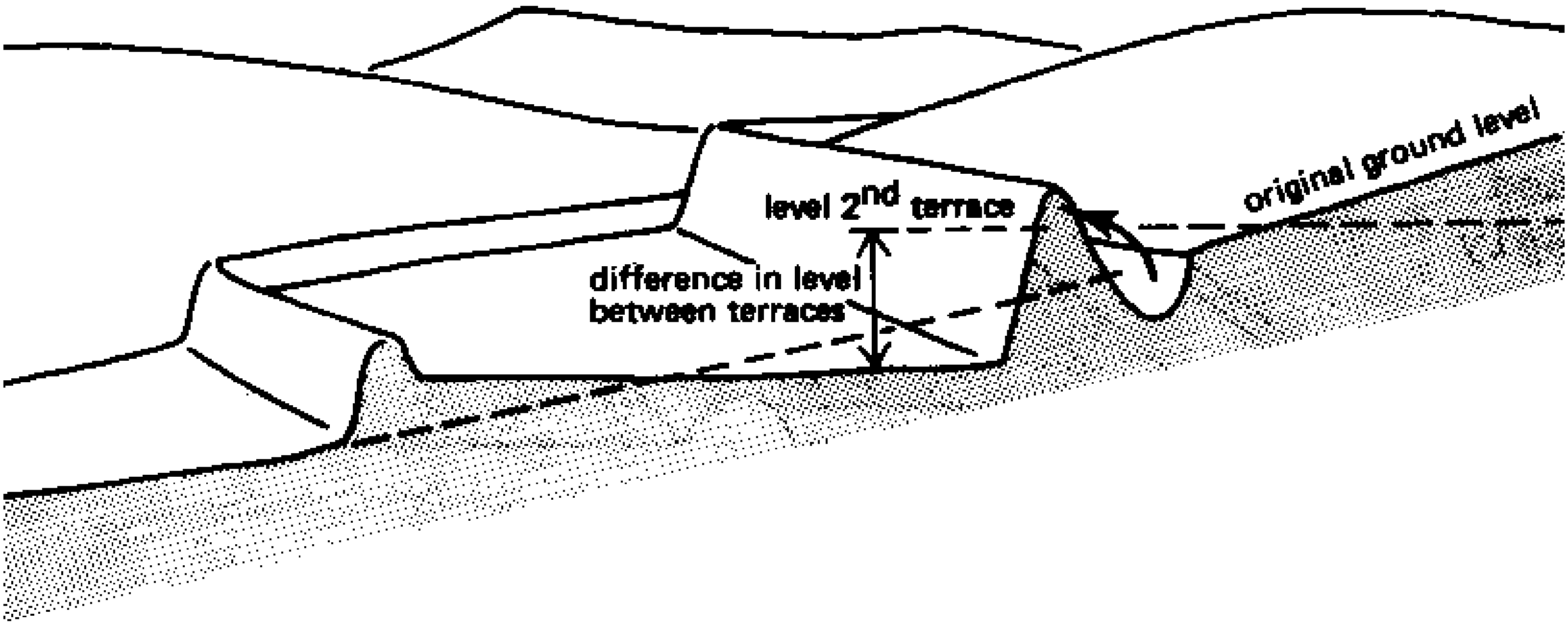


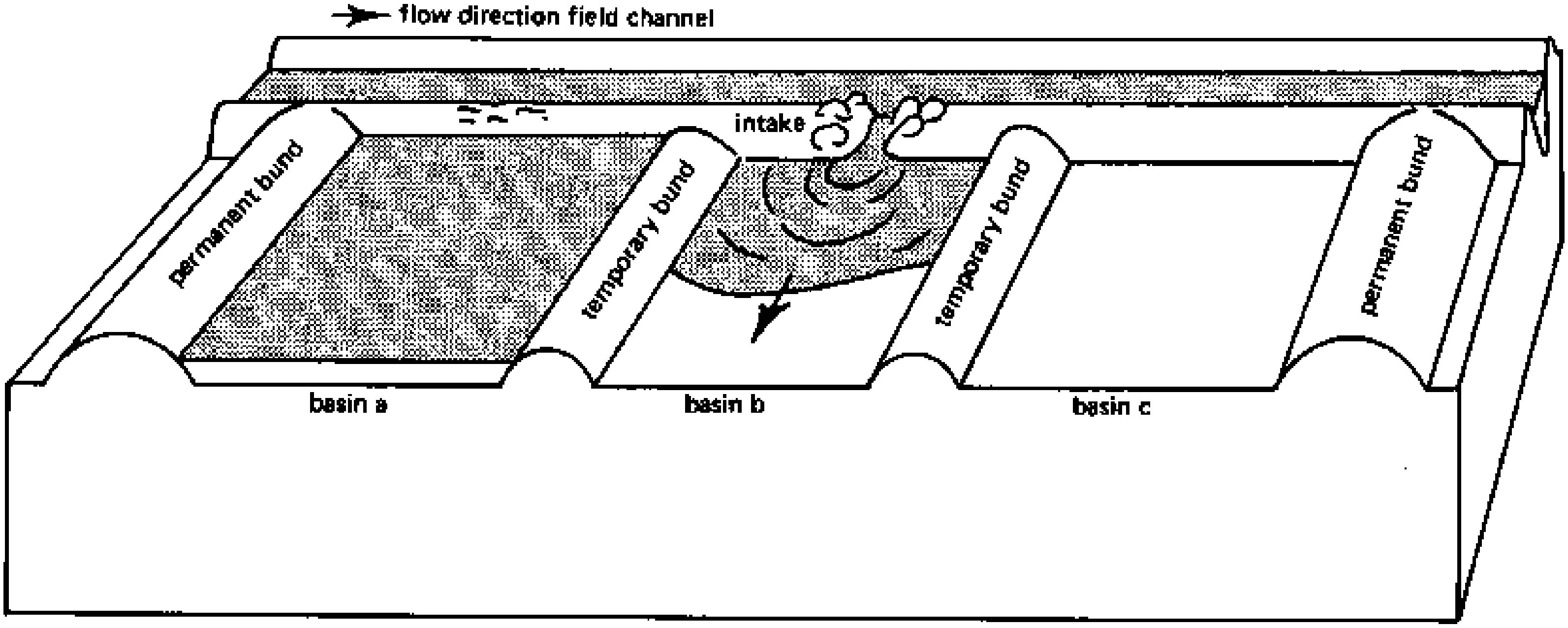


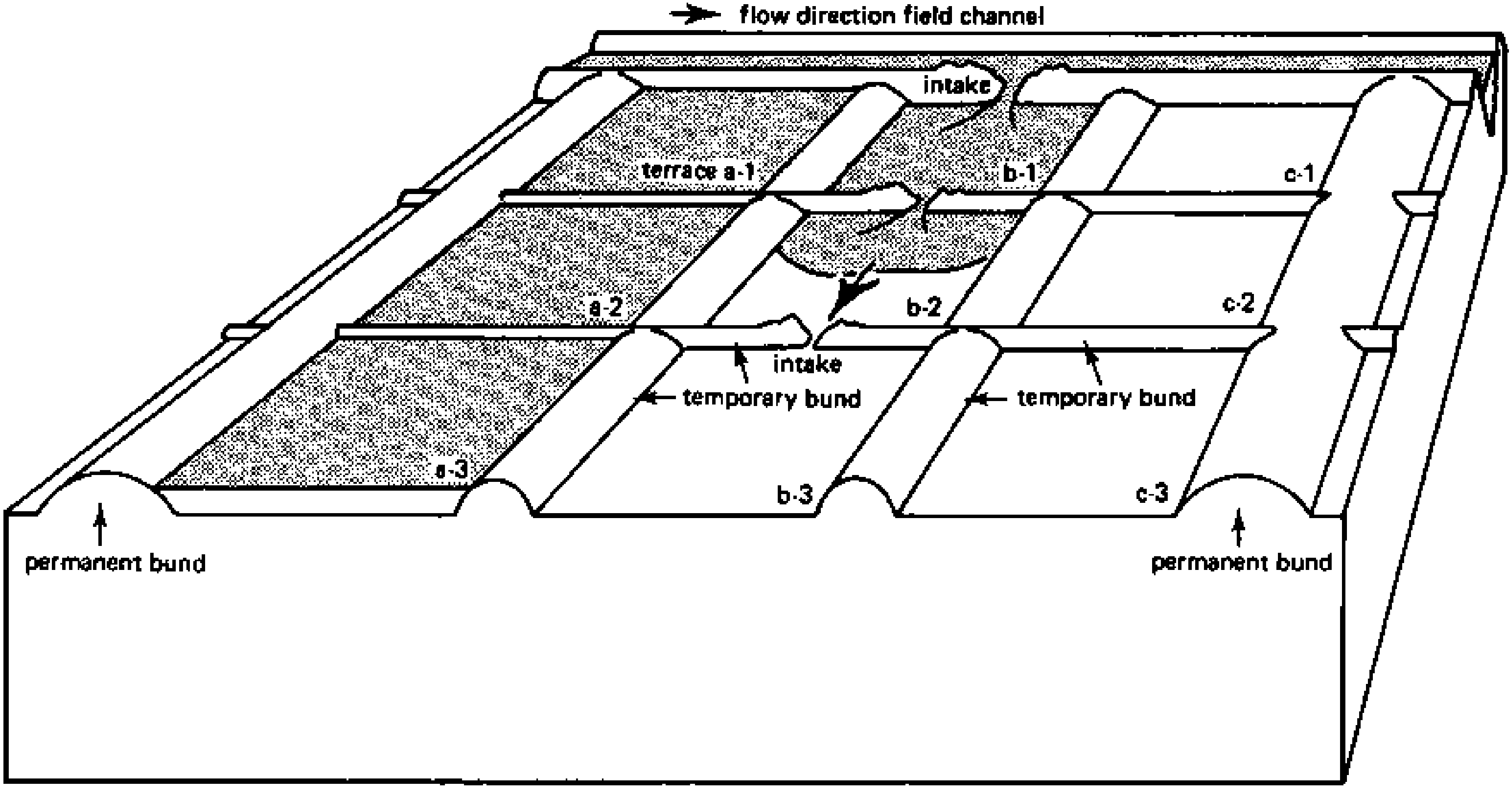


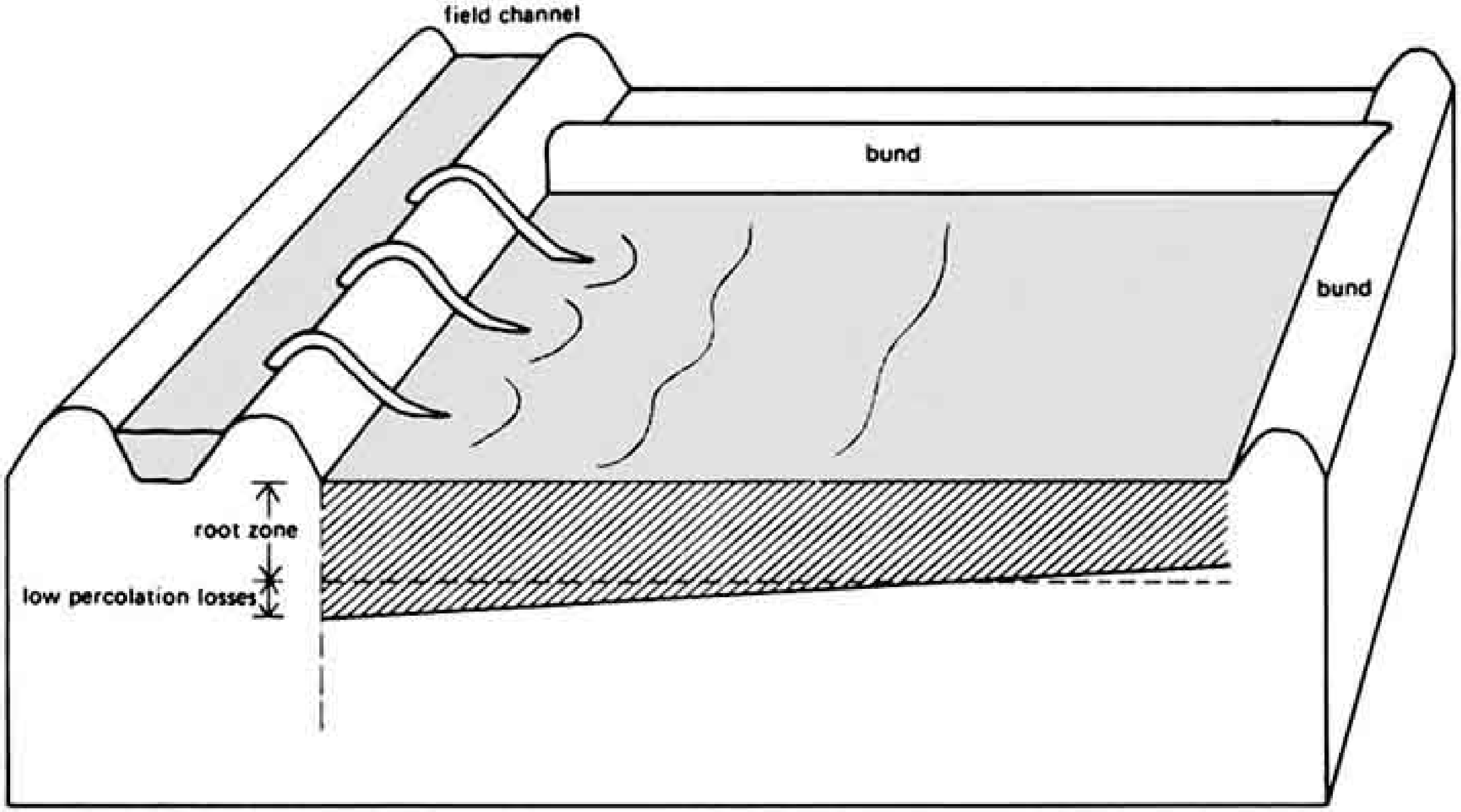

original ground level
borrow furrow

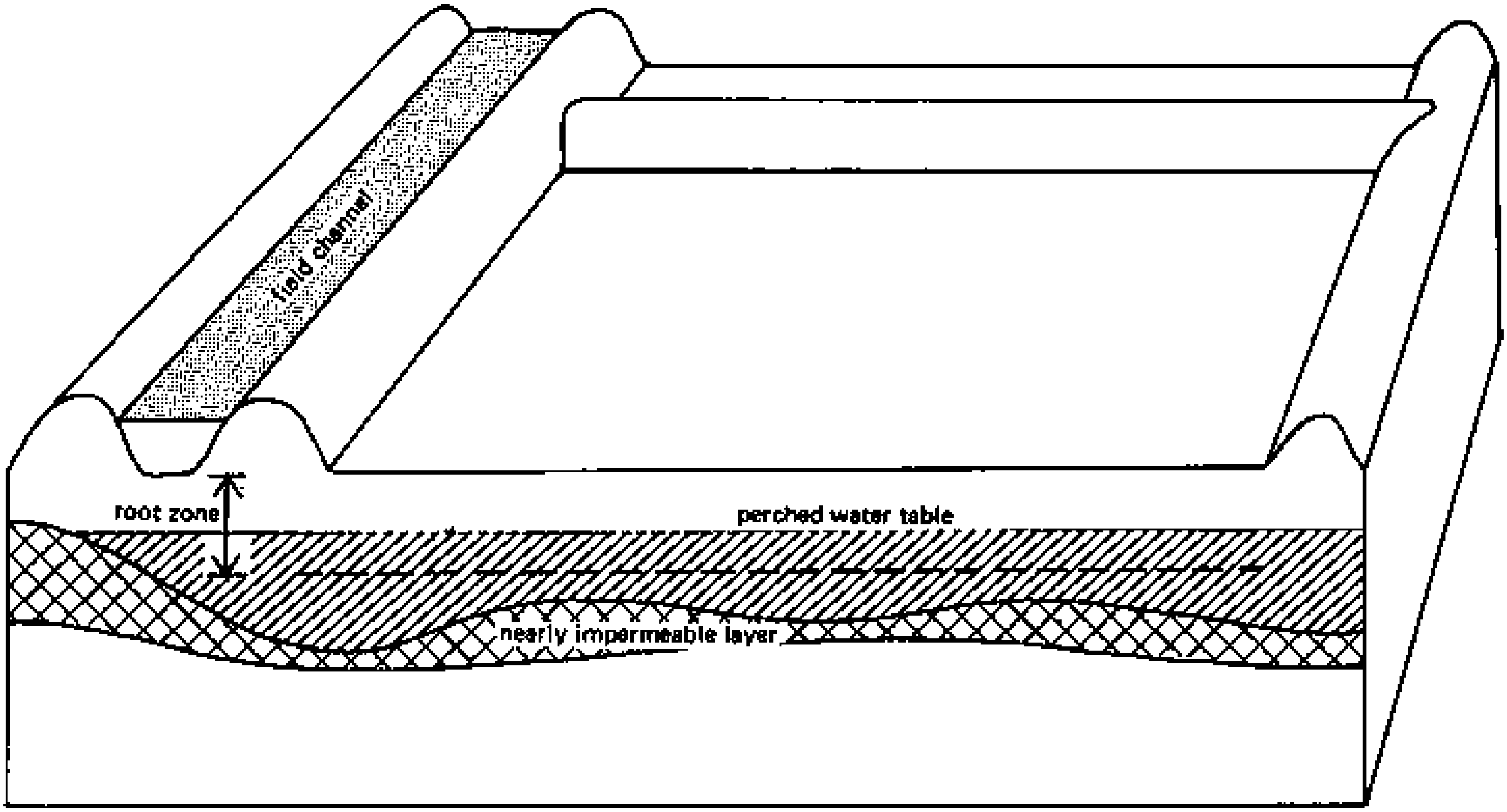

original ground level
required
bund height
required terrace width

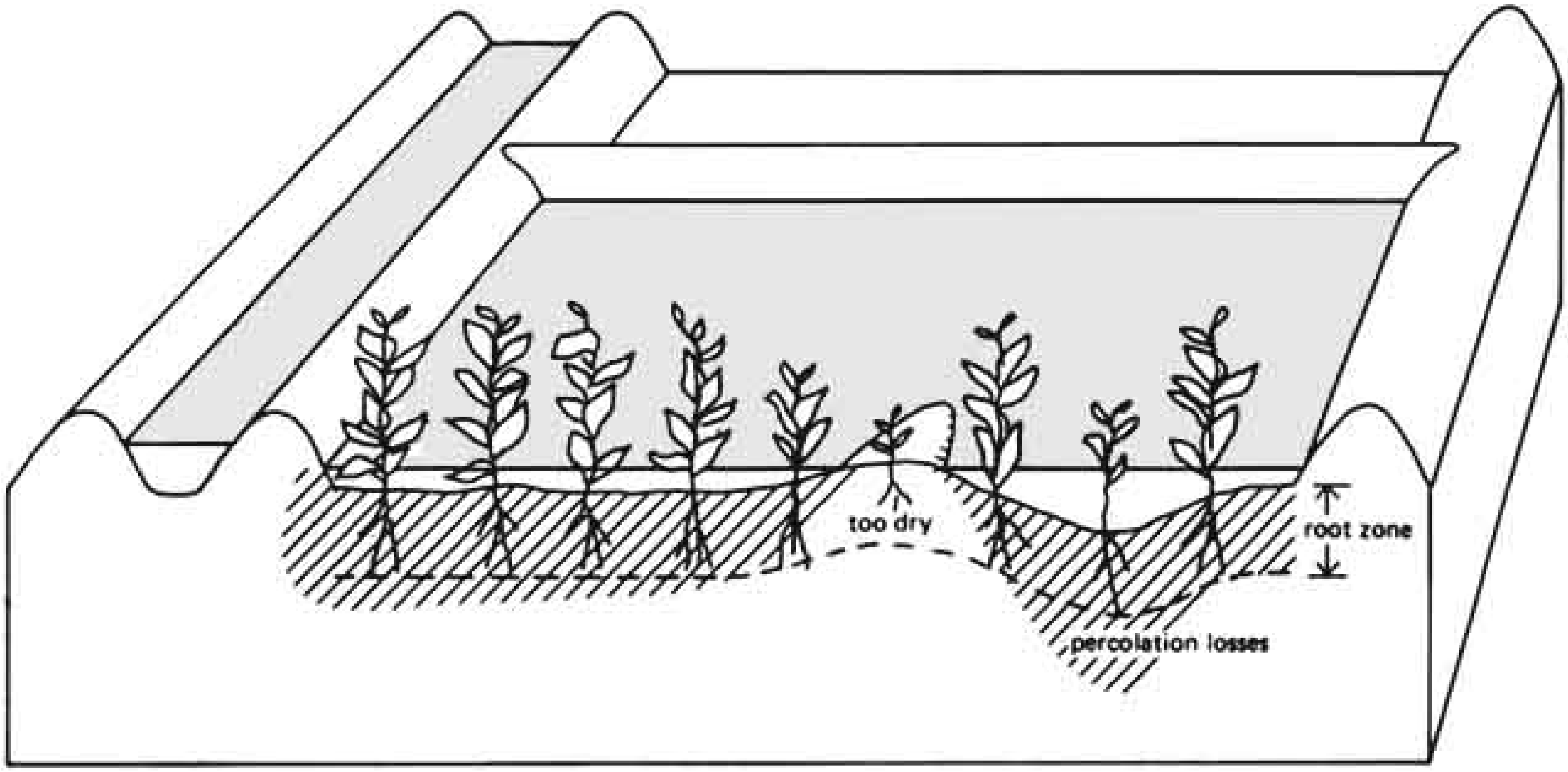

level 2nd terrace
original ground level
difference in level
between terraces

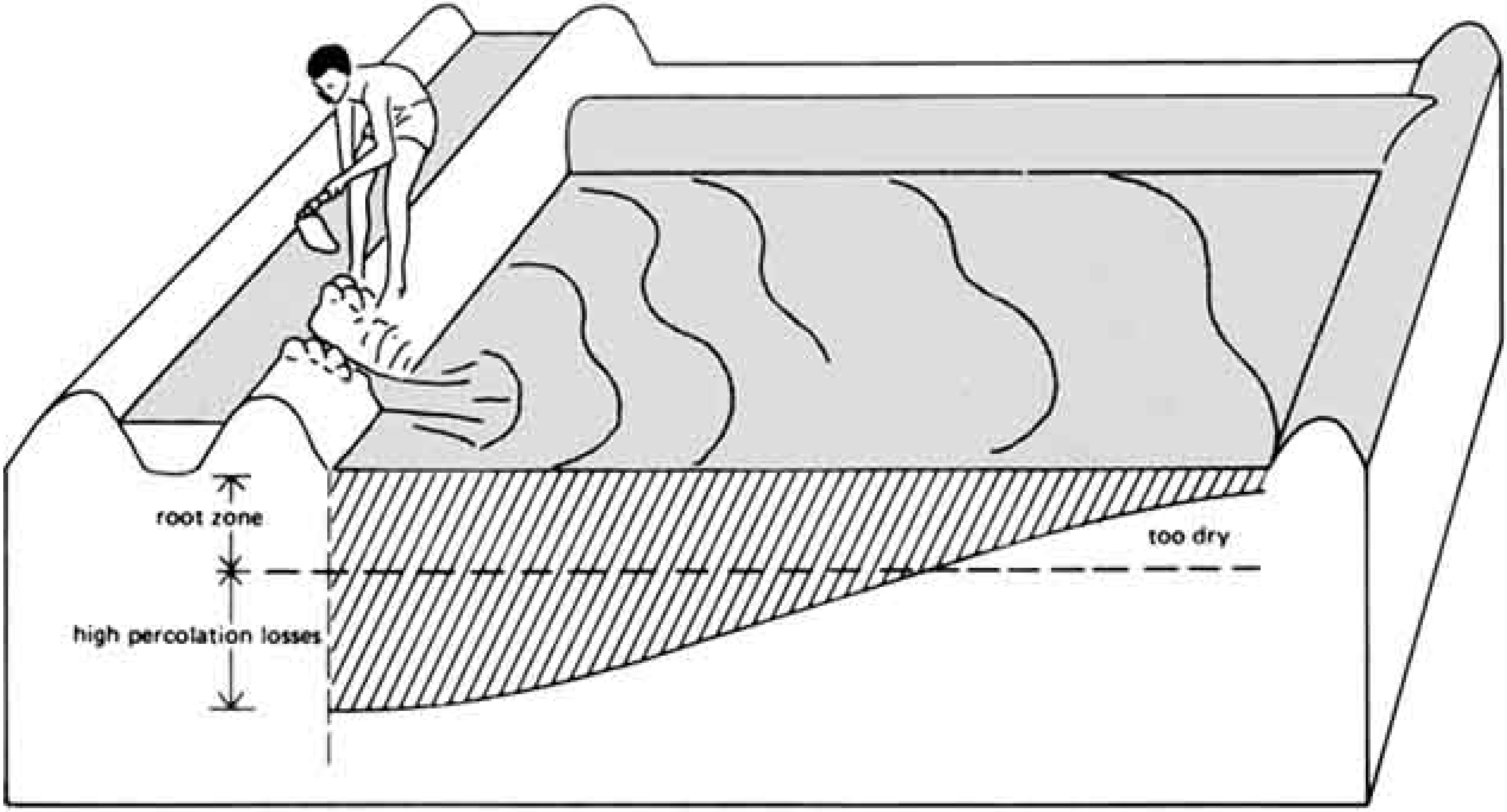

flow direction field channel
intake
permanent bund
temporary bund
temporary bund
permanent bund
basin a
basin b
basin c

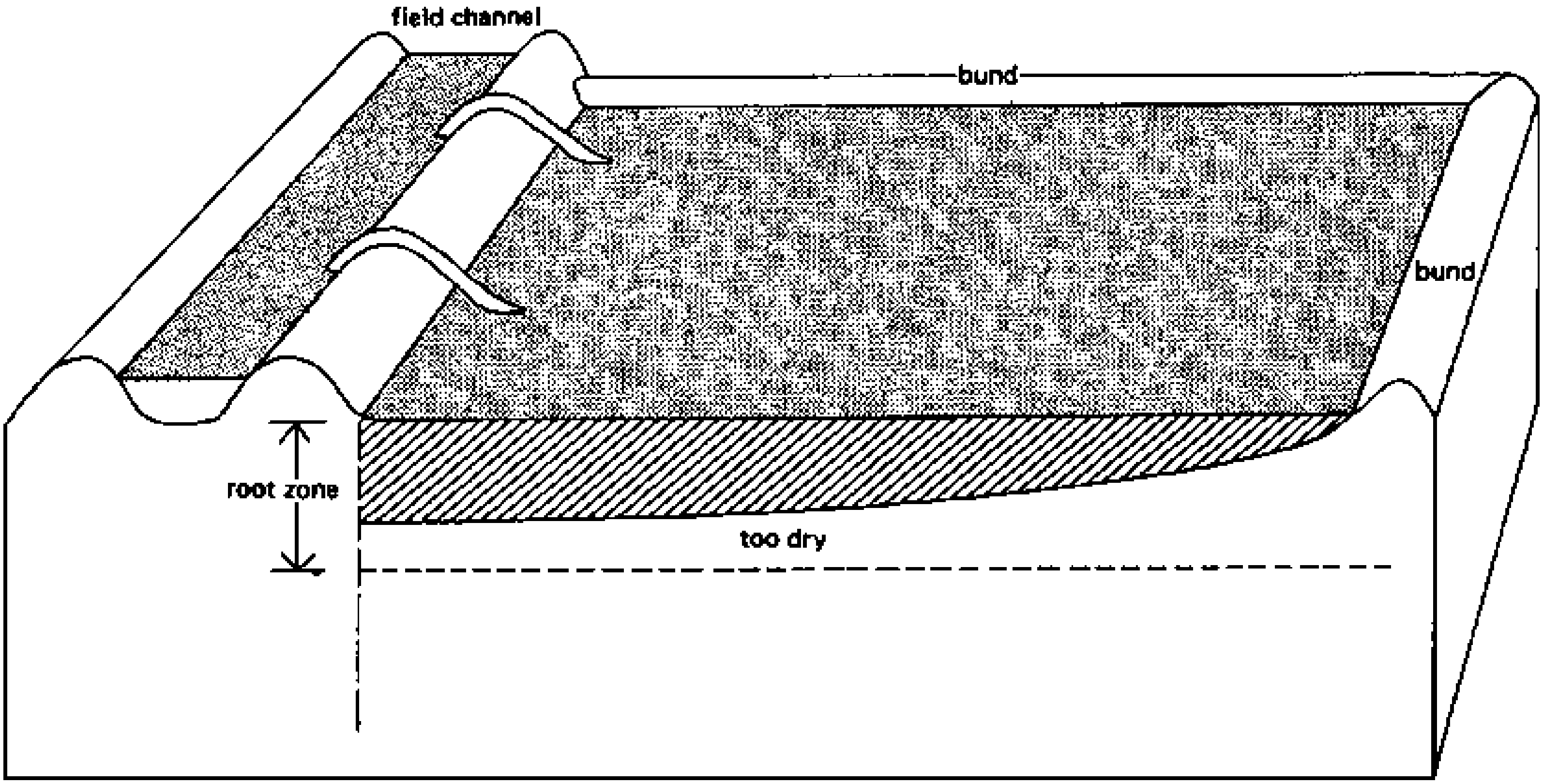

flow direction field channel
intake
terrace a-1
b-1
c-1
a-2
b-2
c-2
intake
temporary bund
temporary bund
a-3
b-3
c-3
permanent bund
permanent bund

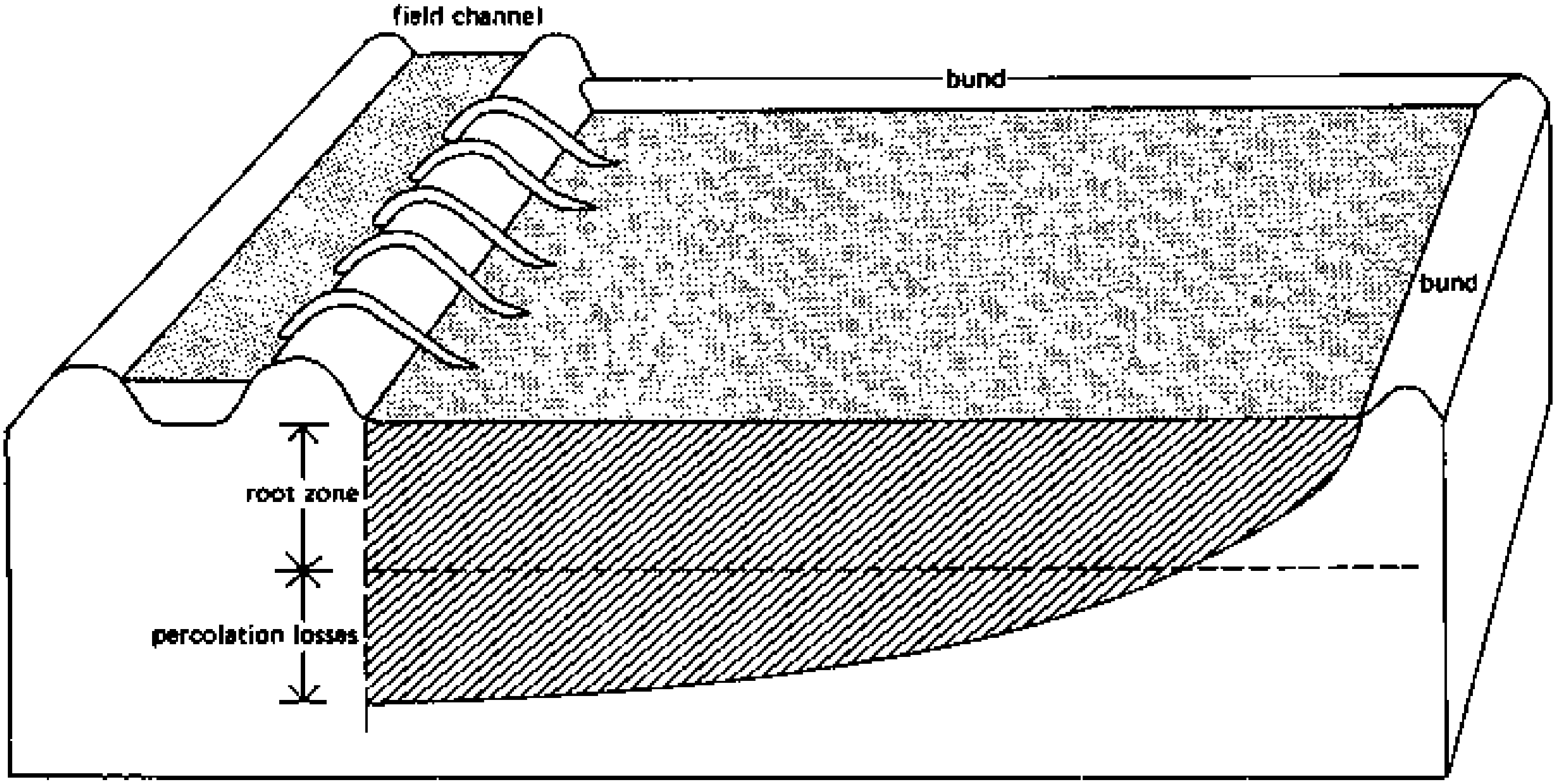

field channel
bund
bund
root zone
low percolation losses

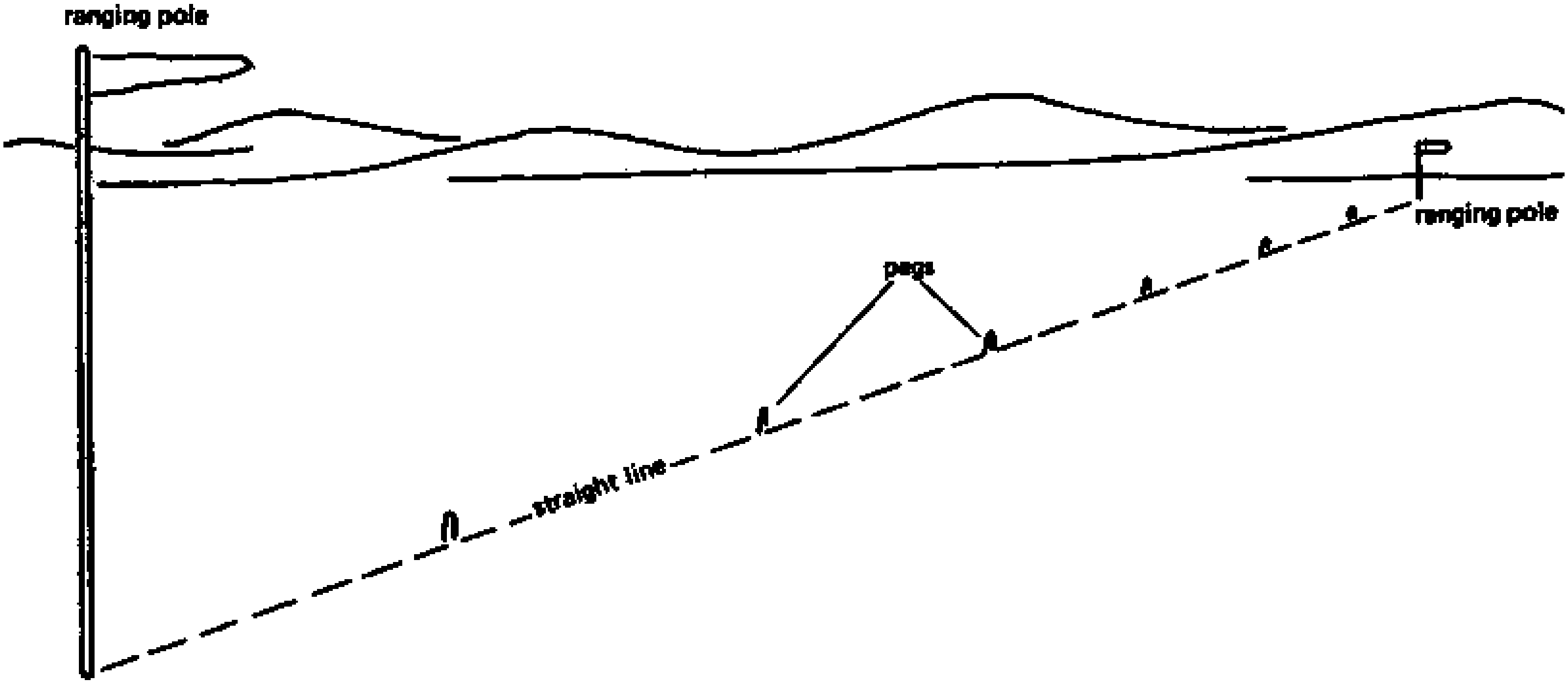

field channel
root zone
perched water table
nearly impermeable layer

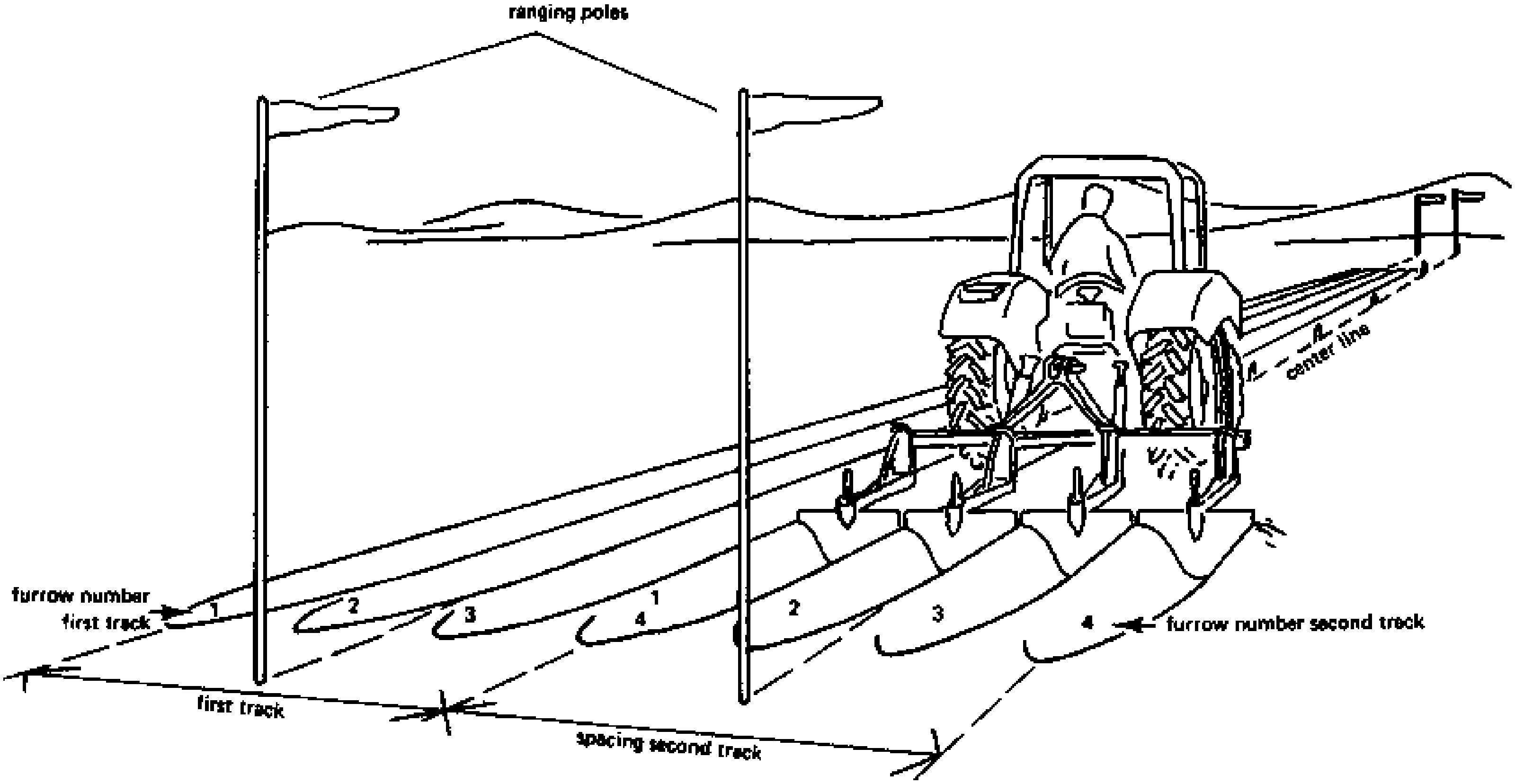

too dry
root zone
percolation losses

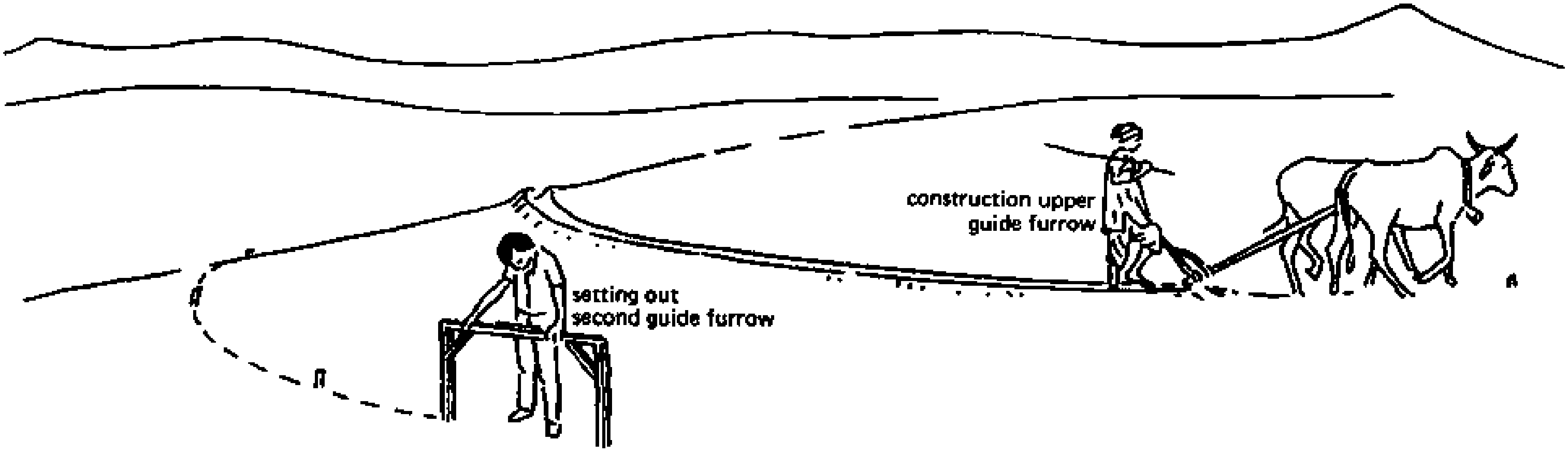

root zone
high percolation losses
too dry

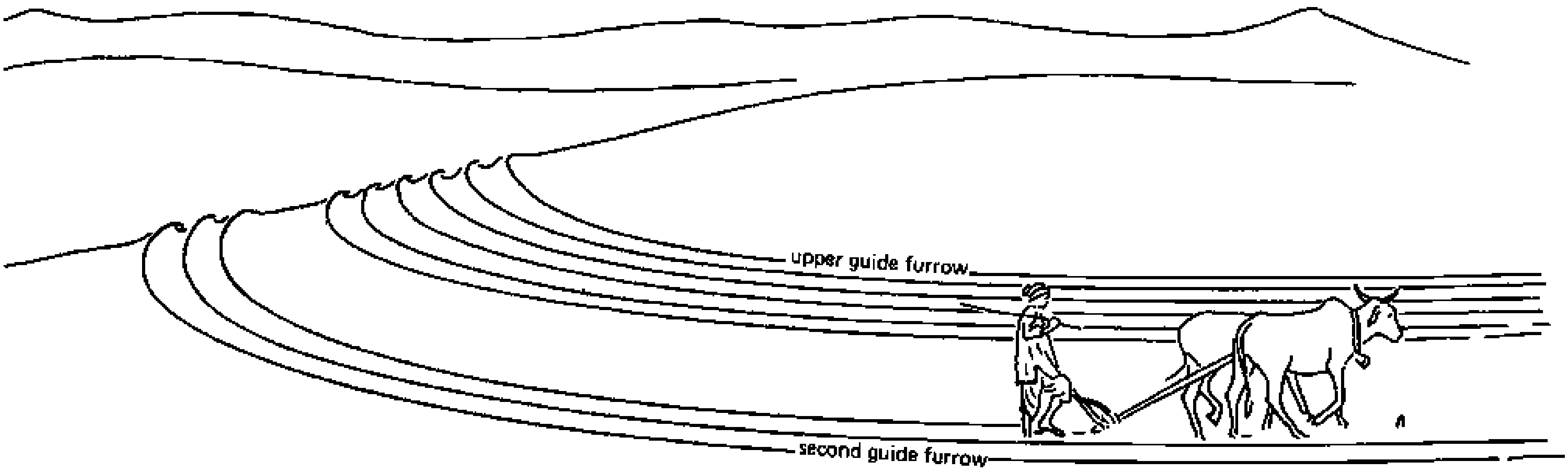

field channel
bund
bund
root zone
too dry

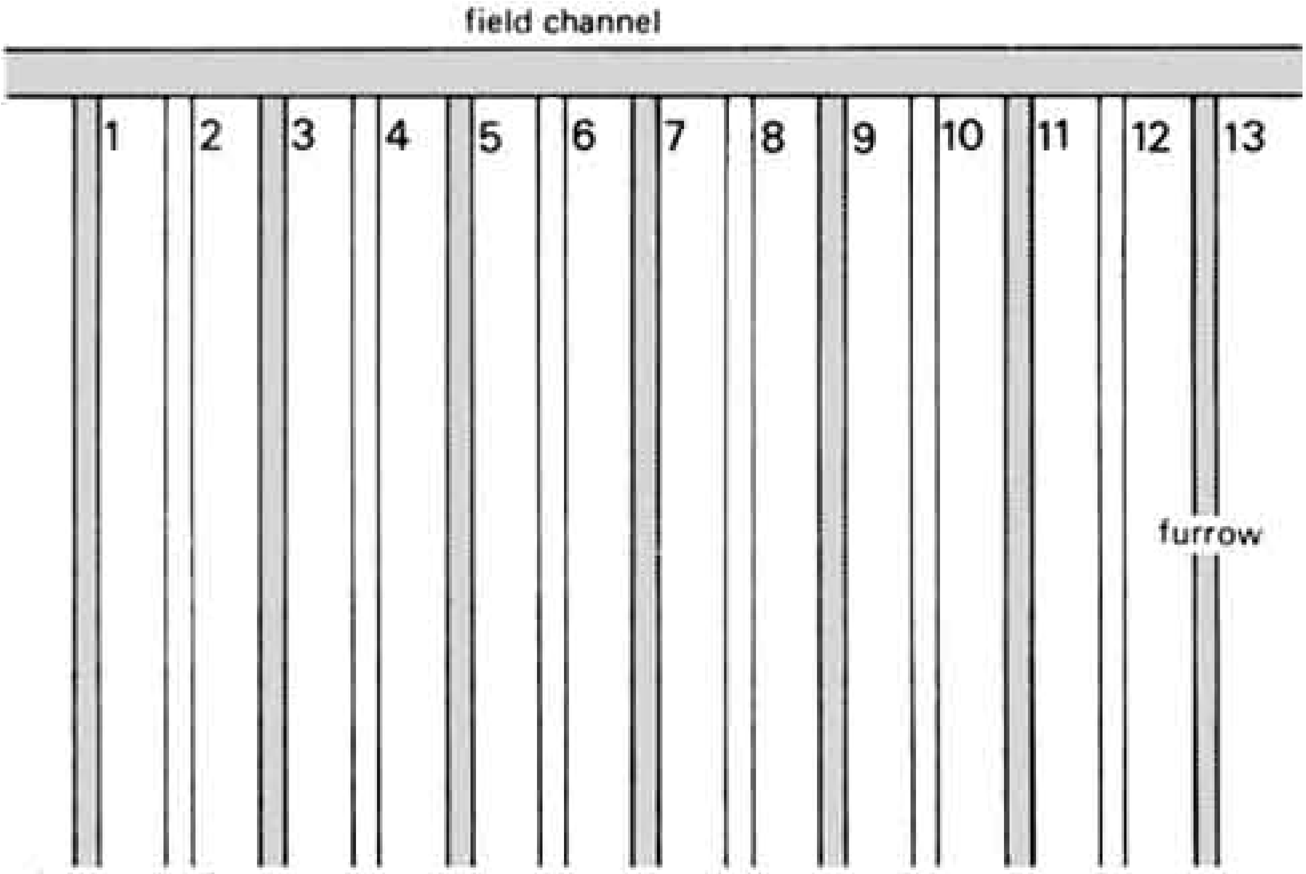

field channel
bund
bund
root zone
percolation losses


ranging pole
ranging pole
pegs
straight line

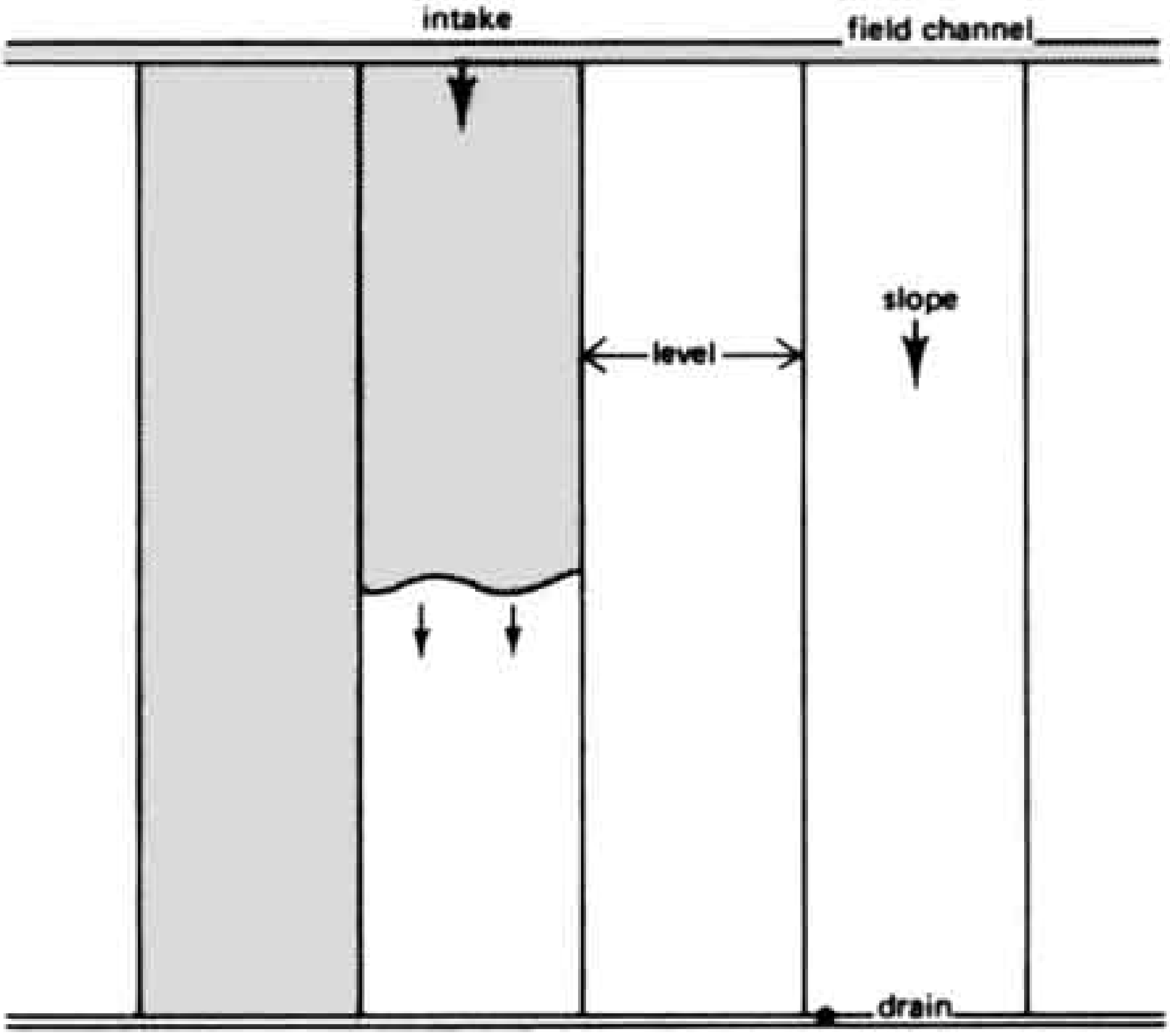

ranging poles
center line
furrow number
first track
1
2
3
4
1
2
3
4
furrow number second track
first track
spacing second track

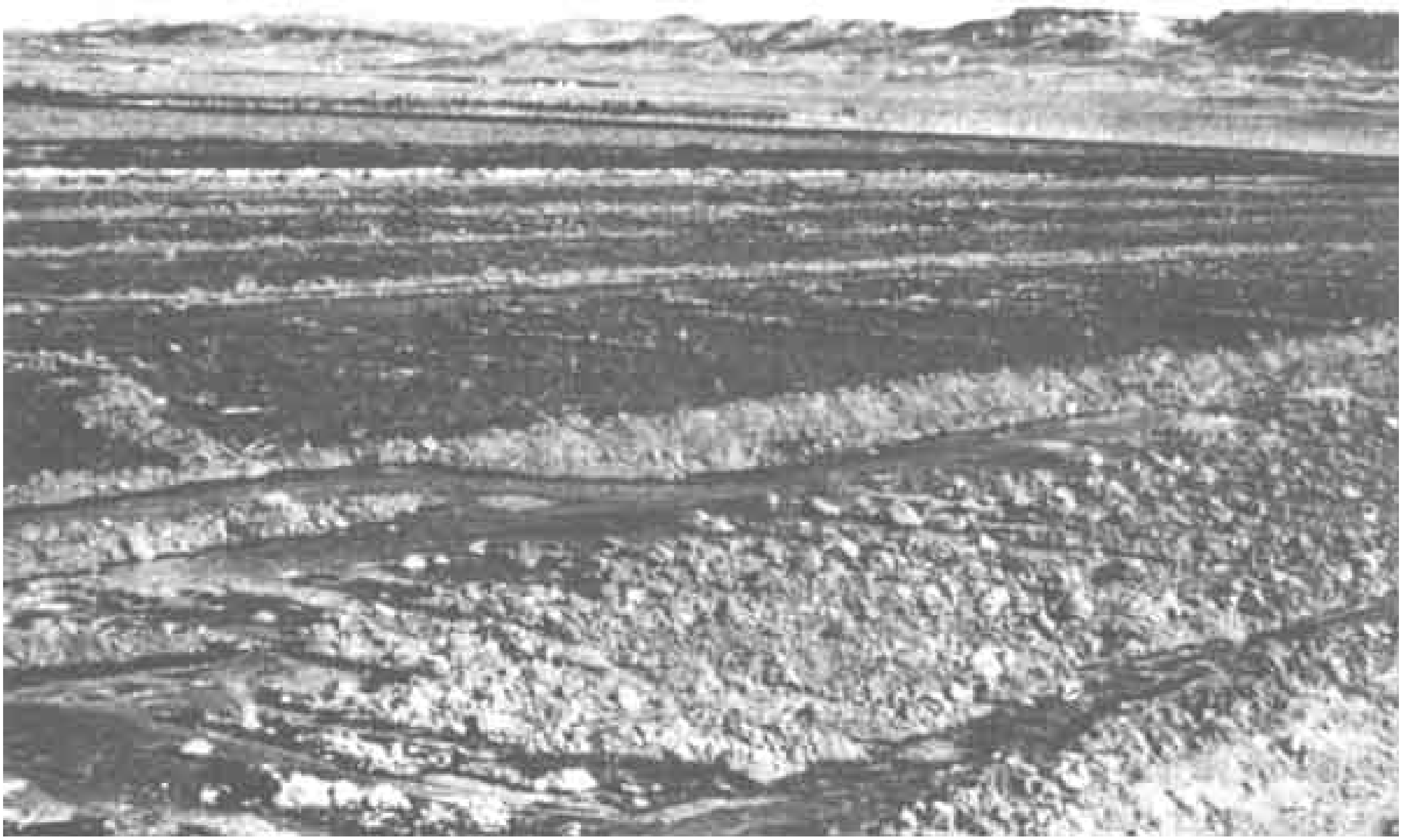

construction upper
guide furrow
setting out
second guide furrow

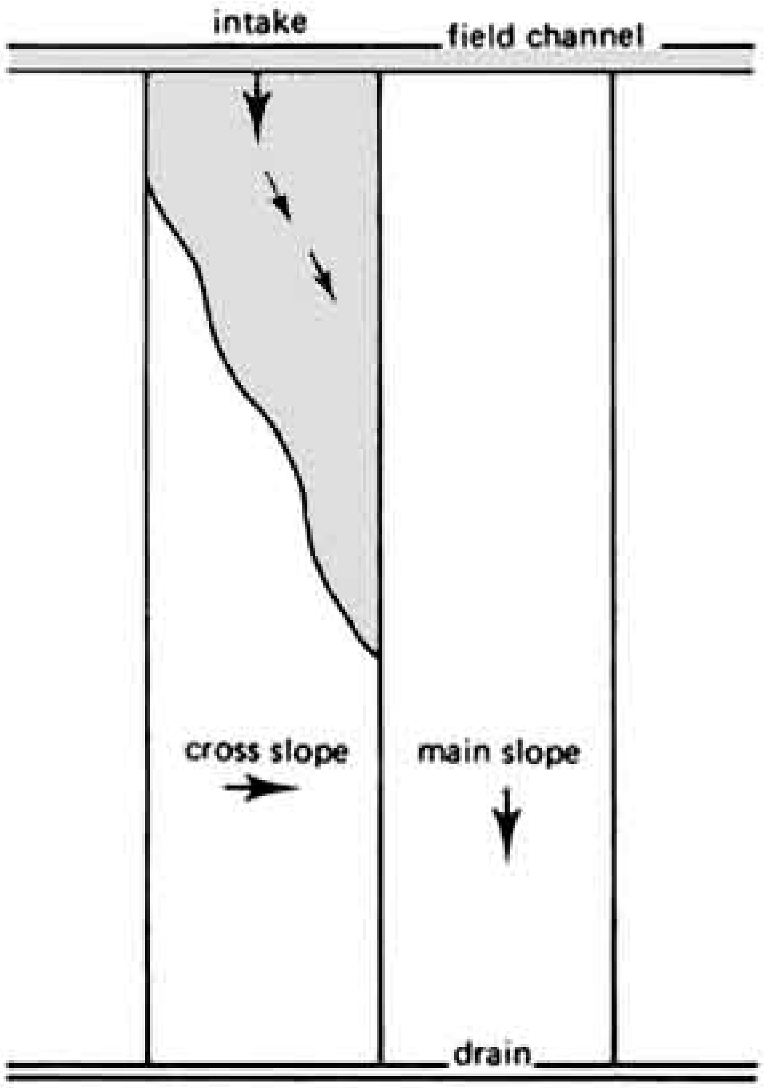

upper guide furrow
second guide furrow

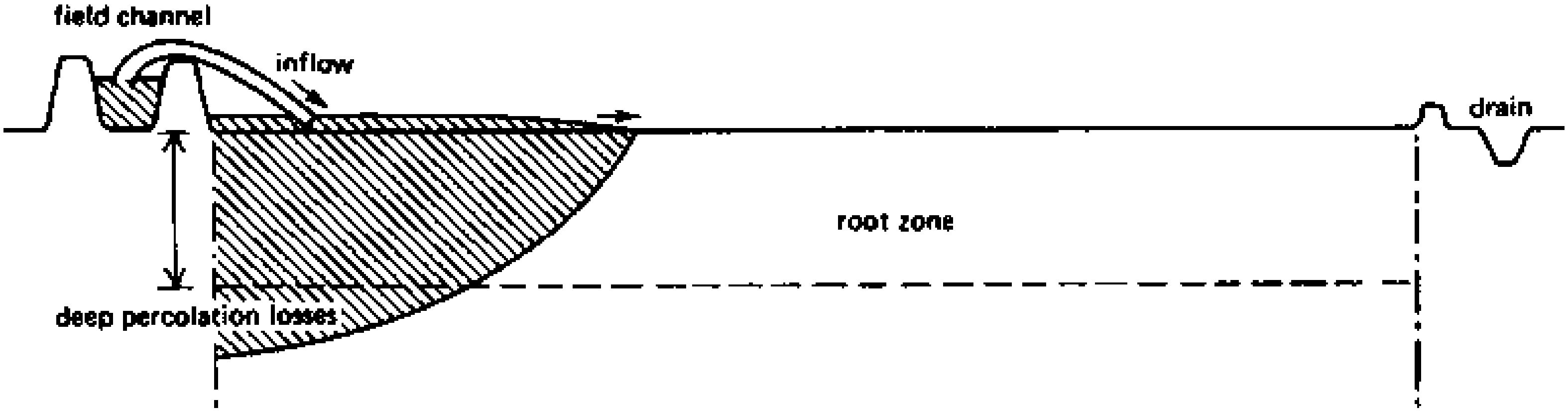


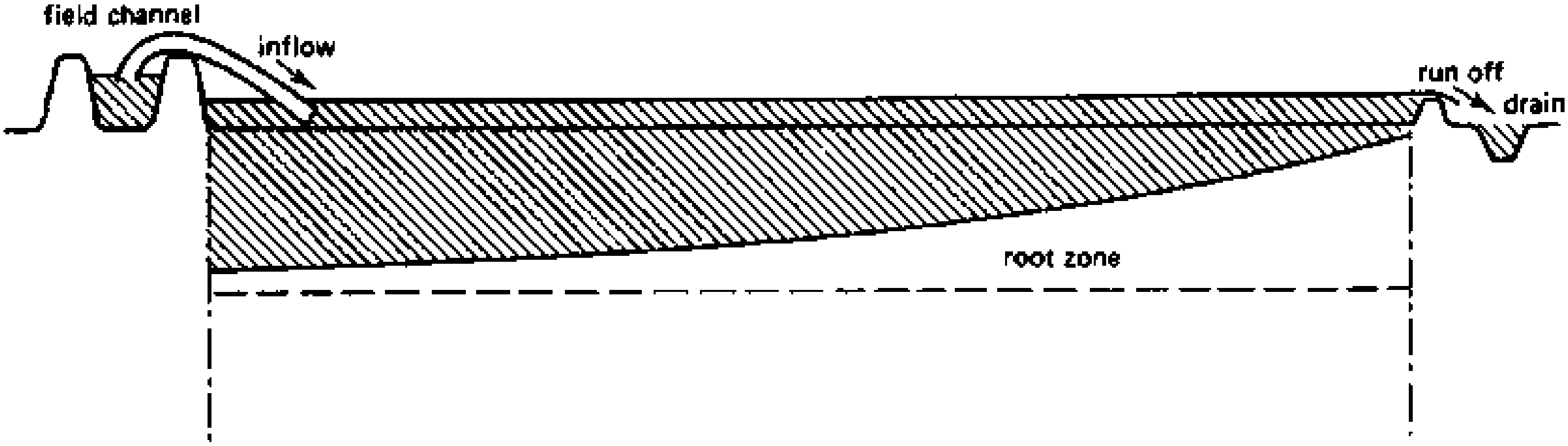
furrows 1, 3, 5 etc. are irrigated on day 5
furrows 2, 4, 6 etc. are irrigated on day 10

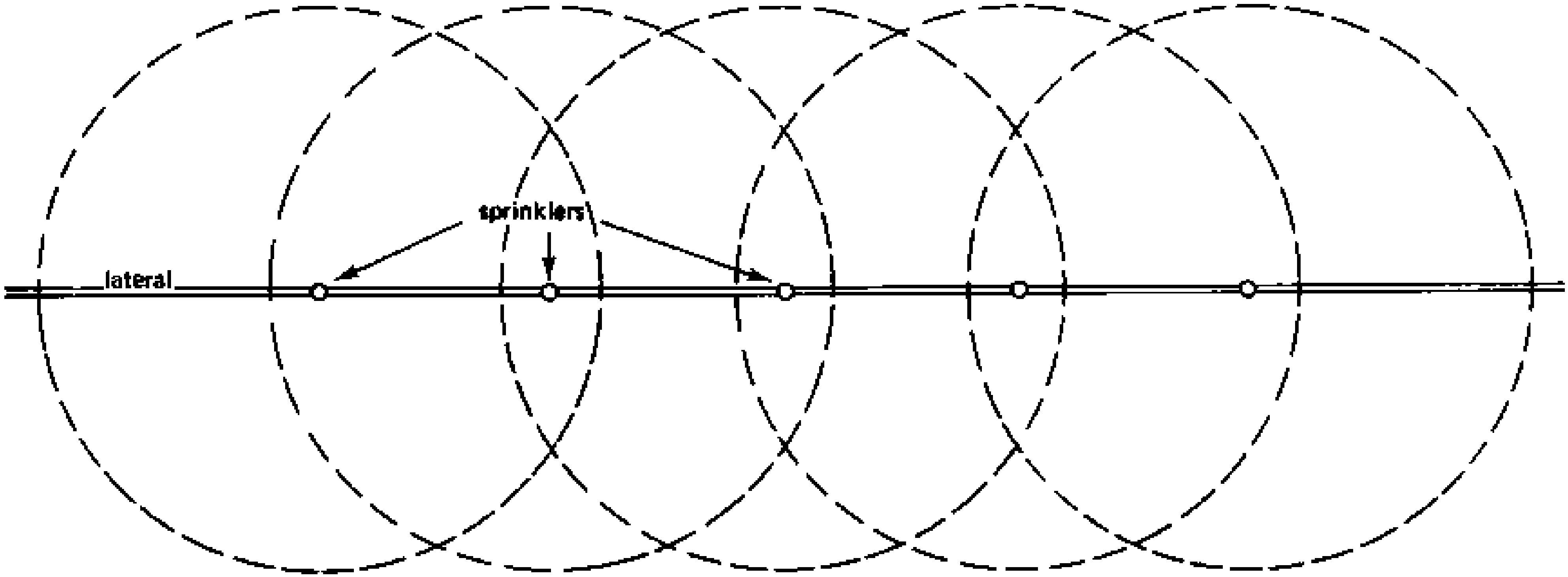

intake
field channel
slope
level
drain

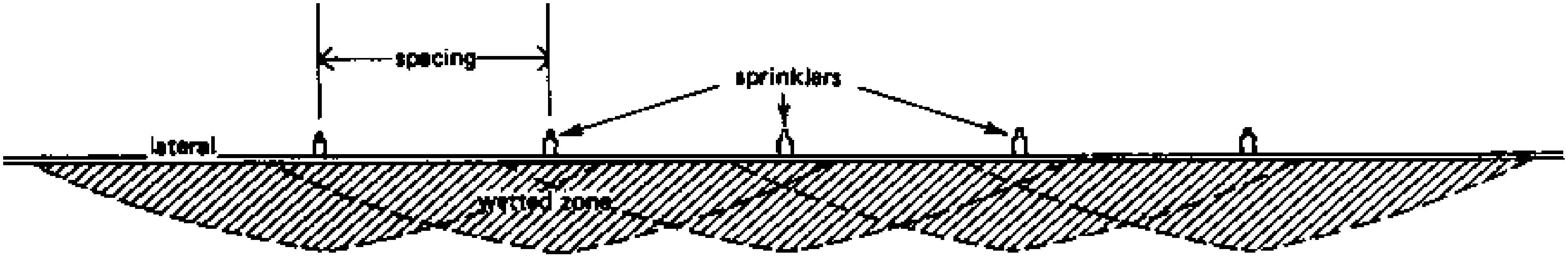


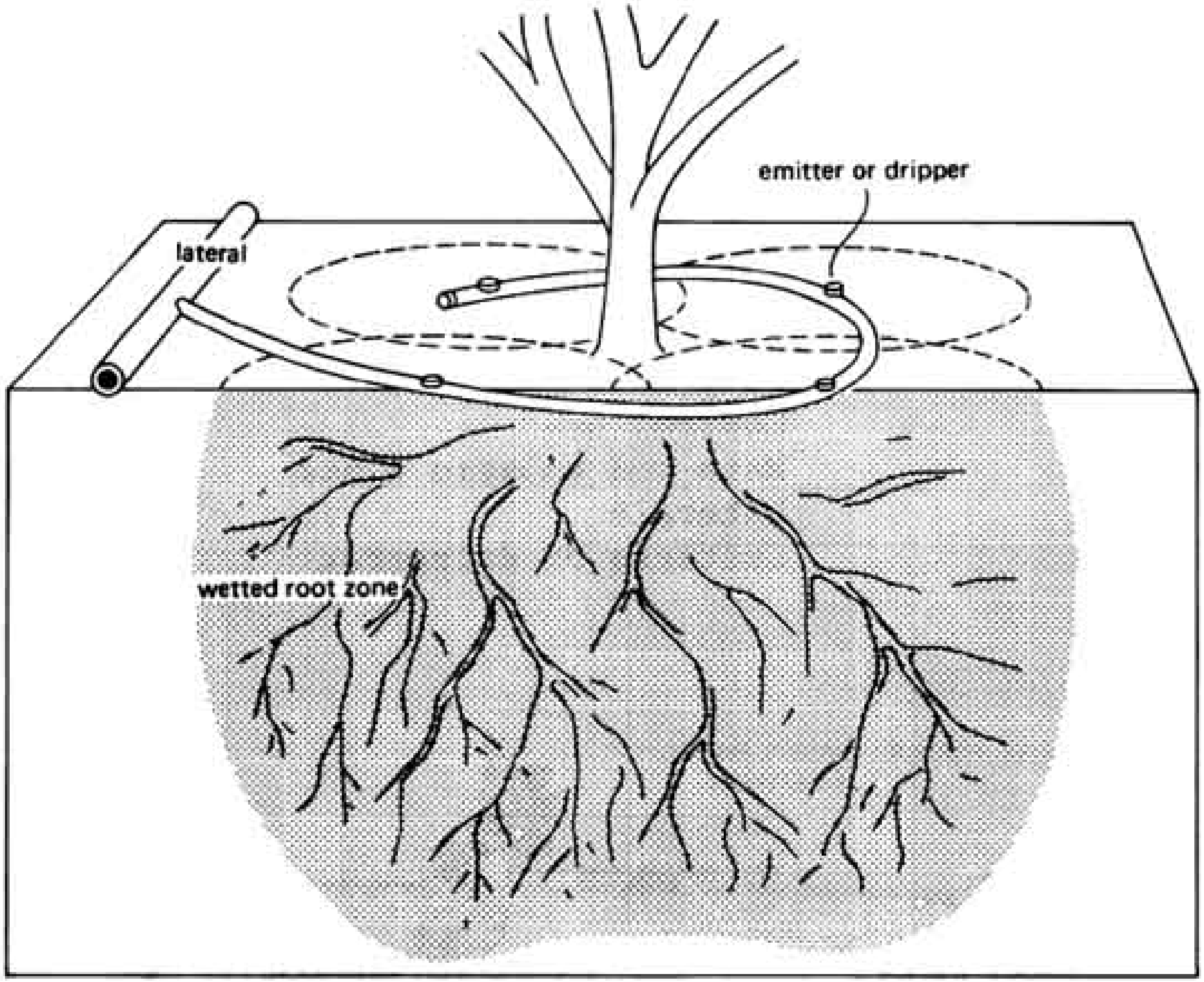

intake
field channel
cross slope
main slope
drain

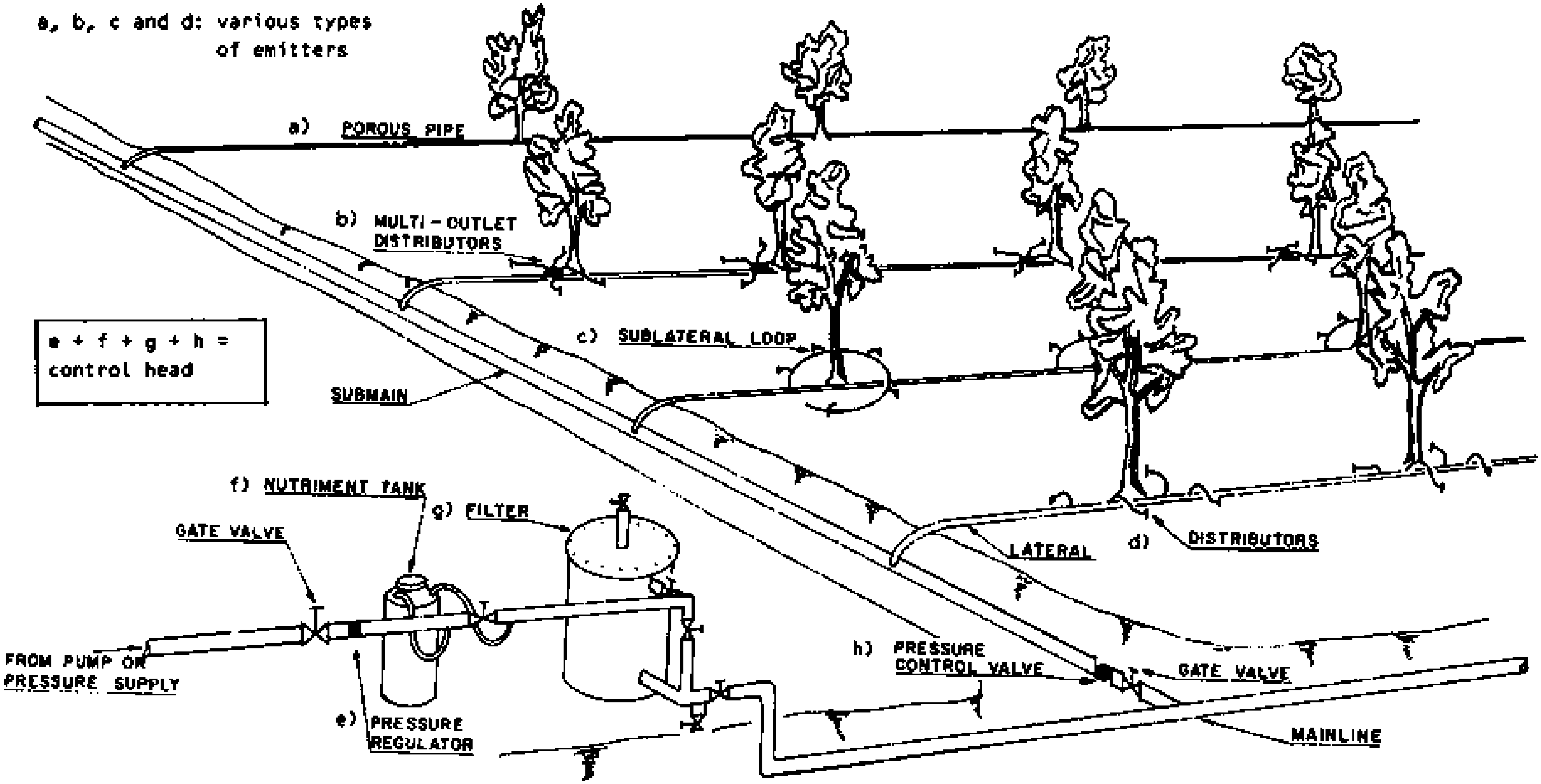

field channel
inflow
drain
root zone
deep percolation losses

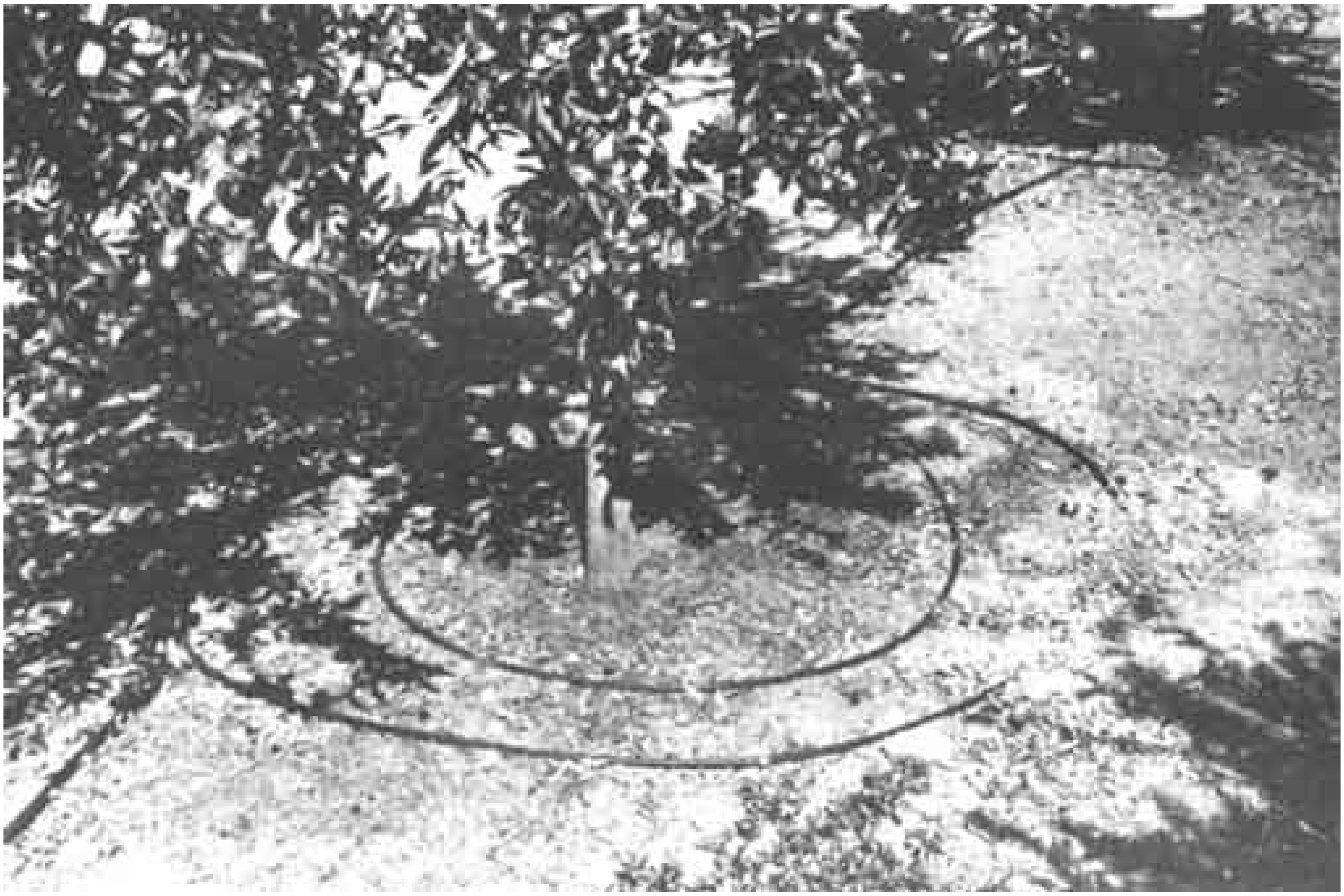

field channel
inflow
run off
drain
root zone

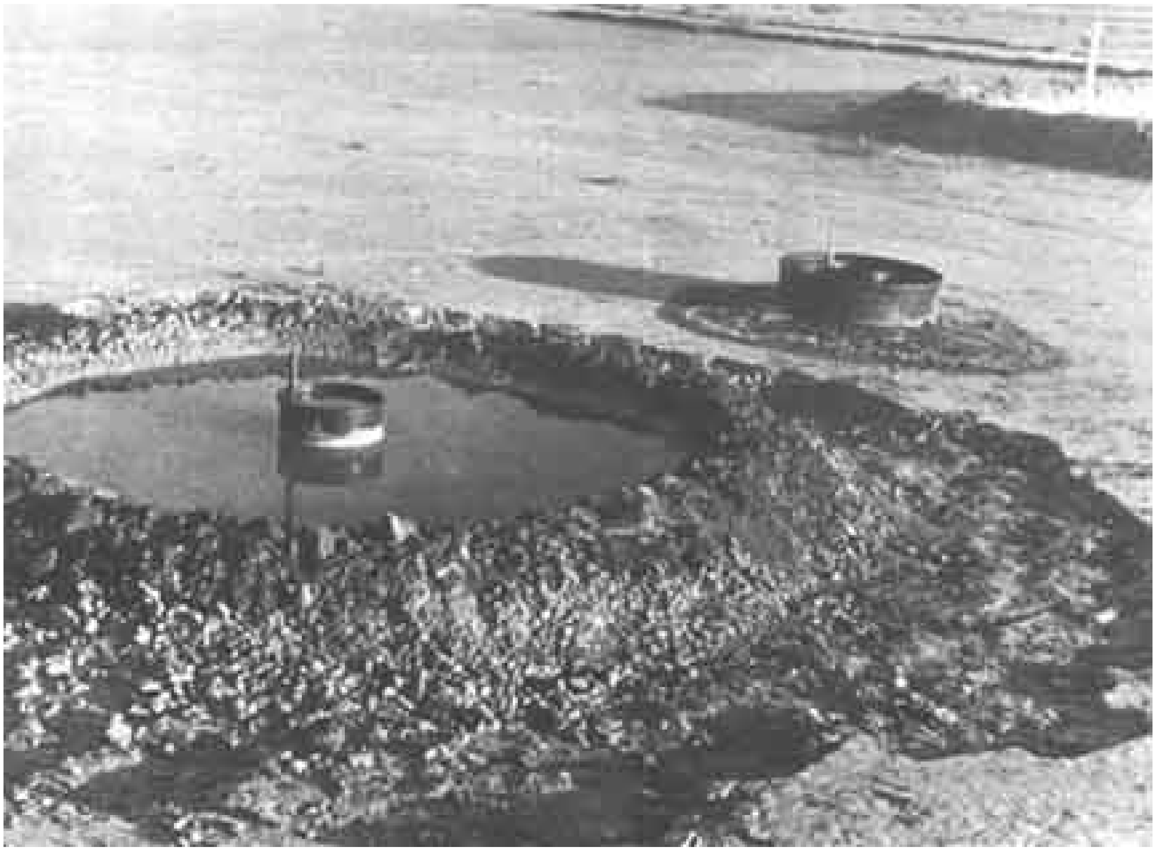

sprinklers
lateral


spacing
sprinklers
lateral
wetted zone


emitter or dripper
lateral
wetted root zone


a, b, c and d: various types of emitters
a) POROUS PIPE
b) MULTI - OUTLET DISTRIBUTORS
e + f + g + h = control head
c) SUBLATERAL LOOP
SUBMAIN
f) NUTRIMENT TANK
g) FILTER
GATE VALVE
LATERAL
d) DISTRIBUTORS
FROM PUMP OR PRESSURE SUPPLY
h) PRESSURE CONTROL VALVE
GATE VALVE
e) PRESSURE REGULATOR
MAINLINE

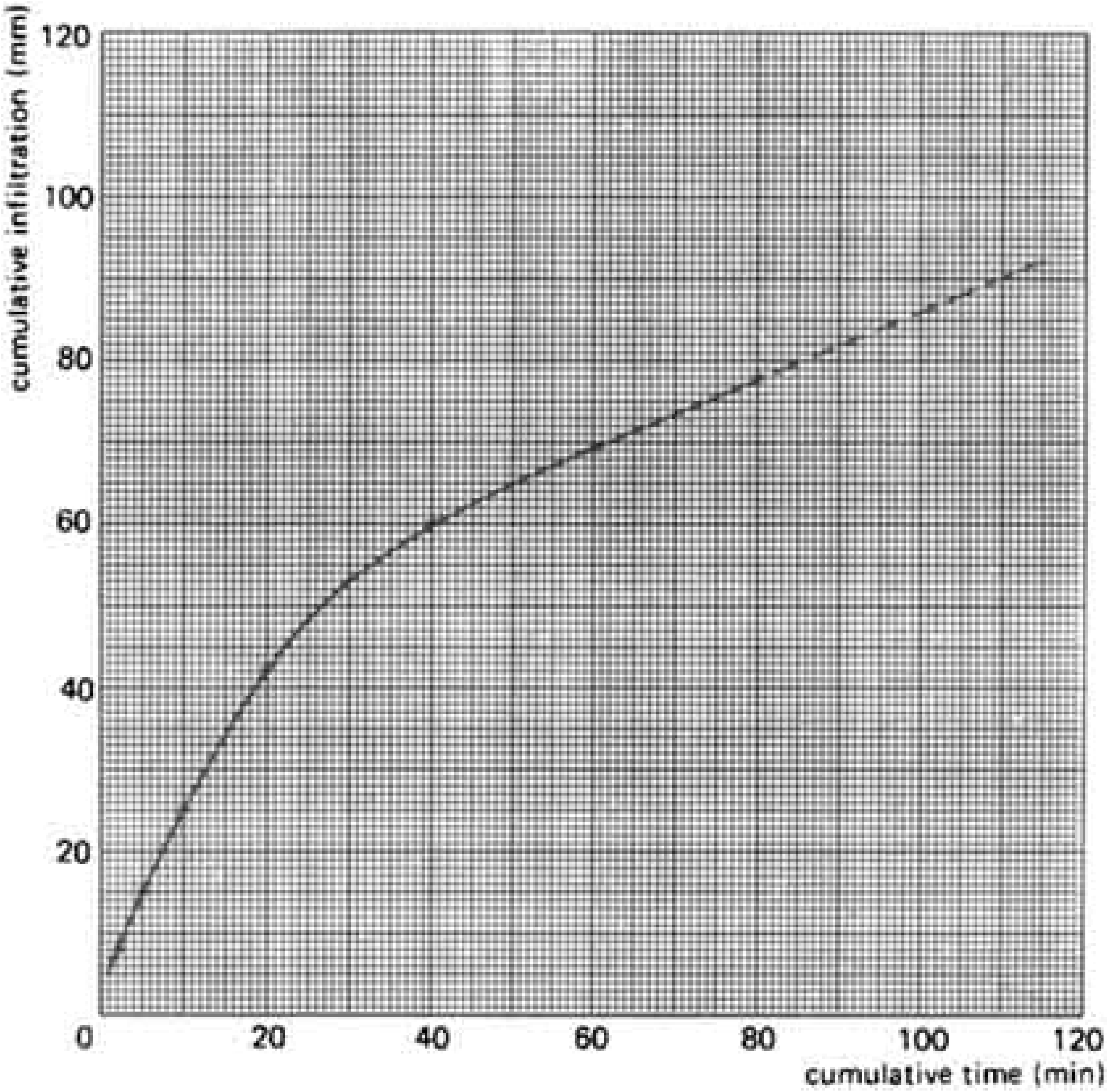




Site location: EXAMPLE Soil type: Loam Test date: 5 DEC 1987

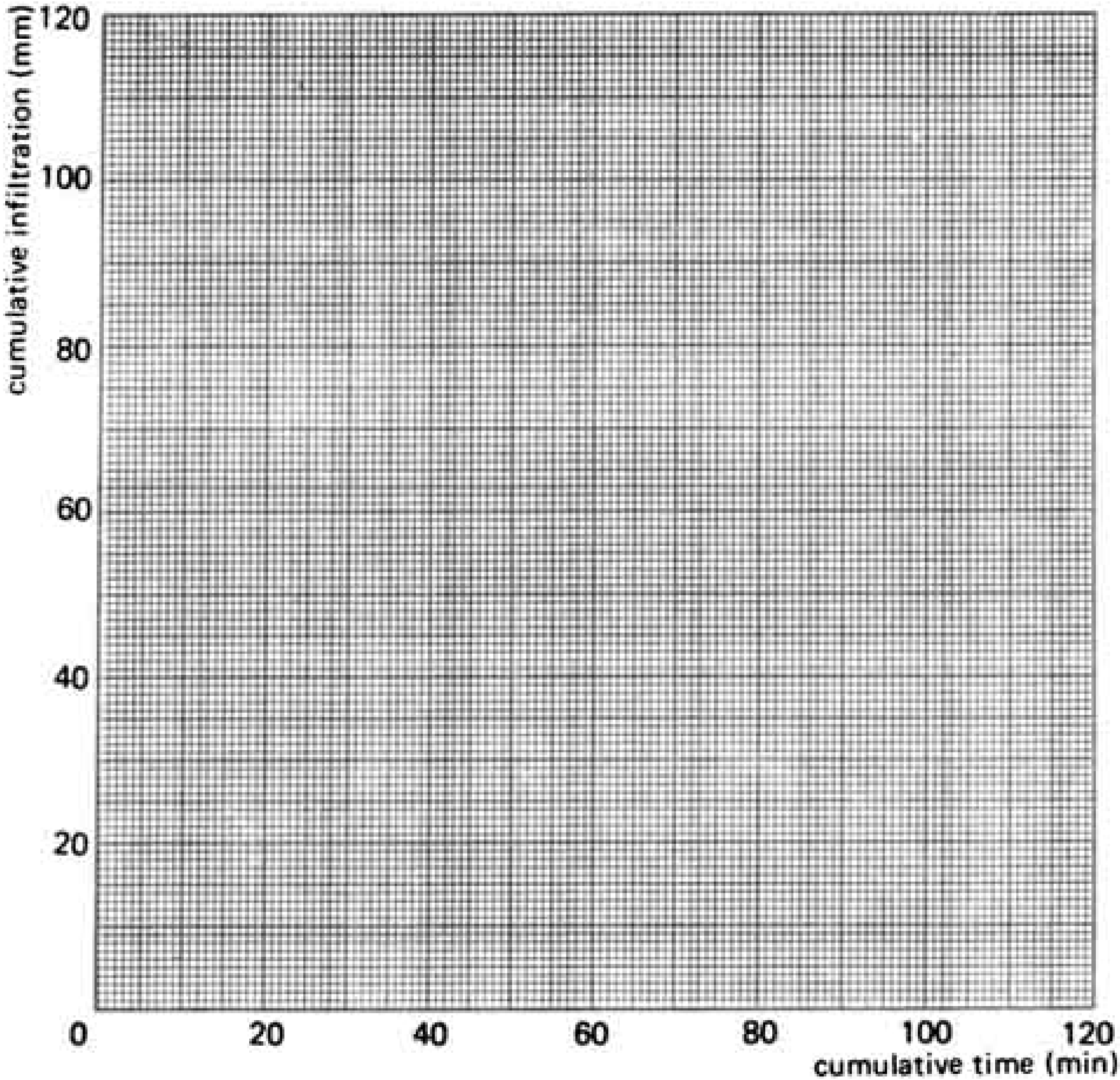
1 Reading on the clock hr min sec	2 Time difference min	3 Cumulative time min	4 Water level readings before filling mm	after filling mm	5 Infiltration mm	6 Infiltration rate mm/min	7 Infiltration rate mm/hour	8 Cumulative infiltration mm
14 05 0	start = 0	start = 0		100				start = 0
14 07 0	2	(0+2) 2	92	100	(100-92) 8	(8/2) 4.00	240	(0+8) 8
14 10 0	3	(2+3) 5	93	99	(100-93) 7	(7/3) 2.33	140	(8+7) 15
14 15 0	5	(5+5) 10	89	101	(99-89) 10	(10/5) 2.00	120	(15+10) 25
14 25 0	10	(10+10) 20	84	100	(101-84) 17	(17/10) 1.70	102	(25+17) 42
14 35 0	10	(20+10) 30	89	102	(100-89) 11	(11/10) 1.10	66	(42+11) 53
14 45 0	10	(30+10) 40	95	101	(102-95) 7	(7/10) 0.70	42	(53+7) 60
15 05 0	20	(40+20) 60	92	100	(101-92) 9	(9/20) 0.45	27 *	(60+9) 69
15 25 0	20	(60+20) 80	91		(100-91) 9	(9/20) 0.45	27 *	(69+9) 78

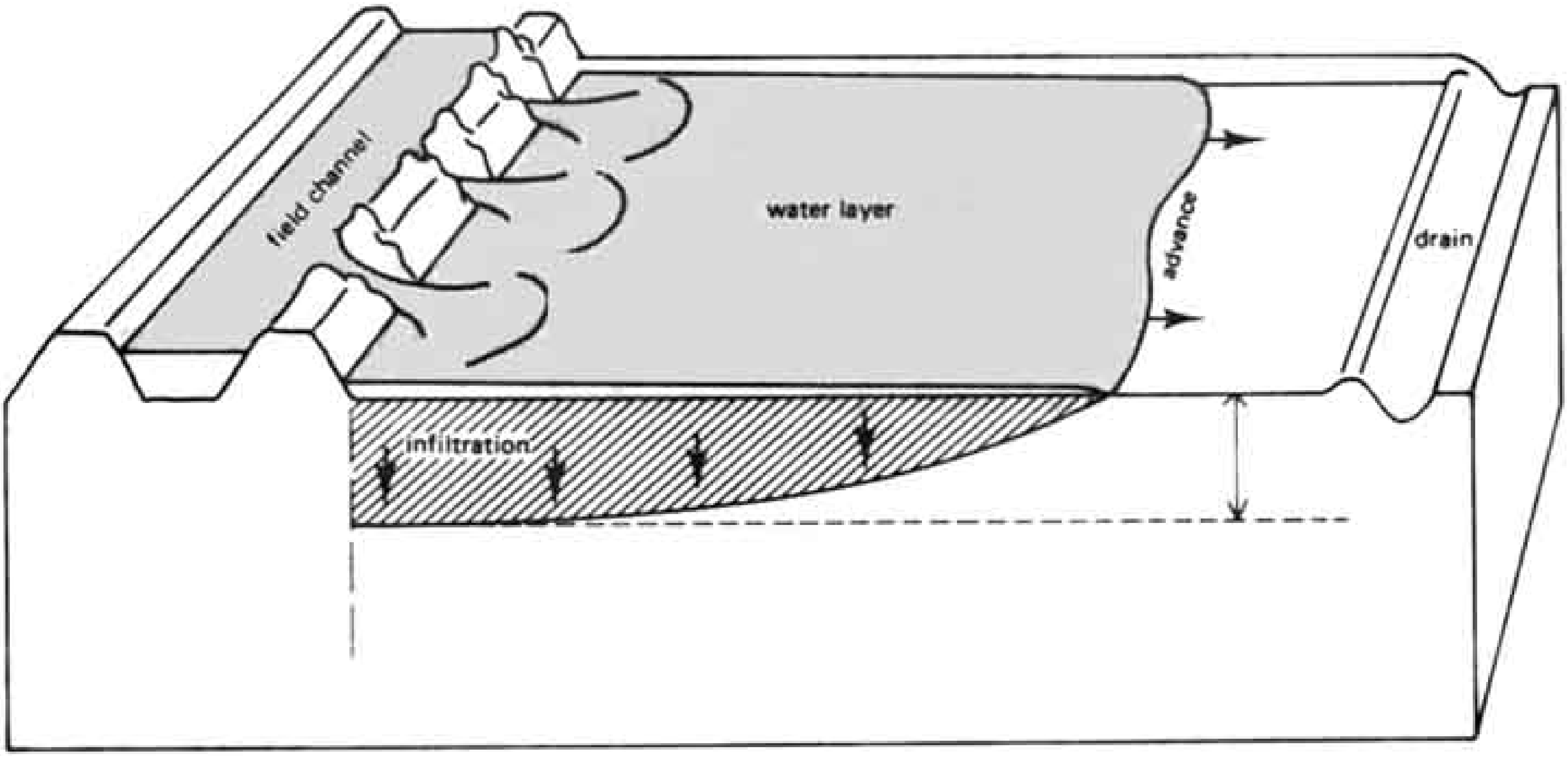
* basic infiltration rate

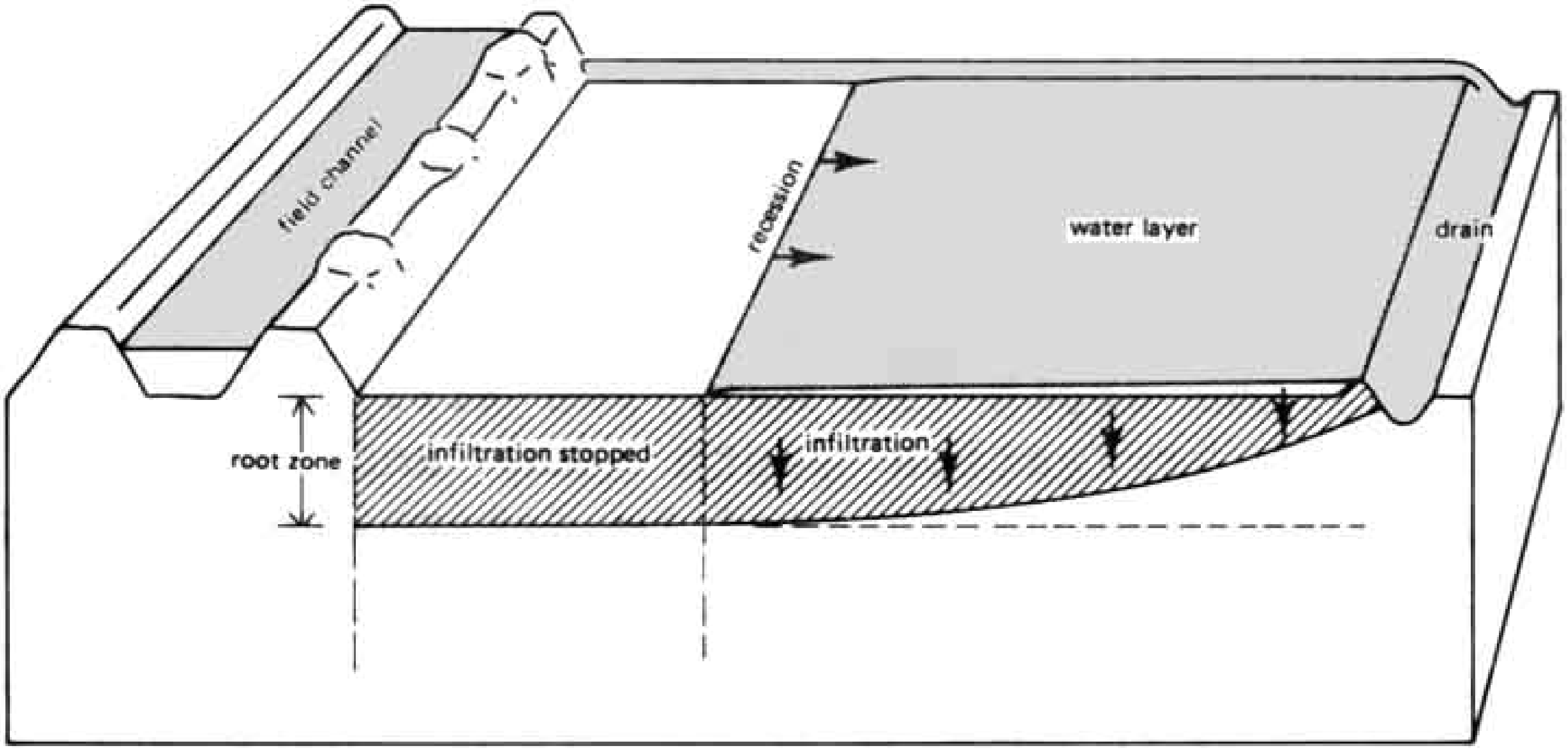

cumulative infiltration (mm)
120
100
80
60
40
20
0
20
40
60
80
100
120
cumulative time (min)

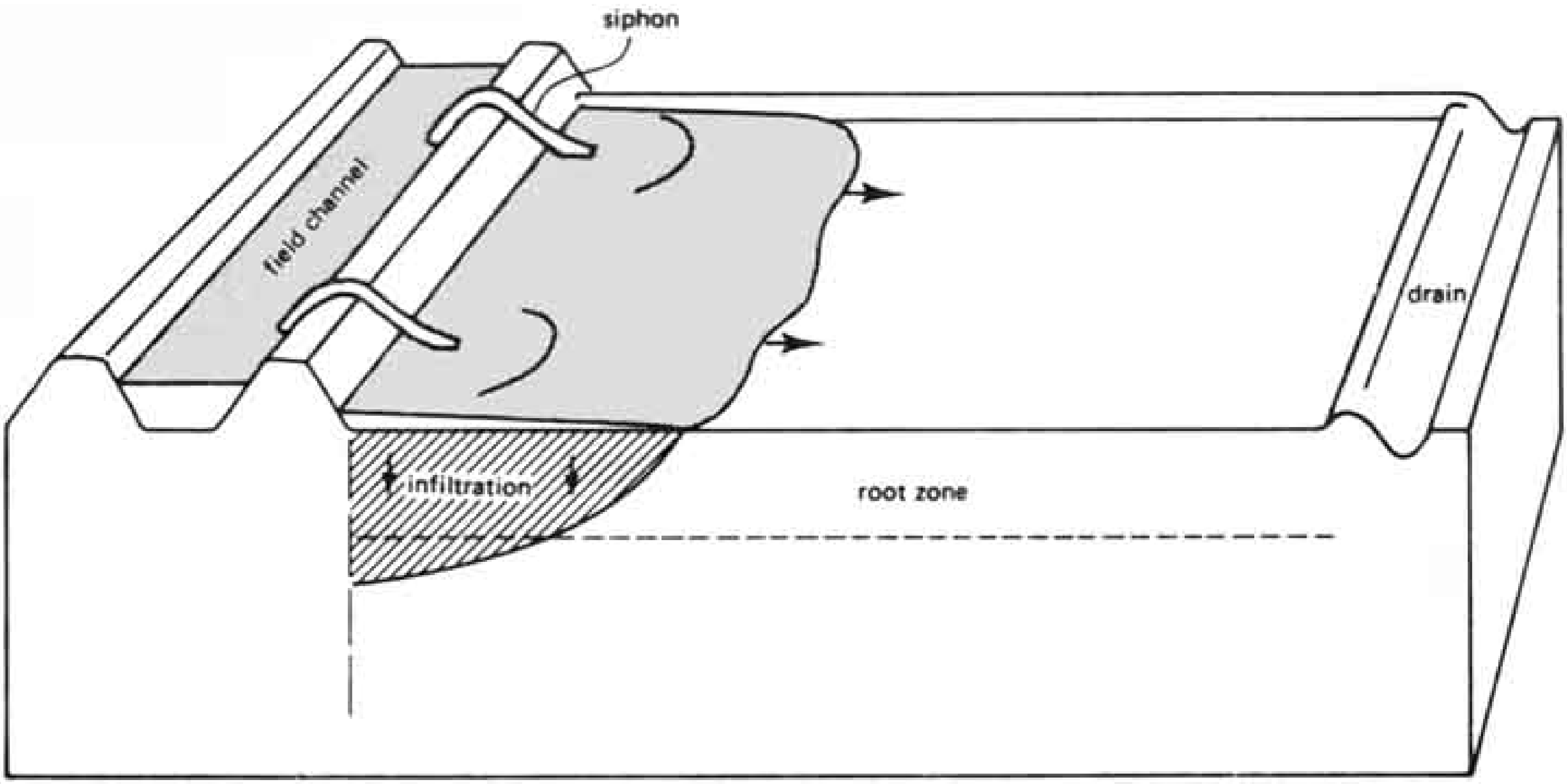
Site location: .... Soil type: .... Test date: ....

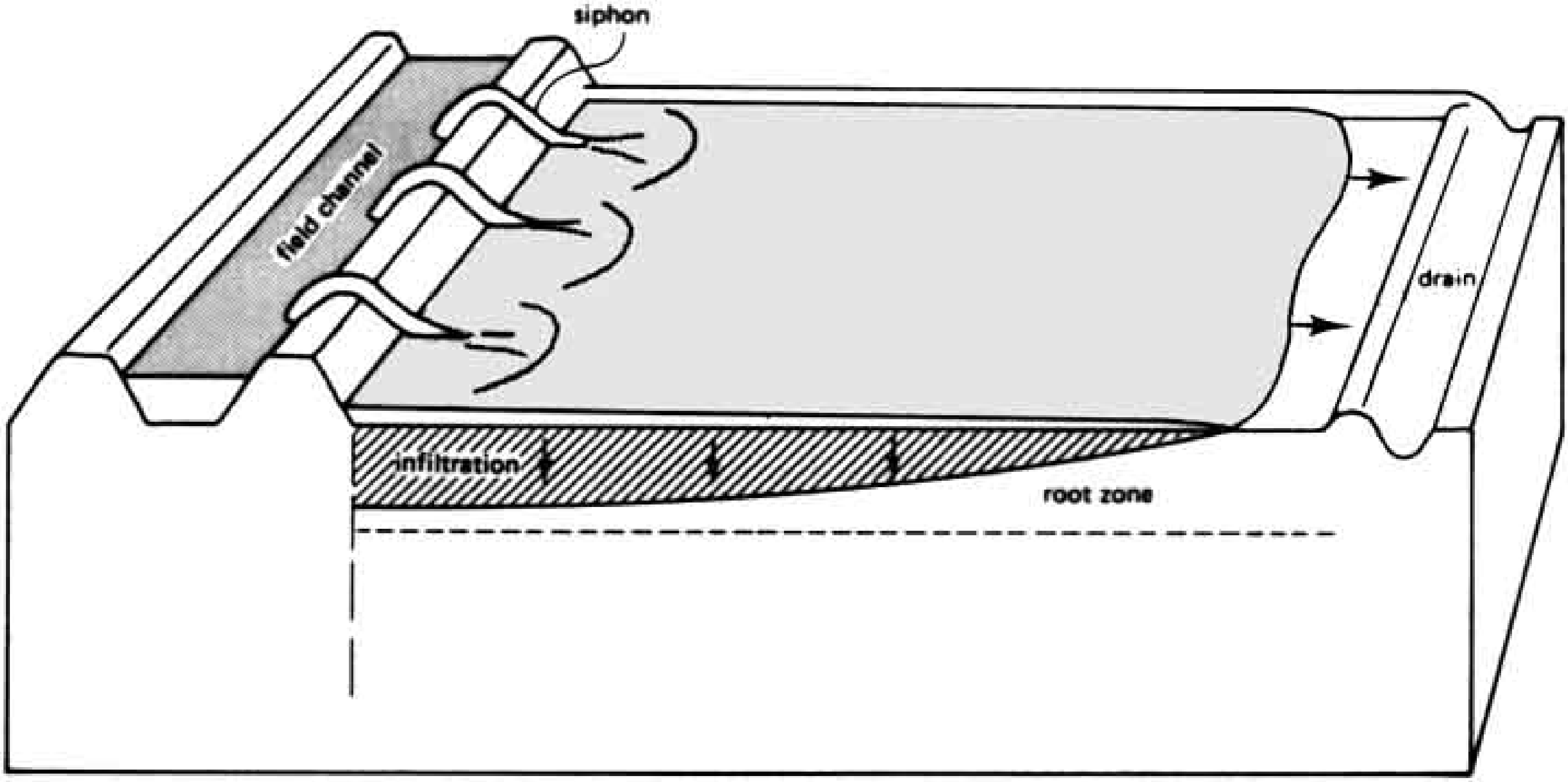
1 Reading on the clock (hr min sec)	2 Time difference (min)	3 Cumulative time (min)	4 Water level readings: before filling (mm)	4 Water level readings: after filling (mm)	5 Infiltration (mm)	6 Infiltration rate (mm/min)	7 Infiltration rate (mm/hour)	8 Cumulative infiltration (mm)
	start = 0	start = 0						start = 0

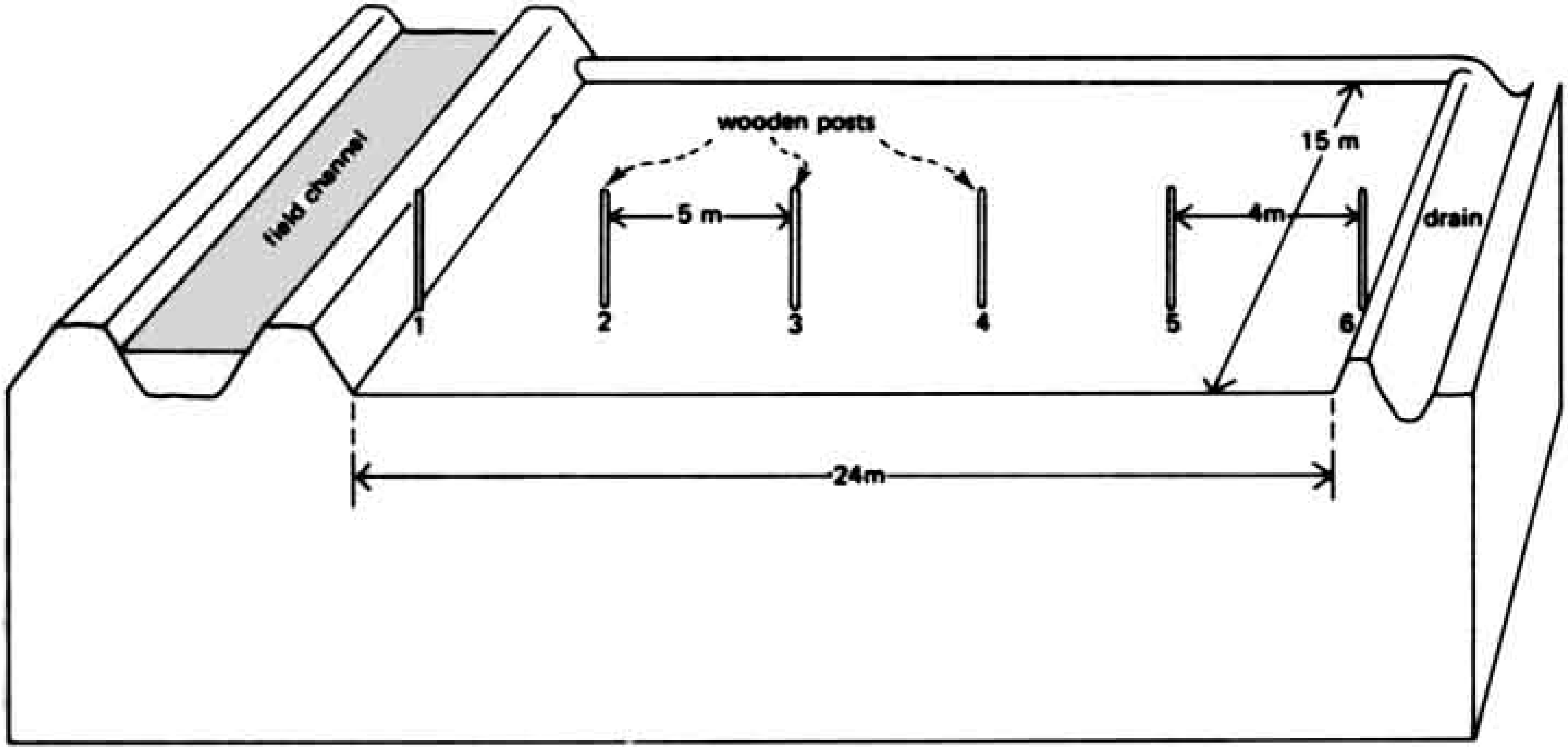

cumulative infiltration (mm)
120
100
80
60
40
20
0
20
40
60
80
100
120
cumulative time (min)

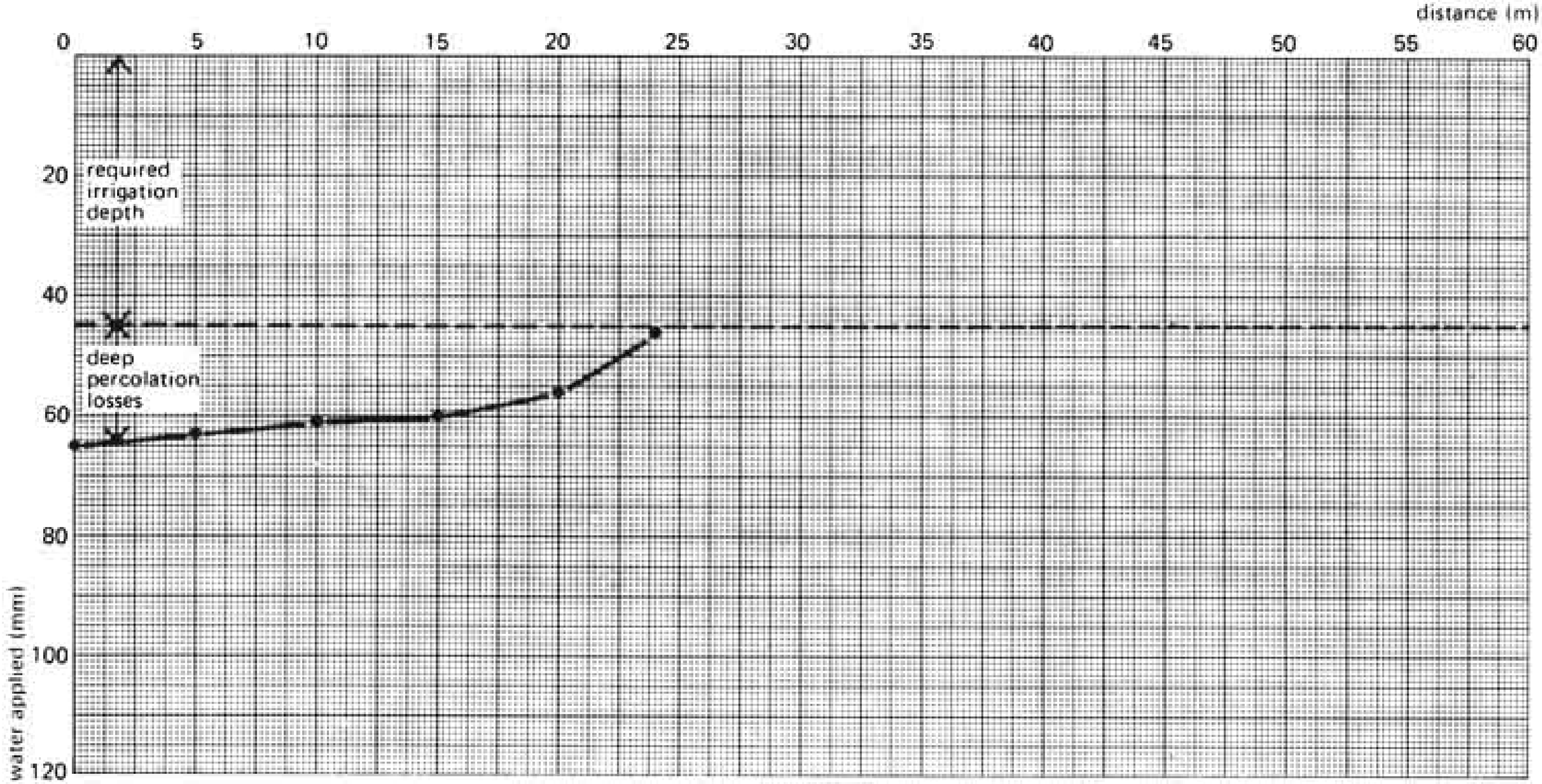

field channel
water layer
advance
drain
infiltration


field channel
recession
water layer
drain
root zone
infiltration stopped
infiltration


siphon
field channel
drain
infiltration
root zone

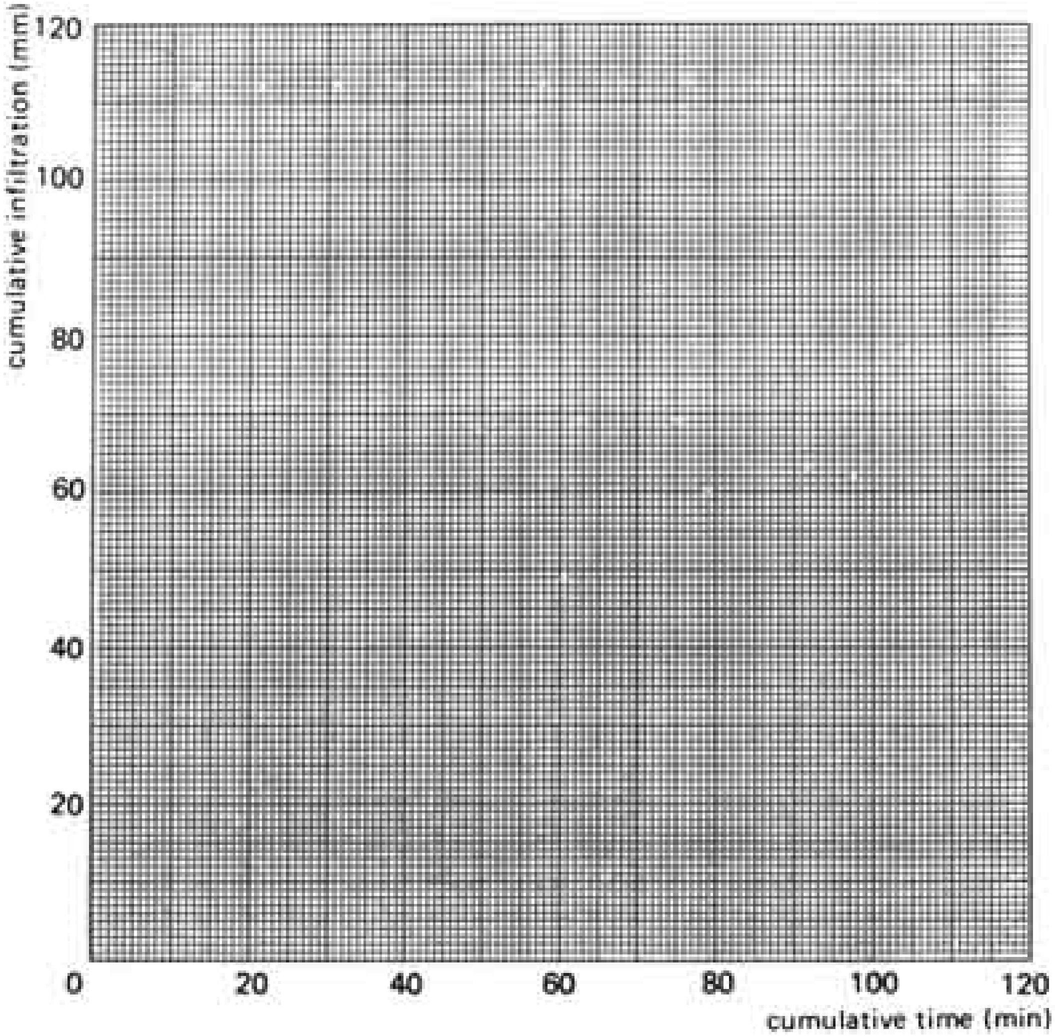

siphon
field channel
drain
infiltration
root zone

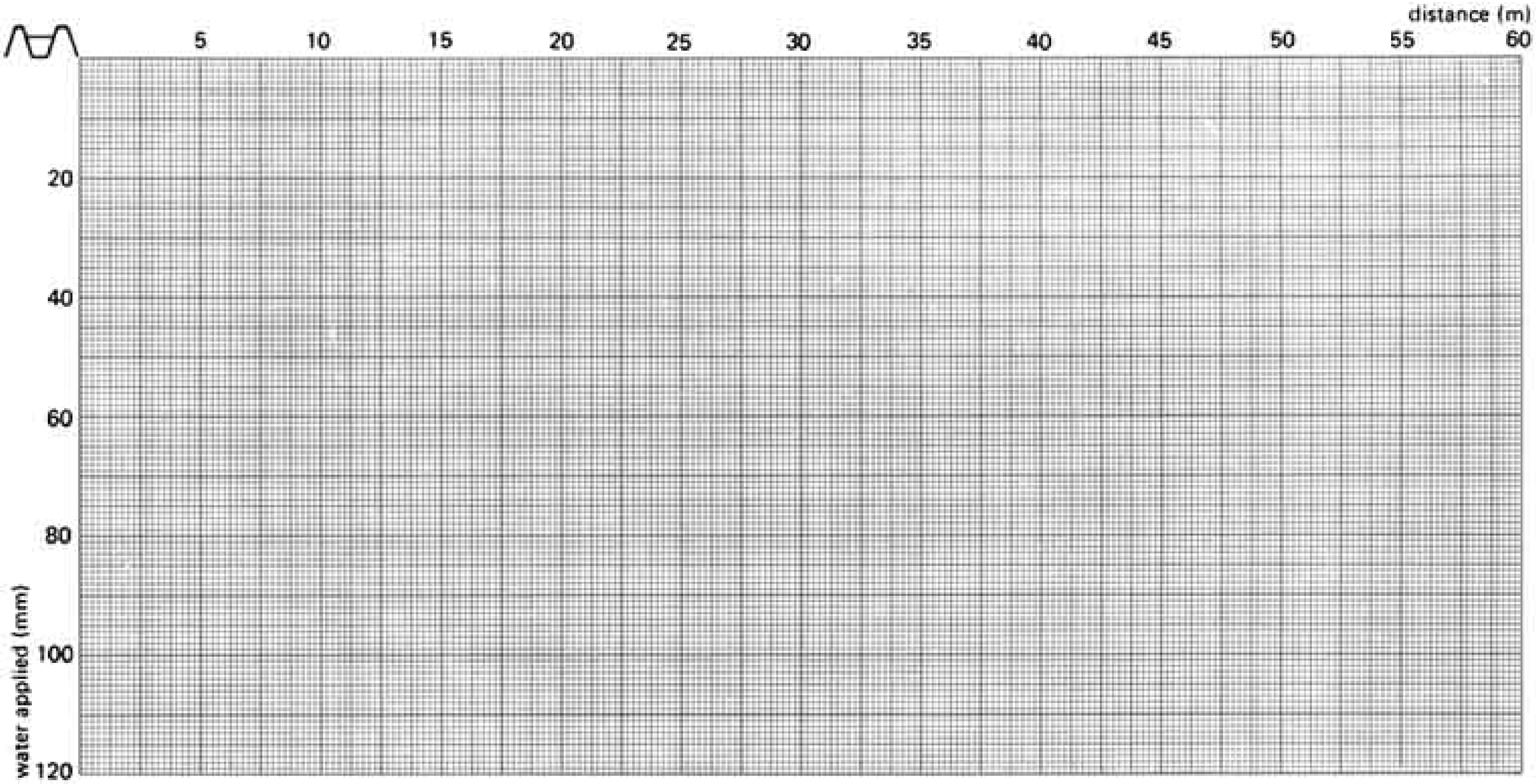

field channel
wooden posts
5 m
4m
15 m
drain
1
2
3
4
5
6
24m


distance (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
20
40
60
80
100
120
water applied (mm)
required irrigation depth
deep percolation losses

Date of test:
Soil type :
Basin size : .... (m) x .... (m) = ... (m^2) or furrow length: .... (m)
Crop :
Net irrigation depth:

1 Post No.	2 Distance from field channel m	3 Advance time clock reading hr min	time elapsed since start min	4 Recession time clock reading hr min	time elapsed since start min	5 Contact time min	6 Water applied mm


cumulative infiltration (mm)
120
100
80
60
40
20
0
20
40
60
80
100
120
cumulative time (min)


distance (m)
5
10
15
20
25
30
35
40
45
50
55
60
20
40
60
80
100
120
water applied (mm)