Agrodok 13

Water harvesting and soil moisture retention

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Foreword

The Agrodok series has lacked a booklet describing how water available from rainfall and run-off, i.e. from smaller sources than rivers and ground water, can be better utilised in agriculture. Antoinette Kome, Rob de Neef and Ton van de Ven have filled the gap by writing this Agrodok: 'Water harvesting and soil moisture retention'. The contents have also been supplemented by the undersigned. The water harvesting techniques described are particularly useful in arid and semi-arid areas, but the techniques described for soil moisture conservation are also of use in sub-humid regions.

Theo Meijer, Max Donkor and Marc Nederlof have contributed technical advice to this Agrodok. Agromisa is also grateful to Anne Gobin of the Institute for Land and Water Management in Leuven, Belgium, and to Pierre Chevallier of the Hydrology Department of ORSTOM in Montpellier, France, for their comments on an earlier version of this Agrodok. Finally, without Barbera Oranje this Agrodok would not have been complete, for she has drawn and adapted a large number of the illustrations.

Justine Anschütz & Marc Nederlof, editors
Wageningen, April 1997

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1 Introduction: why water harvesting and soil moisture retention

Water is one of the main requirements for healthy plant growth. Most arid and semi-arid regions, however, suffer from insufficient and unreliable rainfall. In these areas a high rate of evaporation in the growing season is also common. When it rains in (semi-)arid areas, the rainstorms are usually heavy. The prevailing soils generally cannot absorb the amount of water which falls in such a short time. As a result rainfall in (semi-)arid areas is often accompanied by a large amount of surface runoff.

These climatic characteristics of (semi-)arid regions mean that it is important to use the limited amount of rainfall available as efficiently as possible. One way to do this is to use surface runoff (*water harvesting*). Another is to encourage infiltration and storage of rainwater (*soil moisture retention or conservation*). The advantages of water harvesting and moisture retention techniques in (semi-)arid areas may be summarized as follows. A higher amount of water available for crops may lead to a greater reliability and a higher level of yields. In addition, it can tide a crop over an otherwise damaging dry spell and it can make crop production possible where none is viable under existing conditions.

Most techniques for water collection make use of large water sources such as rivers and ground water (eg. wells and irrigation systems), and require large-scale investments. But in many countries in the world small-scale, simple methods have been developed to collect surface runoff for productive purposes. Instead of runoff being left to cause erosion, it is harvested and utilized. A wide variety of water harvesting techniques with many different applications is available. This Agrodok **'Water harvesting and soil moisture retention'** presents a number of these techniques. Whereas water harvesting makes use of and even induces surface runoff (Figure 1), soil moisture retention aims at preventing runoff and keeping rainwater in the place where it falls as much as possible. However, the distinction between the two types of techniques is not always clear, especially when the (runoff producing) catchment area is very small. In addition, soil moisture retention techniques can be applied in the cultivated area of water harvesting systems.

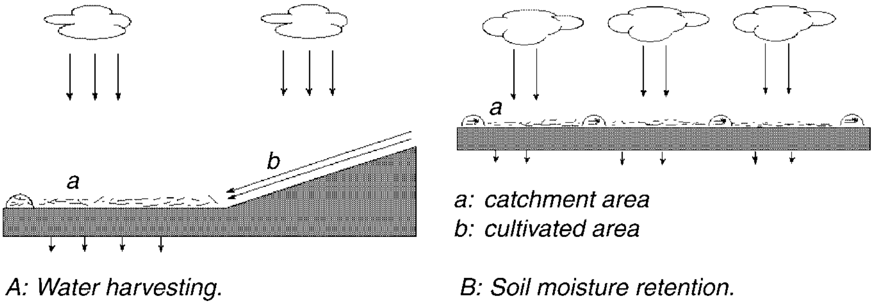


Figure 1: Water harvesting and soil moisture retention.

This Agrodok is written for agricultural extension workers who work with farmers faced with water shortages, eroded soils and low yields in (semi)-arid areas. Two warnings are necessary here. Firstly, the techniques described in this booklet cannot increase the total amount of rainfall available in an area. They can only increase the availability of water to plants, by collecting water that would otherwise be lost. Secondly, all water harvesting techniques concentrate runoff water in a limited (cultivated) area which increases the potential risk of erosion.

The structure of this Agrodok is as follows:
Part I is dedicated to water harvesting. After an introduction in Chapter 2, Chapter 3 explains the theory for designing a water harvesting system. Chapter 4 helps to select an appropriate water harvesting system and chapters 5 and 6 give examples of small-scale systems.
Part II covers the subject of soil moisture retention (conservation). Chapter 7 and 8 describe a number of measures to increase infiltration of water into the soil. Part II ends with Chapter 9 describing ways to reduce evaporation of water from the soil and measures to optimize the use of soil moisture.

The glossary provides a list of technical terms and their explanations. The two appendices cover respectively a description of ridging equipment for draught animals to decrease hand labour and an extensive explanation of the use of the water tube level in measuring height, staking out contour lines and defining the slope gradient.

Part I: Water harvesting

2 The basic principles of water harvesting

2.1 Definition

Water harvesting in its broadest sense can be defined as the collection of runoff for its productive use. Runoff may be collected from roofs and ground surfaces as well as from seasonal streams. Water harvesting systems which harvest runoff from roofs or ground surfaces fall under the term rainwater harvesting while all systems which collect runoff from seasonal streams are grouped under the term flood water harvesting.

This Agrodok focuses on harvesting rainwater from ground surfaces. The purpose of the techniques described in this Agrodok is water harvesting for plant production. The basic principle of these water harvesting techniques is illustrated by Figure 2. The techniques described are small-scale and can be applied by individual farmers.

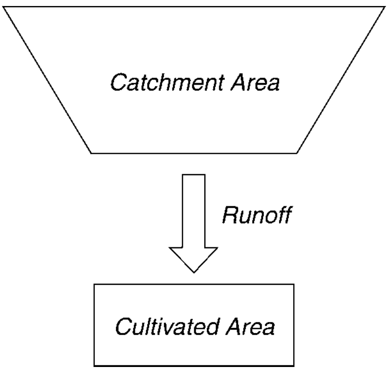


Figure 2: Principle of water harvesting for plant production (Critchley, 1991).

A certain amount of land, the catchment area, is deliberately left uncultivated. Rainwater runs off this catchment area to the zone where crops are grown, the cultivated area. The runoff is ponded in the cultivated area, using soil moisture conservation methods (structures made of earth or stones), which allow the water to infiltrate into the soil and become available to the roots of the crops.

Small-scale rainwater harvesting techniques catch rainfall and runoff from small catchments covering relatively short slopes: slope length less than 30 m (micro-catchments). Rain water harvesting on longer slopes (30m - 200m), outside the farm fields, is possible but not described in this Agrodok. Figure 3 is an example of a micro-catchment system.

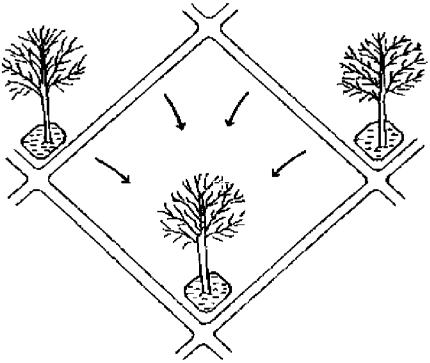


Figure 3: Micro-catchment system (Critchley, 1991).

2.2 Conditions for water harvesting

Climates

Water harvesting is particularly suitable for semi-arid regions (300-700 mm average annual rainfall). It is also practised in some arid areas (100-300 mm average annual rainfall). These are mainly subtropical winter rainfall areas, such as the Negev desert in Israel and parts of North Africa. In most tropical regions the main rainfall period occurs in the 'summer' period, when evaporation rates are high. In more arid tropical regions the risk of crop failure is considerably higher. The costs of the water harvesting structures here are also higher because these have to be made larger.

Slopes

Water harvesting is not recommended on slopes exceeding 5% because of the uneven distribution of runoff, soil erosion and high costs of the structure required.

Soils and soil fertility management

Soils in the cultivated area should be deep enough to allow sufficient moisture storage capacity and be fertile. Soils in the catchment area should have a low infiltration rate. See Chapter 3, 'water-soil system'.
For most water harvesting systems soil fertility must be improved, or at least maintained, in order to be productive and sustainable. The improved water availability and higher yields derived from water harvesting lead to a greater exploitation of soil nutrients. Sandy soils do not benefit from extra water unless measures to improve soil fertility are applied at the same time. Possible methods for maintaining soil fertility in the cultivated area being described in Agrodok no 2: Soil Fertility.

Crops

One of the main criteria for the selection of a water harvesting technique is its suitability for the type of plant one wants to grow. However, the crop can also be adapted to the structure. Some general characteristics with regard to water requirements are given in Chapter 3.
The basic difference between perennial (e.g. trees) and annual crops is that trees require the concentration of water at points, whereas annual crops usually benefit most from an equal distribution of water over the cultivated area. The latter can be achieved by levelling the cultivated area. Grasses are more tolerant of uneven moisture distribution than cereal crops.
More information on suitability of crops used in water harvesting systems is given in Chapter 3.

Technical criteria

When selecting a suitable water harvesting technique, two sets of criteria, of equal importance, should be taken into account:

1 A water harvesting technique should function well from a technical point of view.
2 It should 'fit' within the production system of the users.

If the risk of production failure of the new technique is too high compared with proven techniques, or the labour requirements of the new technique are too high, your proposed water harvesting system, although designed well, will not be adopted because the priorities of the future users are different.

2.3 Inputs for water harvesting

As with all agricultural practices, there should be a balance between costs and benefits of water harvesting systems. The most tangible benefit is an increase in yield for farmers. In years with an average amount of rainfall, water harvesting provides increases of approximately 50 to 100% in agricultural production, depending on the system used, the soil type, land husbandry, etc. In addition, some systems make cropping possible, where nothing could be grown previously. In years of below average rainfall, yields are usually higher than on control plots, although in a very bad year the effect may be neutral.

Costs, labour and equipment

The major costs of a water harvesting scheme are in the earth and/or stone work. The quantity of digging of drains, collection and transport of stones, maintenance of the structures, etc. will provide an indication of the cost of the scheme. Usually these labour requirements are high.

Most water harvesting structures are built in the dry season. However, it is not correct to assume that farmers are automatically willing to invest much labour in these structures on a voluntary basis. In the dry season they are often engaged in other activities, like cattle herding or wage labour on plantations or in urban areas. Under specific circumstances, such as high land pressure and increasing environmental degradation, farmers might be more willing to invest in water harvesting.

Labour requirements depend very much on the type of equipment used. The choice of equipment depends on the power sources available. In small-scale systems labour is mostly carried out using hand tools. Draught animals like oxen, donkeys and horses can be used for ridging and bed-making. Simple ridging equipment exists which may be drawn by animals, for example mouldboard ridgers. More information about this equipment is given in Appendix 2.

3 Designing water harvesting systems

3.1 Introduction

The water shortage in the cultivated area is supplemented by water from the catchment area (Figure 2). When designing a water harvesting system the size of the catchment area is calculated or estimated, in order to ensure that enough runoff water is harvested for the crops in the cultivated area. The relation between the two areas is expressed as the C:CA ratio, the ratio between the catchment area (C) and the cultivated area (CA). For seasonal crops a C:CA ratio of 3:1 is often used as a rule of thumb: the catchment area C is three times the size of the cultivated area CA.

Although calculation of the C:CA ratio results in accurate water harvesting systems, it is often difficult to calculate the C:CA ratio. The data required (rainfall, runoff and crop water requirements) are often not available and if they are, variability is often high. They may differ from one location to an other, or from year to year. Calculations may give an impression of accuracy but this is misleading if they are based on data with a high variability.

For this reason water harvesting systems are often designed using an educated guess for the C:CA ratio. Many successful water harvesting systems have been established by starting on a small experimental scale with an estimated C:CA ratio. The initial design can then be modified in the light of experience.

In order to be able to estimate the C:CA ratio and to assess critically the results of the first experimental water harvesting system, it is necessary to have a thorough understanding of how water harvesting works. Which aspects influence the functioning of a water harvesting system? The following paragraphs will deal with each of these aspects. A formula is presented for calculation of the C:CA ratio in the last paragraph.

3.2 The water-soil system

The objective of a water harvesting system is to harvest runoff. Runoff is produced in the water-soil system where the interaction between rainfall and the soil takes place (Figure 4). The principle of this system is as follows:
the soil has a certain capacity to absorb rainwater. The rain which cannot be absorbed by the soil flows away over the soil surface as runoff. The amount of runoff depends on the absorbtion capacity of the soil and the amount of rain.

The amount of rain which falls in a certain period of time on the soil is called the *rainfall intensity* and is expressed as the quantity of rainwater depth in mm per hour: mm/hour.
The absorbtion capacity of a soil is called the *infiltration capacity*. The size of this capacity, the infiltration rate is expressed as the quantity of water depth in mm per hour: mm/hour. Runoff is produced when the rainfall intensity is greater than the infiltration rate of the soil.

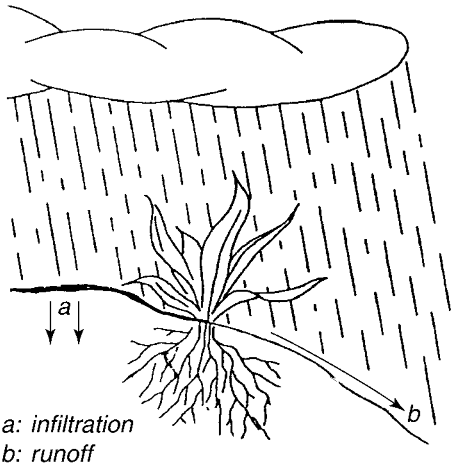


Figure 4: Water-soil system, (Brouwer et al, 1986).

3.3 Infiltration and runoff

Factors influencing infiltration and runoff are described here.

Soil type and texture

Table 1 lists typical infiltration rates for the major soil types. It can be seen that the infiltration rate is different for each soil type. The type of soil you have depends on the *texture* of the soil: the mineral particles which compose the soil. Three main soil types are distinguished, based on the three main types of mineral particles: sand, silt and clay. A soil which consists of mainly large sand particles (a coarse textured soil) is called a sand type of soil or sandy soil; a soil which consists of mainly medium sized, silt particles (a medium textured soil) is called a loam type of soil or loamy soil; a soil which consists of mainly fine sized, clay particles (a fine textured soil) is called a clay type of soil or clayey soil. You will often find that soils are composed of a mixture of mineral particles of different sizes. For example the sandy loam soil of Table 1 consists of an equal mixture of sand and silt particles.

Table 1: Typical infiltration rates (Brouwer et al, 1986).

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

The size of the mineral particles of a soil determines the size of the open spaces between the particles, the *soil pores*. Water infiltrates more easily through the larger pores of a sandy soil (higher infiltration capacity) than for example through the smaller pores of a clay soil (lower infiltration capacity).

Soil structure

The structure of a soil also influences the infiltration capacity. Soil structure refers to the way the individual mineral particles stick together to form lumps or aggregates. A heap of dry, loose sand is a soil with a sandy texture and a grainy structure because the individual sand particles do not stick together into larger aggregates. Some clay soils on the contrary form large cracks when dry, and the aggregates (lumps) can be pulled out by hand. These types of soils have a fine texture (clay particles) and a coarse, compound structure. The size and distribution of the 'cracks' between the aggregates influence the infiltration capacity of a soil: a soil with large cracks has a high infiltration rate.

Catchment area and cultivated area

Ideally the soil in the catchment area should convert as much rain as possible into runoff: i.e. it should have a low infiltration rate. E.g. if a rainstorm with an intensity of 20 mm/hour falls on a clay soil with an infiltration rate of 5 mm/hr, then runoff will occur, but if the same rainstorm falls on a sandy soil (with an infiltration rate of 30 mm/hr) there will be no runoff. For this reason sandy soils are not suitable for a water harvesting system because most of the rain which falls on the catchment area is absorbed by the soil and little or no runoff will reach the cultivated area.

The soil in the cultivated area should not only have a high infiltration rate, but also a high capacity to store the infiltrated water and to make this water easily available to the cultivated crop. The ideal situation is a rocky catchment area and a cultivated area with a deep, fertile loam soil. In practice the soil conditions for the cultivated and the catchment area often conflict. If this is the case the requirements of the cultivated area should always take precedence.

Sealing

The infiltration capacity of a soil also depends on the effect the raindrops have on the soil surface. The rain drops hit the surface with considerable force which causes a breakdown of the soil aggregates and drives the fine soil particles into the upper soil pores. This results in clogging of the pores and the formation of a thin but dense and compacted layer on top of the soil, which greatly reduces the infiltration rate. This effect, often called capping, crusting or *sealing*, explains why in areas where rainstorms with high intensities are frequent, large quantities of runoff are observed.

Soils with a high clay or loam content are the most prone to sealing. Coarse, sandy soils are comparatively less prone to sealing.

Sealing in the catchment area is an advantage for water harvesting because it decreases the infiltration capacity. In the cultivated area, however, it is a disadvantage. A farmer can increase the infiltration rate in the cultivated area by keeping the soil surface of the cultivated area rough by using some form of tillage or ridging (see Part II on soil moisture retention).

Vegetation

Vegetation has an important effect on the infiltration rate of a soil. A dense vegetation cover protects the soil from the raindrop impact, reduces sealing of the soil and increases the infiltration rate. Both the root system as well as organic matter in the soil increase the porosity and hence the infiltration capacity of the soil. On gentle slopes in particular, runoff is slowed down by vegetation, which gives the water more time to infiltrate. Soil conservation measures make use of this.

In water harvesting systems the catchment area will ideally be kept smooth and clear of vegetation.

Slope length

In general steep slopes yield more runoff than gentle slopes and, with increasing slope length the volume of runoff decreases. With increasing slope length the time it takes a drop of water to reach the cultivated area increases, which means that the drop of water is exposed for a longer amount of time to the effects of infiltration and evaporation. Evaporation is an important factor in loss of runoff in (semi)arid zones with summer rainfall, due to the low humidity and often high surface temperatures.

3.4 Rainfall and runoff

Only a part of the rainfall on the catchment area becomes runoff. The size of the proportion of rainfall that becomes runoff depends on the different factors mentioned preceding to this paragraph. If the rainfall intensity of a rainstorm is below the infiltration capacity of the soil, no runoff will occur.

The proportion of total rainfall which becomes runoff is called the runoff factor. E.g. a runoff factor of 0.20 means that 20% of all rainfall during the growing season becomes runoff.

Every individual rainstorm has it's own runoff factor. The seasonal (or annual) runoff factor however, R, is important for the design of a water harvesting system.

The R-factor is used to calculate the C:CA ratio. In the last paragraph of this chapter - 'Calculation of the C:CA ratio' - you find more information about the determination of the R-factor.

Efficiency

The runoff water from the catchment area is collected on the cultivated area and infiltrates the soil. Not all ponded runoff water can be used by the crop because some of the water is lost by evaporation and deep percolation (see Appendix 1 for these concepts). The utilization of the harvested water by the crop is called the efficiency of the water harvesting system and is expressed as an efficiency factor. E.g. an efficiency factor of 0.75 means that 75% of the harvested water is actually used by the crop. The remaining 25% is lost. The consequence for the design of a water harvesting system is that more water has to be harvested to meet the crop water requirements: the catchment area has to be made larger.

Storage capacity

The harvested water is stored in the soil of the cultivated area. The capacity of a soil to store water and to make it easily available to the crop is called the *available water storage capacity*. This capacity depends on (i) the number and size of the soil pores (texture) and (ii) the soil depth. The available water storage capacity is expressed in mm water depth (of stored water) per metre of soil depth, mm/m.

Table 2: Available water holding capacity.

Soil type	Available water (mm/m)
sand	55
sandy loam	120
clay loam	150
clay	135

Table 2 gives typical water holding capacities for the major soil types. A loam soil with an excellent available water holding capacity of 120 mm per metre depth loses its value when it is shallow. E.g. 40 cm of soil on a bed rock provides only 48 mm of available water to the crop.

The available water storage capacity and the soil depth have implications for the design of a water harvesting system.

In a deep soil of, for example, 2 m with a high available water capacity of 150 mm/m the water storage capacity is 300 mm of water and there is no point in ponding runoff water on the cultivated area to depths greater than 300 mm (30 cm).
Any quantity of water over 30 cm deep will be lost by deep drainage and will also form a potential waterlogging hazard.
The available water capacity and soil depth also influence the selection of the type of crop to be grown. A deep soil with a high available water capacity can only be utilized effectively by a crop with a deep rooting system. Onions, for example, have a rooting depth of 30 to 40 cm, and therefore cannot fully utilize all the stored soil moisture. Table 3 gives the rooting depth of some common crops.

Table 3: Effective rooting depth of some crops (Doorenbos et al, 1979).

Crop	Effective rooting depth (m)
Bean	0.5 - 0.7
Maize	1.0 - 1.7
Onion	0.3 - 0.5
Rice	0.8 - 1.0
Sorghum	1.0 - 2.0
Sunflower	0.8 - 1.5

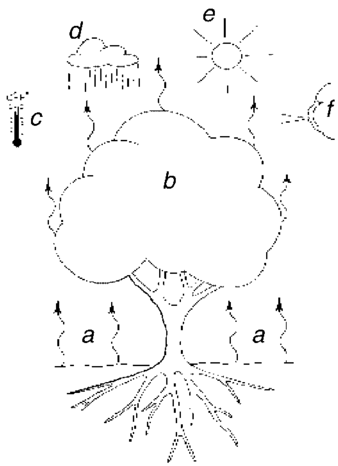
3.5 Crop water requirements

Crop water requirements are the amount of water that a certain crop needs in a full growing season.Each type of crop has its own water requirements. For example a fully developed maize crop will need more water per day than a fully developed crop of onions (Table 4).
Within one crop type however, there can be a considerable variation in water requirements. The crop water requirements consist of transpiration and evaporation (Figure 5) usually referred to as evapotranspiration. The crop water requirements are influenced by the climate in which the crop is grown. For example a certain maize variety grown in

a cool and cloudy climate will need less water per day than the same maize variety grown in a hot and sunny climate. The major climatic factors are presented in Figure 5 and Table 5.

Table 4: Water requirements, growing period and sensitivity to drought of some crops (Brouwer et al, 1986).

Crop	Total growing period (days)	Crop water requirement (mm/growing period)	Sensitivity to drought
Bean	95 - 110	300 - 500	medium - high
Maize	125 - 180	500 - 800	medium - high
Melon	120 - 160	400 - 600	medium - high
Millet	105 - 140	450 - 650	low
Onion	150 - 210	350 - 550	medium - high
Rice (paddy)	90 - 150	450 - 700	high
Sorghum	120 - 130	450 - 650	low
Sunflower	125 - 130	600 - 1000	low - medium



a: evaporation
b: transpiration
c: temperature
d: humidity
e: sunshine
f: wind

Figure 5: Major climatic influences on crop water needs (Brouwer et al, 1986).

The length of the total growing season of each crop is different and hence the total water requirements for the growing season depends on the crop type. For example, while the daily water need of melons may be less than the daily water need of beans, the seasonal water need of melons will be higher than that of beans because the duration of the total growing season of melons is much longer. Table 4 gives an indication of the total growing season for some crops. In general the growing season of a crop is longer when the climate is cool.

Table 5: Influence of climate on crop water requirements (Brouwer et al, 1986).

Climatic factor	**Crop water requirements**	
	High	**Low**
Temperature	hot	cool
Humidity	low (dry)	high (humid)
Wind speed	windy	little wind
Sunshine	sunny (no clouds)	cloudy (no sun)

Within a growing season the daily water need of a crop vary with the growth stages of the crop.
Apart from different water requirements, crops differ in their response to water deficits. When the crop water requirements are not met, crops with a high drought sensitivity suffer greater reductions in yield than crops with a low sensitivity. Table 4 gives an indication of the sensitivity to drought of some crops. For water harvesting where it is not sure when the runoff can be harvested, crops with a low sensitivity to drought are most suitable.

Crops
Due to the large variation in crop water requirements, it is best to try and obtain local data on the water requirements of a certain crop. Where no data are available, it is often sufficient to use estimates of water requirements for common crops like those given in Table 4.

Trees
In general, the water requirements for trees are more difficult to determine than for crops. The critical stage for most trees is in the first two years of seedling establishment. Once their root system is fully

developed, trees have a high ability to withstand moisture stress. There is little information available on the response of trees, in terms of yield, to moisture deficits.

Rangeland and fodder

The water requirements for rangeland and fodder species grown in semi-arid and arid areas under water harvesting schemes are not usually estimated or calculated. The objective is to improve performance and to ensure the survival of the plants from season to season, rather than fully satisfying water requirements.

3.6 Calculation of C:CA ratio

Calculation of crop water requirements

As described in the preceding paragraph the water requirements of a certain crop depend on both the crop type and the climatic conditions under which the crop is cultivated. To facilitate the calculation of the crop water requirements under certain climatic conditions, grass has been taken as a standard or reference crop. The water requirements of this reference crop have already been determined for the major climatic zones and are presented in Table 6.

Table 6: Indicative values of the reference Evapotranspiration ET_o (Brouwer et al, 1986)

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

The water requirements of the reference crop are called the reference evapotranspiration, ET_o which is expressed in mm water depth per day, mm/day. There are more sophisticated ways to determine the reference evapotranspiration, but for the design of water harvesting system an estimation using Table 6 is sufficient. Accurate data on the ET_o are best obtained locally. By using the water requirements of the reference crop as starting point for calculation of the crop water requirements, the influence of the climate has already been taken into account. What remains is to relate the water requirements of the reference crop to those of the crop you want to grow. This is done by using the crop factor, K_c, a factor by which the water requirements of the reference crop are multiplied in order to obtain the water requirements of the crop to be grown. In formula:

$ET_{crop} = K_c \times ET_o$
ET_{crop} = the crop evapotranspiration in mm/day
K_c = the crop factor
ET_o = the reference evapotranspiration in mm/day.

The crop water requirements vary with the growth stages of the crop. With water harvesting, the farmer has little control over the quantity of water supplied, let alone the timing. Therefore, it makes little sense to calculate how much water is required by the crop at each of its growth stages. For the design of a water harvesting system it is sufficient to calculate the total amount of water which the crop requires over the entire growing season.

ET_{crop} is calculated using the formula $ET_{crop} = K_c \times ET_o$,
with average values of K_c and ET_o for the total growing season.

Table 7 gives the average K_c values for some crops.

Table 7: Average crop factors (Critchley, 1991).

Crop	Average K_c
Cotton	0.82
Groundnuts	0.79
Legumes	0.79
Maize	0.82
Millet	0.79
Sorghum	0.78

An example of the calculation of the crop water requirements is given below.

Example of Calculation of Crop water requirements.

Crop to be grown: Sorghum
Length growing season: 120 days
Average K_c: 0.78

ET_o (from local meteorological service or estimated):

month	1	2	3	4
ET_o (mm/day)	9	8.5	8	8

Calculation of average ET_o for the growing season:
$ET_o = (9 + 8.5 + 8 + 8) / 4 = 8.4$ (mm/day)

Calculation of ET_{crop}:
$ET_{crop} = 0.78 \times 8.4 = 6.55$ (mm/day)

Average water requirement for growing season:
$6.55 \times 120 =$ approx. 790 mm

(Source: Critchley, 1991)

The design rainfall

For the design of a water harvesting system you have to know the quantity of rainfall during the growing season of the crop.
The quantity of rainfall according to which a water harvesting system is designed, is called the *design rainfall*.
The difficulty with selecting the right design rainfall is the high variability of rainfall in (semi-)arid regions. While the average annual rainfall might be 400 mm there may be years without any rain at all, and 'wet' years with 500 - 600 mm of rain or even more.
If the actual rainfall is less than the design rainfall, the catchment area will not produce enough runoff to satisfy the crop water requirements;

if the actual rainfall exceeds the design rainfall there will be too much runoff which may cause damage to the water harvesting structure.

When starting with water harvesting techniques, it is recommended that you design your systems on the 'safe side' to test if your design can withstand flooding. Use crops which are resistant to drought to minimize the risk of crop failure in years when your design rainfall does not fall. We recommend you try drought resistant varieties which are cultivated already in your area in order to compare their performance in the new water harvesting scheme.

Determination of the runoff factor

The first way to determine the R-factor is by making an educated guess, and following it up by trial and error. The value of the seasonal (or annual) runoff factor, R, is usually between 0.20 and 0.30 on slopes of less then 10%. It may be as high as 0.50 on rocky natural catchments. The runoff factor R is often estimated and evaluated in the light of the results of the first experimental water harvesting systems.

The second, more accurate but also more laborious, way to determine the R-factor is to measure first the r-factor for individual rainstorms after which the seasonal (annual) runoff factor is calculated. Critchley (1991) recommends that measurements of the r-factor are taken for at least a two year period before any larger construction programme starts. For the measurement of the r-factor, runoff plots are established. These are plots sited in a representative part of the area where the water harvesting scheme is planned. With the runoff plots it is possible to measure the quantity of runoff for each individual rainstorm.
It is also possible to use seasonal runoff factors determined for nearby areas, but this must be done with care. The runoff factor is highly dependent on local conditions.

The efficiency factor.

The part of the harvested water which can be actually used by the crop is expressed by the efficiency factor. Efficiency is higher when the cultivated area is levelled and smooth. As a rule of thumb the efficiency factor ranges between 0.5 and 0.75. When measured data are not available (check nearby irrigation schemes) the only way is to estimate the factor on the basis of experience: trial and error.

The formula to calculate the C:CA ratio:

1 Water needed in the Cultivated Area (CA) = Water harvested in the Catchment area (C)

2 Water needed in the Cultivated Area (CA) = [Crop Water Requirements - Design rainfall] × CA (m^2)

and

Water harvested in Catchment area (C) = R × Design rainfall × Efficiency factor × C (m^2)

3 Therefore:

[Crop Water Requirements - Design rainfall] × CA = R × Design rainfall × Efficiency factor × C

or

$$C : CA = \frac{\text{Crop water requirements} - \text{Design rainfall}}{R \times \text{Design rainfall} \times \text{Efficiency factor}}$$

Calculation of the C:CA ratio with this formula is useful primarily for systems where crops are to be grown.
For trees the C:CA ratio is difficult to determine and a rough calculation is sufficient. Trees are usually grown in micro catchments. As a rule of thumb the size of a micro catchment area for each tree should range between 10 m^2 and 100 m^2, depending on the climate and the species grown.
For rangeland and fodder in water harvesting systems the objective is to improve performance rather than fully satisfying the water requirements of the plants. Hence a general guideline for the estimation of the

C:CA ratio is sufficient. The calculation of the C:CA ratio for crops is illustrated with an example in the box.

Example of Calculation of the C:CA ratio for crops

Climate: Semi-arid
Water harvesting technique: Small scale, e.g. contour ridges
Crop: Sorghum
Crop water requirement: 550 mm
Design rainfall: 320 mm
Runoff coefficient (R): 0.50
Efficiency factor: 0.70

C:CA = (550 - 320) / (320 × 0.50 × 0.70) = 2.05

Conclusion: the catchment area must be approximately 2 times larger than the cultivated area.
In the beginning of this chapter it was mentioned that the C:CA ratio of 3:1 is often used as a rule of thumb. In small scale systems the ratio is often lower however. This is due to the higher runoff coefficient because of the shorter catchment slope, and the higher efficiency factor because the runoff water is less deeply ponded in the cultivated area.

(Source: Critchley,1991)

A C:CA ratio of 2:1 to 3:1 is, generally speaking, appropriate for the design of micro-catchment systems, which are usually used for range-land and fodder.

4 Selecting a water harvesting technique

4.1 An overview of the systems and their criteria

When selecting a suitable water harvesting system the conditions mentioned in Chapter 2 should be taken into account. These conditions concern climate, slopes, soils and soil fertility, crops and technical aspects.

Figure 6 provides an overview of preliminary selection of a water harvesting technique. The list of water harvesting techniques in Figure 6 is far from complete. You will probably come across different traditional and/or non-traditional techniques.

The water harvesting techniques described in this Agrodok are suitable for systems covering a short slope of between 1 and 30 m. Only semi-circular bunds are suitable to cover longer slopes of between 30 and 200 m as well.

Water harvesting systems can be grouped into two categories: Systems in which the bunds follow the contour line are called *contour systems*. Systems in which bunds do not follow the contour line, but enclose a part of the slope are called *freestanding systems*.

Water harvesting systems for trees usually have an infiltration pit because the harvested water has to be concentrated near the tree.

On long slopes systems with an infiltration pit are not advisable, because these systems harvest a large quantity of runoff water, too much to be collected in an infiltration pit. On long slopes the water is collected in a larger, cultivated area and used for either fodder/rangelands or crops.

All kinds of variation are possible within water harvesting systems. The bunds can be constructed using a variety of materials: earth, stones and living and/or dead vegetable material (living barriers or trash lines). The bunds may or may not have a provision for draining the excess harvested water (see following paragraph). For the freestanding systems variations are also possible in the layout of the bunds. They can be semi-circular, V-shaped or rectangular.

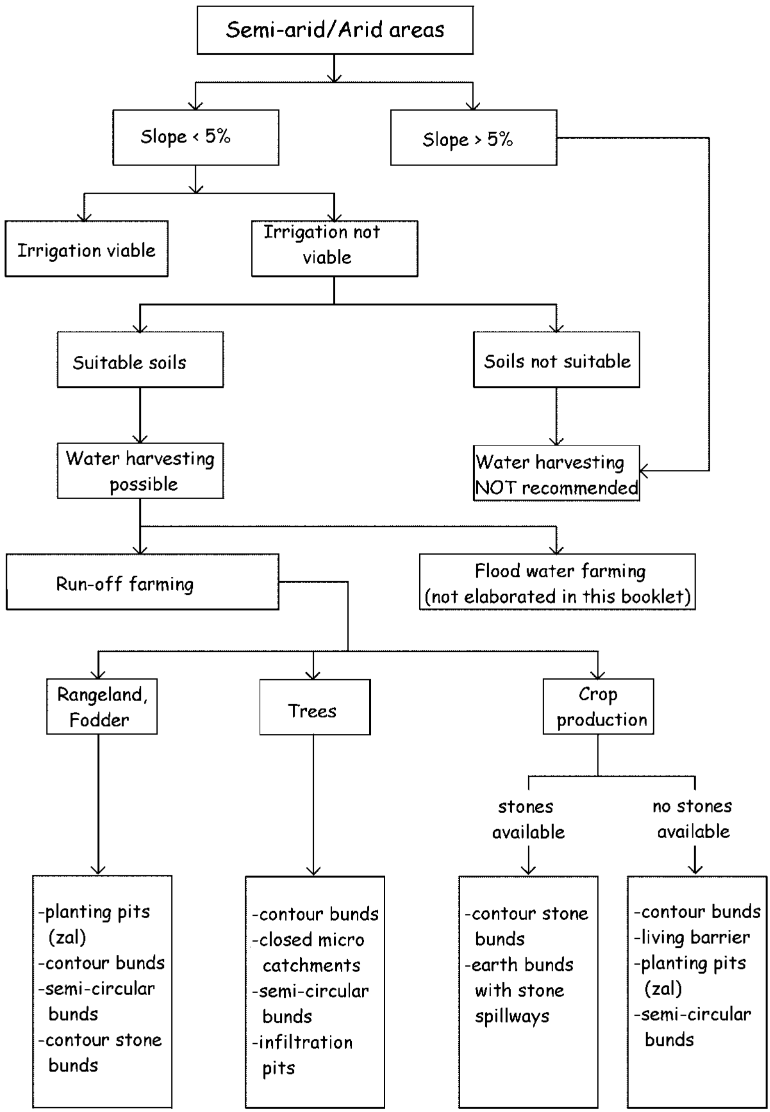


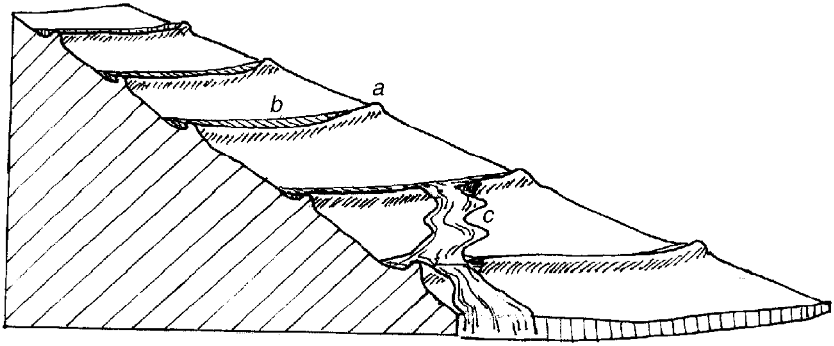
Figure 6: Selection of a water harvesting system (Critchley, 1991).

The enclosed area can be very small, as in the 'Zaï' or 'planting pit' system, or large as the case can be for the area enclosed by the semi-circular (or trapezoidal) bunds. As so many variations are possible, it means it is possible to adapt the systems described in this booklet to local circumstances. The systems described are collected from the experiences of other water harvesters.

In the following paragraph you will find a description of draining excess water. In Chapters 5 and 6 the most common water harvesting systems are explained: The contour systems in chapter 5, followed by the freestanding systems in Chapter 6.

4.2 Drainage

Although it is recommended that slopes for water harvesting schemes do not exceed 5%, the concentration of runoff still presents a potential risk of soil erosion, in particular where conditions include high intensity rainfall, long slopes and steep gradients. Most of the water harvesting techniques described in this booklet make provisions for draining excess runoff in a controlled way.
Water harvesting structures are usually constructed along the contours of a hill side. In this way these systems are more likely to prevent soil erosion and they cause the collected water to be distributed evenly over the cultivated area. The construction and use of a simple instrument for surveying contours, the water tube-level, is explained in Appendix 3. Other techniques are explained in Agrodok No.6 'Field surveying'.
Water harvesting structures are usually made of earth or stone. Earth and stone bunds differ in their capacity to deal with water collecting behind them. Earth bunds are more susceptible to overtopping, i.e. water flowing over the top of a bund, and to breaching, than stone bunds. Stone bunds are less compact and allow the water to seep through. The risk of breaching and waterlogging is therefore smaller with the latter.
Figure 7 shows what happens if too much water collects behind an earth bund.



a: bund following the contour line
b: water collected behind a bund
c: runoff water forming a gully and breaking the structures below

Figure 7: Contour bund broken by overtopping.

Overtopping

When a bund is overtopped, the next contour structure downhill must collect more water. Eventually this will lead to one of the bunds breaching. The water flows through the opening, and a gully will form. The same will also happen where the structures do not follow the contour line exactly. The water will run down to the lowest point along the contour structure, which will then be weakened and probably break.
The risk of overtopping is greatest where there is high variation in the amount and intensity of rainfall, or where the slope is irregular. In these cases it may be necessary to construct spillways (see Appendix 1) in the (earth) contour bunds, or to lay out a drainage channel. Good drainage is necessary on more clayey soils.

Drainage channel

Figure 8 shows an example of a drainage system for a contour structure. The ridges are made to slope 0.25% downwards from the contour line. In this way the water is forced to run into the drain. **Note:** The drain should not be longer than 400 m, otherwise the amount of water becomes too large, and the speed at which it flows becomes too great and the risk of gully formation increases. The flow speed of water can be decreased by growing grass in the drainage channel.

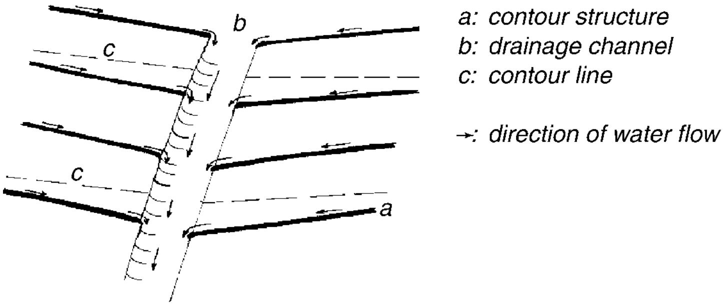


Figure 8: Drainage of a contour structure.

Cut-off drain

Apart from the drainage provision within the individual water harvesting structures, the designer has to pay attention to the location of the system. A water harvesting system will often be located on the lower parts of the hills, where suitable, deep soils with a gentle gradient are found. Attention should be given to the surface runoff from the higher areas on the slopes, which may enter the water harvesting scheme and cause considerable damage. As a first protection a *cut-off drain* (or diversion ditch) can be constructed just above the water harvesting scheme. The cutoff drain diverts the excess runoff to a main drain, which may be either natural or man-made. In this case attention should be paid to the design of the main drainage system. The cutoff drain is 0.50 m deep, 1.0 to 1.5 m wide and has a gradient of 0.25%. The excavated soil is placed downslope of the diversion ditch.

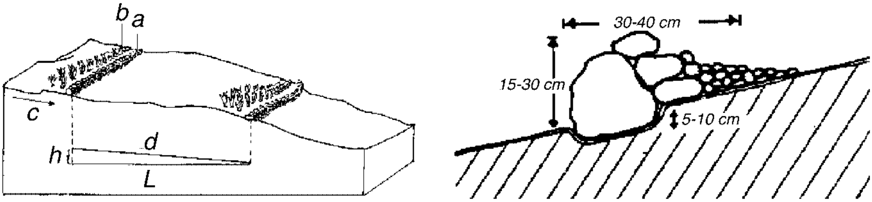
A more sustainable solution is to assess whether it is possible to reduce the surface runoff from the higher parts of the slopes through erosion control measures and afforestation.
Both design of a main drainage system and watershed development are beyond the scope of this booklet, but more information on these subjects can be obtained from Agromisa and Agrodok No.11 'Erosion control in the tropics'.

5 Water harvesting techniques - contour systems

5.1 Stone bunds, Living barriers and Trash lines

Background

Stone bunds along the contour line (Figure 9) are the most simple form of a contour water harvesting system. Because the bunds are permeable, they do not pond runoff water, but slow down its speed, filter it, and spread the water over the field, thus enhancing water infiltration and reducing soil erosion. Silt trapped on the higher side of the barrier forms natural terraces (Figure 10).



A: View from above. *B: Cross-section of a stone bund.*

a: stone bund
b: crop growing in front of the stone bund
c: direction of runoff
h: height difference between stone bunds (in metres)
d: distance between two bunds over the ground (in metres)
L: horizontal distance of two bunds

Figure 9: Stone bunds.

Stone bunds can be reinforced with earth and thus be made only semi-permeable. Where there a few stones available, stone lines can be used to form the framework of the system. Grass, or other vegetative material, is planted immediately above the stone lines and forms, over a period of time, a living barrier. Crop residues like millet and sorghum

stalks, piled weeds or branches of trees, can also be used to reinforce the stone lines. In this case the barrier is called a trash line.
These techniques are used on fairly gentle slopes (0.5 to 3%). Since these structures are permeable, it means that small errors in the contour determination are less important than for constructions which do not let water through. However, proper alignment along the contour makes the technique considerably more effective. The advantage of systems based on stones is that there is no need for spillways or diversion ditches to drain excess runoff water in a controlled way. Making bunds or simple stone lines is traditional practice in parts of Sahelian West Africa. It has proved to be an effective technique, which is popular and quickly mastered by farmers.

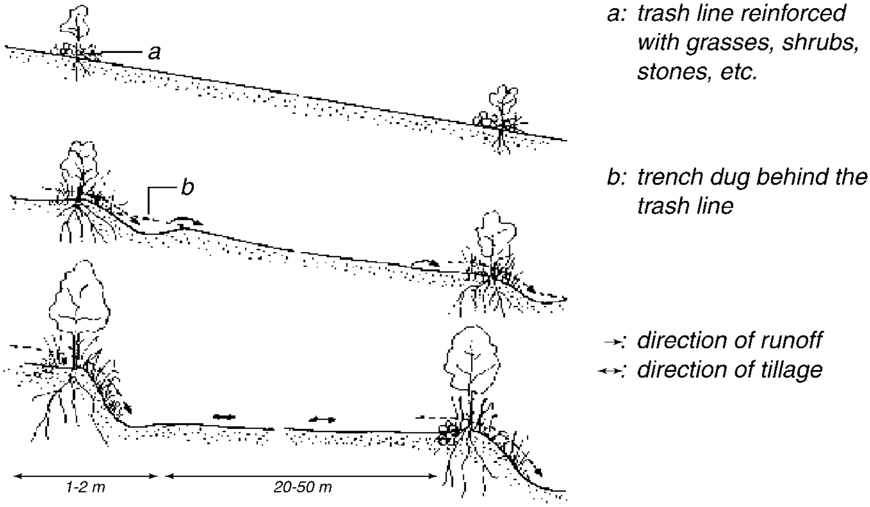


Figure 10: Trash lines: the land between the lines slowly levels out.

The soil is carried away by runoff (and tillage) from the lower side of the upper line (Figure 10 (b)) and deposited at the higher side of the next line lower. In that way gradually a horizontal terrace is built up and runoff is reduced. As the terrace forms, the lower line can be made slightly higher so that as much rainwater as possible is kept inside the cropped strip.

Conditions.

Rainfall:	200 - 750 mm.
Soil:	All soils which are suitable for agriculture. Stone bunds can be used on fields which are already cultivated, especially on clayey soils and on soils that crack or develop tunnels. They can also be used in combination with planting pits (Zaï) on badly degraded fields with a hard earth crust (see: 'Planting pits or Zaï'). Trash lines are usually used on more sandy soils.
Slope:	0.5 to 3%, preferably below 2%.
Topography:	Does not need to be completely even.

Constraints

Stones must be locally available. The collection and transport of stones is time-consuming.

Size and layout

Stone bunds follow the contour more or less. The distance between the bunds is usually 10 to 30 m, depending on the slope and the amount of stones and labour available. If the objective is to form natural terraces over the years, the stone bunds sometimes have wings at an angle of less than 45° to the contour line. These wings have to be at least 2 m long. They lead runoff into the catchment area and protect the bunds against gully formation by excess water.

The height difference between two stone bunds is usually 25 cm. On the basis of the slope gradient (s) (Figure 9A) and the vertical distance between two bunds (h), the spacing (d) between the bunds can be estimated using the following formula:

$d = (h \times 100)/s$

d = distance between two bunds over the ground (in metres)

h = height difference between stone bunds (in metres)

s = gradient of slope (%)

In fact with this formula the horizontal distance (L) is calculated instead of d, but on very gentle slopes d is equal to L. See Appendix 3 for defining the slope gradient.

For example: if the gradient of the slope (s) is 2%, the distance over the ground (d) between two bunds is: $(0.25 \times 100)/2 = 12{,}5$ m. For slopes of less than 1% spacing at 20 m intervals is recommended; for slopes of 1 to 2%, a spacing of 15 m between the bunds is recommended.

C:CA ratio

The cultivated area is determined in an experimental way. In the first years a small strip above the stone bunds is cultivated, and if possible, extended up the slope in the following years.

Ridge design

A bund height of at least 25 cm is recommended (Figure 9B) with a base width of 30 to 40 cm. Large stones are first placed in a shallow trench which helps to prevent undermining by runoff. The stones are carefully packed with the large stones on the lower side and the smaller stones on the higher side of the slope. The smaller stones on the higher side act as a filter. If only large stones are used, the runoff water is not stopped but will flow freely through the stone bund.

Construction

1 The average slope gradient is determined, for example using a water tube-level (Appendix 3), and the spacing of the bunds is decided upon. If labour is a limiting factor, farmers can start with a single bund at the bottom of their fields and work upslope in the coming years.
2 The contour lines are marked out at each location where a bund is to be made (using water tube-level and hoe or pegs). The contour lines are adjusted to form a smooth line.
3 A shallow trench is excavated along the contour line: 5-10 cm deep, width equal to the base width of the bund, 30-40 cm. The excavated soil is placed upslope.
4 The bunds are constructed as described above under "Ridge design".

Maintenance

Dislodged stones have to be replaced. Small gaps, where runoff forms a tunnel through the bund, have to be plugged with small stones or gravel. After a few seasons the stones sometimes start to sink into the ground as the earth between the stones is washed away, or the bunds silt up and become impermeable. This can be prevented by planting grass strips upslope from the stone bunds which can gradually take over the functions of the stone bunds (Part II on soil moisture retention). Sometimes vegetables or trees are grown along the bunds, thus strengthening the bunds with the roots.

Planting procedure

Stone bunds are often used to rehabilitate infertile and degraded land. In order to achieve this objective the bunds are often combined with planting pits or Zaï. Manure placed in the pits improves plant growth and better use is made of the harvested water. Regular weeding is essential to prevent the harvested water from being used by the 'wrong' plant.

5.2 Contour ridges for crops (contour furrows)

Background

Contour ridges, sometimes called contour furrows, are small earthen banks, with an furrow on the higher side which collects runoff from an uncultivated strip between the ridges. In Israel and North America they are called 'desert strips'. Through their shape, soil moisture is increased under the ridge and the furrow, in the vicinity of plant roots (Figure 11). The advantage of this system is that the runoff yield from the short catchment length is very efficient.

Labour requirements are relatively low and contour ridges are easy to make using hand tools. Thus they are easy to manage for small farmers.

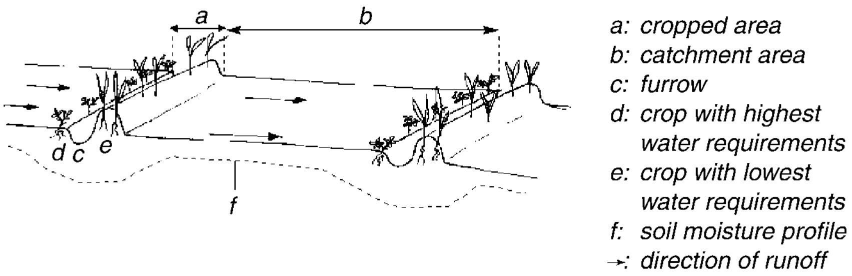


Figure 11: Contour ridges and furrows.

Conditions

Rainfall:	350 - 700 mm
Soil:	Good results on silty loam to clay loam soils. On heavier, more clayey soils they are less effective because of the lower infiltration rate. Heavy and compacted soils may also be a constraint to construction by hand.
Slope:	From almost 0% to 5%. Most suitable are slopes of 0.5-3%.
Topography:	Must be even. Areas with rills or small depressions are less suitable due to the uneven distribution of water.

Constraints

Contour ridges are limited to areas with a relatively high rainfall because the amount of harvested water is small, due to the small size of the catchment area.

Size and layout

The distance between the ridges depends on the slope gradient and the size of the catchment area (C:CA ratio) desired.
In the example in Figure 12 (slope of 0.5%) the ridges are spaced at intervals of 1.5 m. Small cross-ties in the furrows are constructed at regular intervals (5 m in the example of Figure 12) and at right angles to the ridges, to prevent flow of runoff water through the furrows (erosion) and to ensure evenly spread storage of runoff.

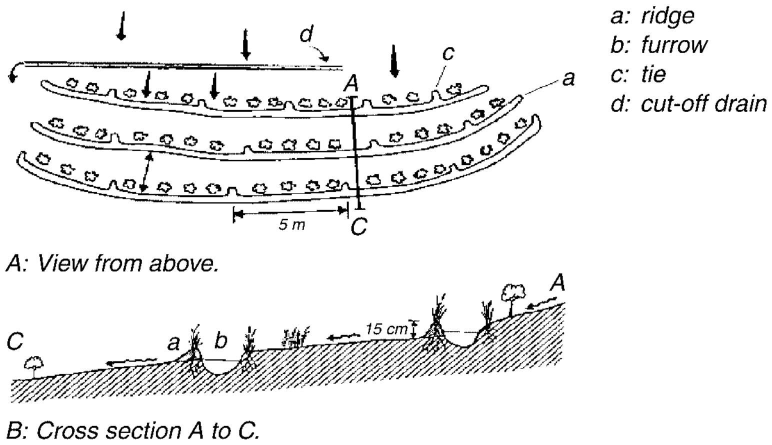


Figure 12: Contour ridges and furrows with ties.

C:CA ratio

Where furrows are used it is not easy to define the cultivated area. A cultivated strip is usually 0.5 m wide with the furrow in the centre. If the distance between two ridges is 1.5 m, the C:CA ratio is 2:1 (a catchment strip 1 m wide, a cultivated strip 0.5 m wide). A distance of 2 m between the ridges gives a C:CA ratio of 3:1.
For annual crops in semi-arid areas a spacing of 1.5 to 2.0 m is generally recommended (a C:CA ratio between 2:1 and 3:1).

Ridge design

The ridges need to be high enough to prevent overtopping. If the distance between the ridges is less than 2 m, a height of 15-20 cm is sufficient. If the bunds are spaced at more than 2 m, the ridge height must be increased. This is also necessary on steeper slopes.

Construction

1 Contour lines are marked every 10 to 15 m on the slope (App.3). The contour lines are adjusted to make smooth lines.
2 The ridges are staked out with pegs or a hoe at the selected interval. On uneven slopes, the ridges (on the contours) may come closer to-

gether at one point. Where the ridges come too close to each other, they are stopped; where the ridges become too far away from each other, new ridges are started in between.

3 The furrows are excavated and the soil is placed downslope, next to the furrow thus forming the ridge.

4 The cross-ties or cross-ridges are constructed by digging a furrow perpendicular to the furrow following the contour line, at intervals of 5 m. The cross-ridges are also 15-20 cm high, and 50-75 cm long.

5 If there is a risk of damage being caused by runoff from slopes above the system, a cut-off drain (diversion ditch) is constructed above the block of contour ridges (see Chapter 4).

Maintenance

If breaches in the ridges occur, they must be repaired immediately.
At the end of each season the ridges need to be rebuilt to their original height. Depending on the fertility of the soil in the cultivated area, it may be necessary to move the system a few metres downslope after a number of seasons, in order to use new, fertile soil for the cultivated area.

Planting procedure

Crops are planted on both sides of the furrow. Cereal crops (sorghum, millet) are usually planted <u>on</u> the ridges. Legumes (cow peas, tepary beans), needing more water, are usually planted on the higher side of the furrows (Figure 11: crops d and e). The catchment area is left uncultivated and clear of vegetation to maximise runoff.

Variations

In more arid regions, especially in overgrazed areas, the ridge-and-furrow system with ties is used for the regeneration of forage, grasses and hardy local trees. In a reforestation project in Baringo, Kenya, the system is used in the following way. The furrows are made larger (approximately 80 cm wide), and tree seedlings are planted in planting holes <u>in</u> the furrows, 1-3 m from each other. Spacing of the ridges is 5 to 10 m. Cross-ties are made at 10 m intervals.

5.3 Contour bunds for trees

Background

The contour bunds for trees are very similar to the contour ridges for crops system (last paragraph).
The difference is that in the system for trees, the harvested water is collected in an infiltration pit, instead of in a furrow as shown in Figure 13.

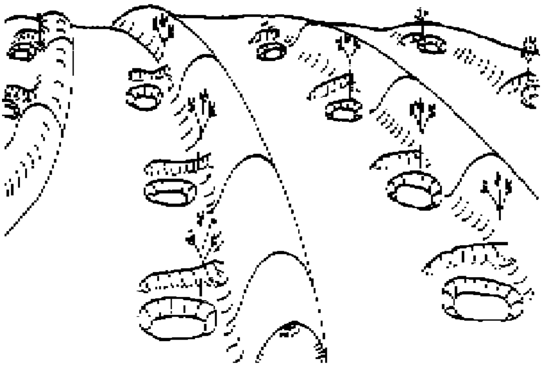


Figure 13: Contour bunds for trees.

As with the contour ridges for crops, the efficiency of contour bunds for trees is high due to the comparatively short slope length of the catchment area.
Construction can be mechanized and the technique is therefore suitable for implementation on a larger scale.

Conditions

Rainfall:	200 - 750 mm. The system is suitable for areas with less rainfall than the contour ridges for crops, because the runoff water is concentrated in the infiltration pit.
Soil:	At least 1.5 m deep, preferably 2 m, to ensure good root development and water storage capacity.
Slope:	From almost flat up to 5%.
Topography:	Even, without rills or depressions to prevent uneven distribution of the runoff water.

Constraints

The contour bunds for trees are not suitable for uneven or for eroded land because water will concentrate in the lower spots, which can lead to bunds breaking.

Size and layout

The layout of the system is similar to the layout of the contour ridges for crops (Figure 12A). Ridges are constructed along the contour line with cross-ties to divide the strips into micro-catchments. Instead of a furrow, infiltration pits are dug at the junction between the cross-tie and the bund. The size of the pit is usually 80 cm × 80 cm and 40 cm deep.

The spacing between the bunds is usually greater than in the system for crops: between 5 and 10 m. Because of this wider spacing, the bunds also have to be made higher: 20-40 cm. A spacing of 10 m is recommended for slopes up to 0.5% and 5 m for steeper slopes (up to 5%). The cross-ties should be at least 2 m long and spaced at 2 to 10 m intervals. The height of the cross-ties is the same as the height of the ridges, 20-40 cm. If a micro-catchment of 25 m² is selected, the bunds can be spaced 10 m apart with cross-ties every 2.5 m. Alternatively the bunds can be 5 m apart with cross-ties every 5 m.

C:CA ratio

Common sizes of the micro-catchment area are between 10 and 50 m² for each tree. The advantage of the contour system for trees (as compared to freestanding systems for trees) is that you can easily play with the size of the catchment area by adding or removing cross-ties within the fixed spacing of the bunds. It is a very flexible system.

Ridge design

See the preceding paragraph on *Size and Layout.*

Construction

1 Contour lines are marked every 40 to 50 m on the slope (Appendix 3). The contour lines are smoothed to a gentle curve.
2 The ridges are staked out using pegs or a hoe at the selected spacing.
3 The ridges are made by excavating the soil on both sides of the ridge, but with the emphasis on the higher side of the ridge. Compaction of the bunds is recommended, this is done by foot or with a barrel filled with sand.

4 An infiltration pit is dug in the furrow above the bund.
5 The cross-ties are constructed perpendicular to the ridges, using the excavated material from the planting pit. The cross-ties are also compacted like the ridges. The distance between the cross-tie and the planting pit is at least 30 cm. The seedling will be planted in this space (Figure 14).

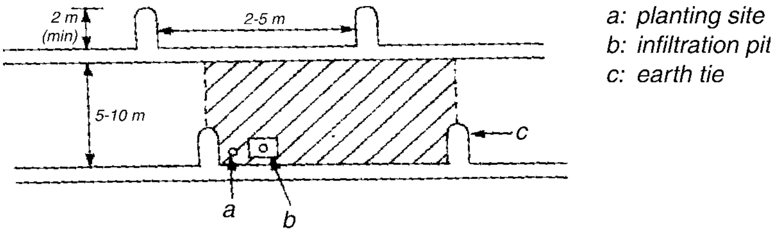


Figure 14: Contour bunds for trees: location of the tree.

6 A cut-off drain (diversion ditch) is constructed above the block of contour ridges if there is a risk of damage being caused by runoff from outside the system. See Chapter 4 on Drainage.

Maintenance
If breaches occur in the ridges, they must be repaired immediately. The catchment area has to be kept clear of vegetation to maximise runoff. At the end of each season the ridges need to be rebuilt to their original height. Grass is allowed to develop on the bunds. The roots will help to consolidate the bunds.

Planting procedure
Tree seedlings of at least 30 cm height are planted immediately after the first runoff is harvested. The seedlings are planted in the space between the cross-ties and the infiltration pit. A second seedling is planted *in* the infiltration pit in case of shortage of rainfall.
Where the contour system is used in areas with high rainfall, it is possible to use the space between the bunds for crop production before the trees become productive. This of course reduces the amount of runoff.

5.4 Earth bunds with stone spillways

Background

The system described in this section is a system of several earthbunds with stone spillways. It is a modification of a traditional water harvesting system called 'meskat' in Tunisia (Figure 15).
The system is a combination of the contour ridges for crops and contour stone bunds. The earthen bunds pond the runoff water, the stone spillways prevent the excess runoff water from flowing over the earthen bunds and damaging the bunds.
The bunds are laid out exactly perpendicular to the steepest slope and parallel to each other. In these earth bunds stone spillways are made, alternatively to the left and to the right. Lateral flow is prevented by other earth bunds, surrounding the cultivated fields. Thus runoff water from the hills above is forced to run down along the bunds until it reaches a spillway. The water then follows a zig-zag path to the lowest point of the cultivated field.

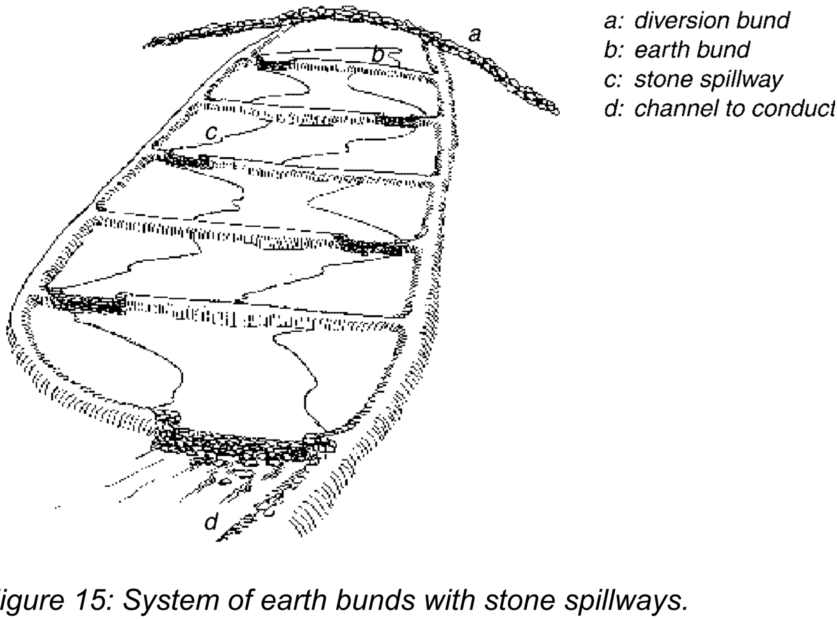


Figure 15: System of earth bunds with stone spillways.

Conditions

The Meskat system is used in Tunisia for olive trees, under the following conditions:

Rainfall:	200-400 mm. Due to the stone spillways this system is suitable for areas with unpredictable, high intensity rainstorms.
Soil:	Deep loamy soils.
Slope:	Maximum slope 6%.
Topography:	Even: no rills or depressions in the catchment area.

Constraints

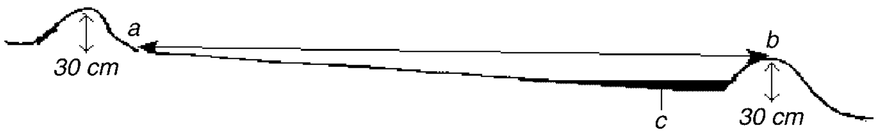
In areas with heavy rainfall it is safer to construct a diversion bund (*a* in Fig. 15) or a cut-off drain on the higher side of the field. This prevents large amounts of water from higher up the slope from flowing into the field, which can cause considerable damage. See also Chapter 4 on 'drainage'. In areas with low rainfall this kind of precautionary measure is not necessary.

Size and layout

The distance between the bunds depends on the gradient of the slope. The top of one bund should be at the same height as the bottom of the bund above it (Figure 16). The steeper the slope, the closer together the bunds. Each bund has one or more spillways, at 20 m intervals along the bund length.

C:CA ratio

Usually the distance between the bunds is calculated on basis of the slope gradient, in the same way as described for the stone bunds. As for the stone bunds, the cultivated area for crops is determined in an experimental way.

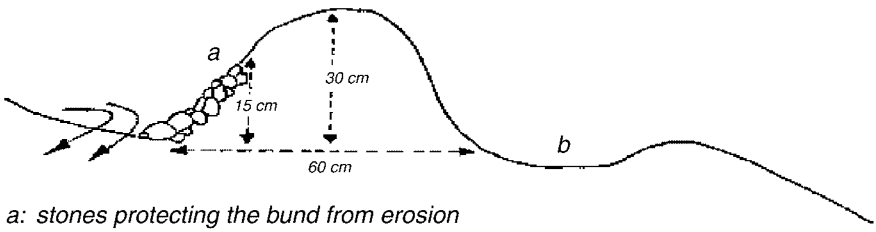


The distance between two bunds is such that the top of one bund (b) is level with the bottom (a) of the bund above it. Earth and silt are desposited at the higher side of each bund (c).

Figure 16: Determining the distance between two bunds.

Ridge design

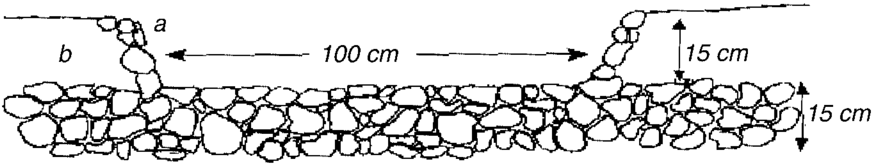
The bunds are twice as wide as they are high. In the example shown in Figure 17 the bund is 30 cm high and 60 cm wide at its base. For a plot of 0.1 ha on a 1% slope, bunds are 40 cm high and 0.5 to 1 m wide at their base. The diversion bund is somewhat larger than the other bunds, constructed of earth and covered with a layer of stones.



a: stones protecting the bund from erosion
b: trench from which earth is dug for the bund
→: runoff water runs alongside the bund

Figure 17: Cross section of an earth bund.

The spillway is made of stones, and is usually 80 cm wide at the base and 10-15 cm high (see Figure 18). The length of the spillway varies from 1 to 2.5 m. A rule of thumb is that the total length of spillways in metres for one earthen bund, is equal to half of the uphill catchment area in hectares. Thus a bund with a catchment area of 8 ha needs a spillway length of 4 m. If this bund is 50 m long, either two spillways of 2 m each or three of 1.35 m each can be constructed. Thus, the lower down the field, the wider the spillways. It is very important that a layer of stones or gravel is laid on the downstream side of each spillway to prevent undermining.



a: stones protecting the spillway against erosion
b: earth bunds

Figure 18: Front view of a stone spillway.

Construction

1 The average slope gradient is determined, using for example a water level-tube (Appendix 3), and the spacing of the bunds is calculated.
2 The contour lines are marked out at each location where a bund has to be made. The contour lines are adjusted to form a smooth line.
3 The width and location of each spillway is calculated and marked out.
4 The earthen bunds are constructed with earth taken from the lower side, and covered with a layer of stones on the upstream side to prevent erosion. Erosion can be further prevented by planting grasses, perennial crops or bushes on top or just in front of the bund.
5 The stone spillways are constructed in the same way as the contour stone bunds.

Maintenance

Maintenance of this system is the same as for contour ridges for crops and stone bunds, see the respective paragraphs.

6 Water harvesting techniques - freestanding systems

6.1 Planting pits or Zaï

Background

Planting pits or Zaï are the most simple form of water harvesting. In Burkina Faso and in Mali planting pits are traditionally used to rehabilitate degraded soils. The planting pit technique consists of digging small holes of about 10 to 15 cm deep, in which a little manure is put together with some seeds (Figure 19).

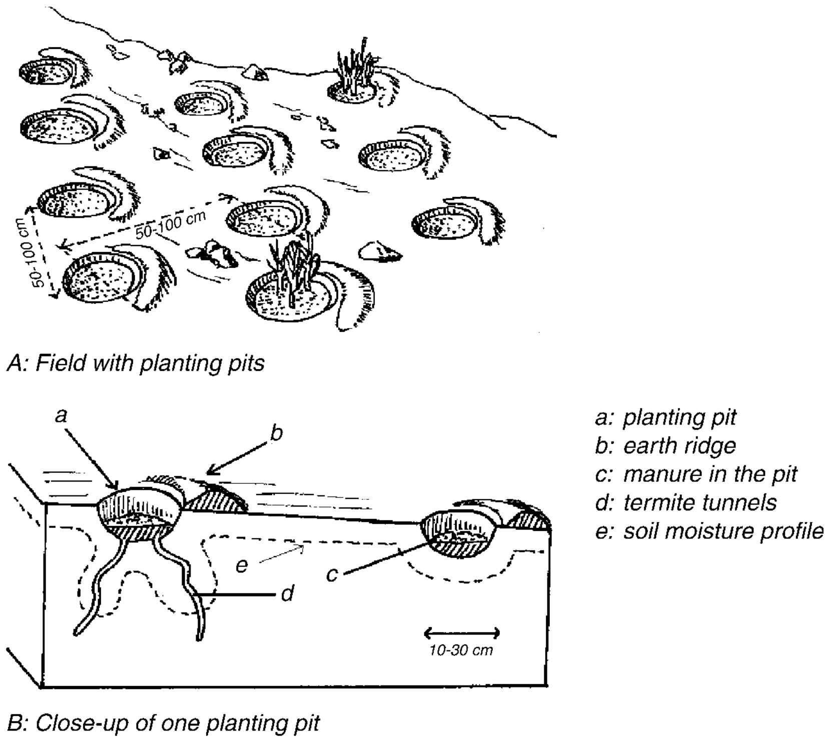


Figure 19: Planting pits or Zaï, an overview and a close-up.

During rainstorms the planting pits catch runoff and concentrate it around the growing plants. Yields are improved in the first season after the land has been treated, and even in very dry years these techniques ensure some yield.

Conditions

Rainfall:	200 - 750 mm.
Soil:	Planting pits are particularly successful for rehabilitating barren, crusted soils and clay slopes, where infiltration is limited and tillage is difficult. These soils are rock hard and usually generate a high amount of runoff. The soil does not need to be deep.
Slope:	Below 2%.
Topography:	Does not have to be even. Suitable technique to rehabilitate uneven, broken terrain.

Constraints

Digging the planting pits is quite labour-intensive. It is not possible to mechanize the digging or to use a plough on land where Zaï have been dug. Where soils are already shallow, they become even shallower when Zaï are dug. In those cases, farmers should not plant <u>in</u> the pit, but rather on top of the ridge of excavated soil in order to maximise rooting depth.

Size and layout

Dimensions of the planting pits vary according to the type of soil in which they are dug. Usually they are between 5 and 15 cm deep, and between 10 and 30 cm in diameter (Figure 19B). The distance between two pits varies between 0.5 and 1 m. The number of Zaï per ha generally is between 10,000 and 25,000. Planting pits may be dug in one line or, more commonly, in staggered rows, following the contour lines (Figure 19A).

C:CA ratio

Usually the C:CA ratio is estimated. Generally it varies from 1:1 to 1:3. The larger the planting pits and the wider the spacing, the more water can be harvested from the uncultivated area between the pits.

Ridge design

Designing the ridge of a planting pit is very simple. The ridge is formed by placing excavated earth from the planting pit immediately downslope of the pit.

Construction

1 It is not necessary to follow the contour line. The position of the pits is marked out with a string equal in length to the selected distance between pits + ½ the diameter of the pit. For example, if the pit has a diameter of 30 cm and the selected distance between the pits is 50 cm, the string needs to be 65 cm long. Tie a peg to both ends of the string, ensuring that the distance between the pegs remains the required length of the string, in the example 65 cm. Place one peg in the soil at the position of the first planting pit, and draw a circle around it with the other peg. Place the first peg on the circle (= the position of the second planting pit) and draw a second circle. Where the two circles cross each other planting pits four and five will be made. Mark out all the planting pits in this way.

2 Digging out the pits is the following step. Cut a stick so that its length is equal to the diameter of the planting pit, and another stick to the length of the depth required. These will assist the persons digging to make uniform pits. The excavated earth is placed immediately downslope of the pit to form a small bund.

Maintenance

In the second year, farmers may sow into the existing holes or, if spacing of the Zaï is large, they may dig new ones in between the existing ones. If the aim is to restore fertility of the whole field, it is advisable to dig new pits.

Planting procedure

Planting pits are dug in the dry season. In the dry season the pits trap litter and fine sand deposited by the wind. The pits are often filled with manure (e.g. compost, animal dung) mixed with earth. This attracts termites, which dig tunnels in the soil, transporting nutrients from deeper layers to the top and improving the infiltration capacity of the soil. After the first rains, cereals (e.g. sorghum, millet) are sown in the pits. Sometimes dry seeding is carried out (Chapter 10). Weeding is not necessary between the pits, because on these degraded soils natural vegetation is unlikely to grow again.

Variations

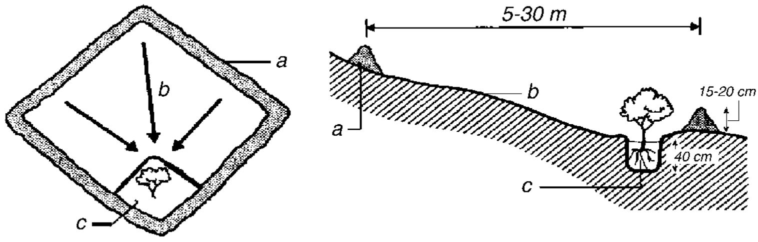
The Zaï technique is often combined with stone bunds along the contour line. The runoff water is slowed down by the stones, it spreads more evenly over the soil surface and then flows into the planting pits. Sometimes earthen bunds or grass strips are used in combination with Zaï for the same purpose.

6.2 Closed micro-catchments

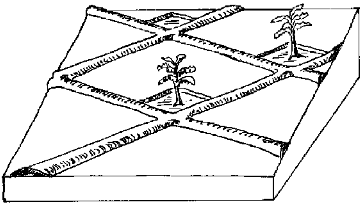
Background

Closed micro-catchments are square or diamond shaped basins surrounded by low earth ridges on <u>all</u> sides. These ridges keep rainfall and runoff in the mini-basin. Runoff water is channelled to the lowest point and stored in an infiltration pit. The structures are easily constructed by hand.

Figures 20 and 21 provide examples of closed micro-catchments, one on sloping land (Fig. 20) and the other on flat land (Fig. 21). Micro-catchments are mainly used for growing trees or bushes. This technique is appropriate for small-scale tree planting in any area with a moisture deficit. It also conserves the soil. In Israel micro-catchments are popular for growing fruit trees, the local name is 'Negarim'. Because this technique has proven to be successful and is easy to carry out, it is advisable to try it out before starting other - more difficult - techniques.



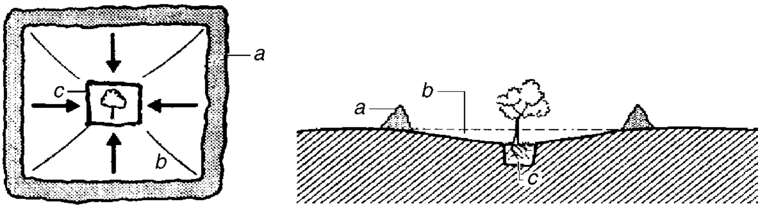
A: View from above. B: Cross-section.



a: earth ridge
b: catchment area, compacted and kept free of weeds
c: planting plot at lowest point, hoed and mulched
→: runoff

C: In perspective.

Figure 20: Closed micro-catchment on sloping land.



A: View from above. B: Cross-section.

a: earth ridge
b: catchment area, compacted and kept free of weeds
c: planting plot at lowest point, hoed and mulched
→: runoff

Figure 21: Closed micro-catchment on flat land.

Conditions

Rainfall: 150 mm per year and above.

Soil:	At least 1.5 m deep, preferably 2 m to ensure adequate root development and water storage capacity.
Slope:	From flat up to 5% but small micro-catchments can be constructed on steeper slopes.
Topography:	Does not need to be even. The micro-catchments divide an uneven slope into even, small slopes.

Constraints
Micro-catchments are easily constructed by hand, mechanized construction is difficult.

Size and layout
The size of a micro-catchment usually ranges between 10 m² and 100 m². Larger sizes are possible, in particular where more than one tree will be grown in one micro-catchment.
On flat land micro-catchments are larger, usually the mini-basins are 250 m² large and the planting plot within the catchment measures 3.5 m × 3.5 m. Ridges are 15 to 20 cm high. The planting plot usually is 40 cm to 1.5 m deep, depending on the depth of the soil.
If there is any risk of damage by runoff from above a block of micro-catchments, a diversion ditch (cutoff drain) has to be constructed.

C:CA ratio
The C:CA ratio is not usually calculated for this system. Average sizes are mentioned above. Take average rainfall and estimated water requirements of the trees in account to decide on the size of the micro-catchment.

Ridge design
The height of the earthen bunds depends on the slope gradient and the size of the micro-catchment.

Table 8: Bund heights (cm) for micro-catchments.

Basin size (m)	**Slope gradient**			
	2 %	**3 %**	**4 %**	**5 %**
3 × 3	25	25	25	625
4 × 4	25	25	25	30
5 × 5	25	25	30	35
6 × 6	25	25	35	45
8 × 8	25	35	45	55
10 × 10	30	45	55	n.r.
12 × 12	35	50	n.r.	n.r.
15 × 15	45	n.r.	n.r.	n.r.
n.r. = not recommended				

Table 8 gives recommended figures. The top of the bund is at least 25 cm wide with side slopes of at least 1:1, which gives bunds of 25 cm high a base width of at least 75 cm. Whenever possible grass is planted on the bunds. This provides good protection against erosion.

The infiltration pit is 40 cm deep. The excavated earth is used to make the two downslope bunds (the two up-slope bunds are made from the excavated earth from the neighbouring upslope infiltration pit). The infiltration pit is square and the size depends on how much earth is required to make the two downslope bunds. E.g. for a micro-catchment of 3 × 3 m, a pit of 1.4 × 1.4 m (40 cm deep) is needed; for one of 10 × 10 m, a pit of 2.5 × 2.5 m (40 cm deep) is needed. In the downslope corner of the infiltration pit, a planting step is left (Figure 22). This is where the seedling will be planted.

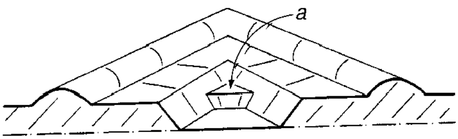
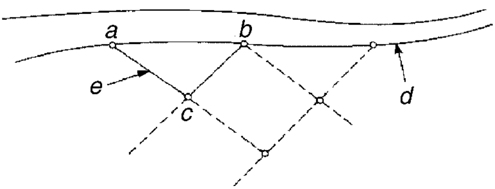


Figure 22: Closed micro-catchments: location of the planting step (a) (Critchley, 1991).

Construction

1 For a block of micro-catchments, first the upper contour line is found using a water tube-level. The contour line is adjusted to form a smooth, more or less straight line.

2 Measure the diagonal of the micro-catchments using a tape (Figure 23: a and b) mark it along the contour line.
3 Point [c] is found using two lengths of string. Each string is the same length as the side length of the micro-catchment. One string is held at point [a], the other at point [b]. Where the two strings meet, point [c] is marked out with a peg. The sides of the micro-catchment are marked out with a hoe. This procedure is repeated till all micro-catchments along the contour line have been marked out.



a-b: diagonal of the square basin
c: bottom corner of the basin
d: contour line
e: side dimension

Figure 23: Setting out micro-catchments (Critchley,1991).

4 The second line of micro-catchments is marked out using the same procedure, but using point [c] from the first line of micro-catchments. After this the third line is marked out and so on.
5 The infiltration pit is marked out in each micro-catchment and the pit is dug out, see under 'ridge design' and Figure 22.
6 Before the bunds are made, the micro-catchment is cleared of all vegetation. The bunds are constructed in two layers: the first layer, to half the height of the bund, which is than compacted, followed by the second half which is compacted again. A uniform bund height is obtained by fixing a string between two pegs at the ends of the bund and above the ground at the desired bund height.

Maintenance

Maintenance is the same as for all earthen bunds. Damage has to be repaired immediately and the micro-catchment must be kept clear of vegetation. Grass planted on the bunds is a good reinforcement.

Planting procedure

A tree seedling of at least 30 cm height is planted on the planting step immediately after the runoff has been harvested in the infiltration pit. It is recommended that a second seedling be planted in the bottom of the infiltration pit, in case it is a very dry year. Manure or compost can be applied to the infiltration pit to improve fertility and the water-holding capacity.

Variations

A common variation is to construct the micro-catchments as free-standing, open-ended structures with a 'V'-shape, or semi-circular shape (see next paragraph). The advantage of an open-ended bund is that excess water can flow around the tips of the bunds. However, the storage capacity is smaller than that of a closed system. Open-ended, free-standing structures are particularly useful on uneven terrain and for small numbers of trees around homesteads.

6.3 Semi-circular bunds

Background

Semi-circular bunds are earth bunds in the shape of a semi-circle with the tips of the bunds on the contour. Dimensions vary, from small structures with a radius of 2 m to very large structures with a radius of 30 m. Large semi-circular bunds are used for rangeland rehabilitation and fodder production; smaller semi-circular bunds for trees, shrubs and crops (Figure 24).

The advantages of these structures are that they are (i) easy to construct, (ii) labour efficient because a maximum enclosed area is obtained with a minimum of bund volume (thanks to the semi-circular shape), and (iii) suitable for uneven terrain because the structures are free-standing.

When used for tree growing, the runoff water is collected in an infiltration pit.

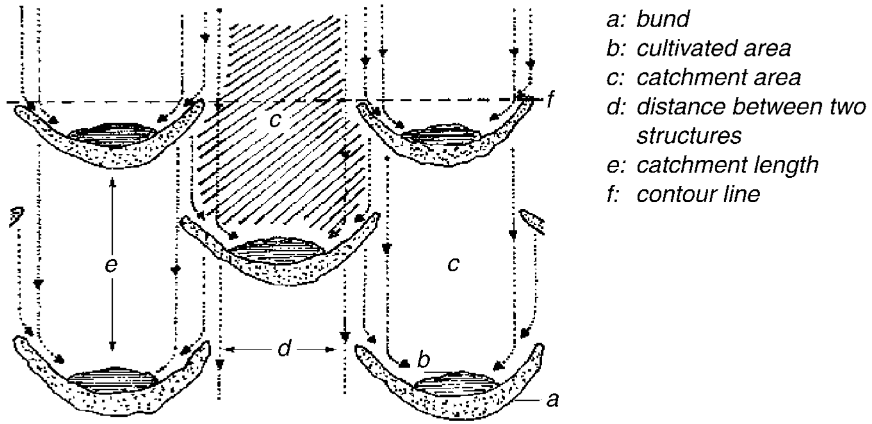


Figure 24: Layout of smaller semi-circular bunds

Conditions

Rainfall:	200 - 750 mm.
Soil:	All soils which are suitable for agricultural production. Deeper soils (1.5 m and deeper) are required for trees in order to allow for adequate root development.
Slope:	Preferably below 2%, but with increased bund height this system can be used on slopes up to 5%.
Topography:	For a staggered layout of the semi-circular bunds (Figure 24) an even terrain is required, but individual structures can be located in uneven terrain.

Constraints

Due to the the semi-circular form, mechanized construction is not easy.

Size and layout

The bunds are laid out in staggered rows, with their tips on the contour. A gap is left between two neighbouring structures so that runoff water can flow downslope to the next structure (Figure 24).
In larger structures stone spillways can be constructed in the bunds to cope with excess runoff from the slopes above (Fig.26). But, when

large amounts of runoff can be expected often, the structures have to be protected by digging a diversion ditch (see Chapter 4).

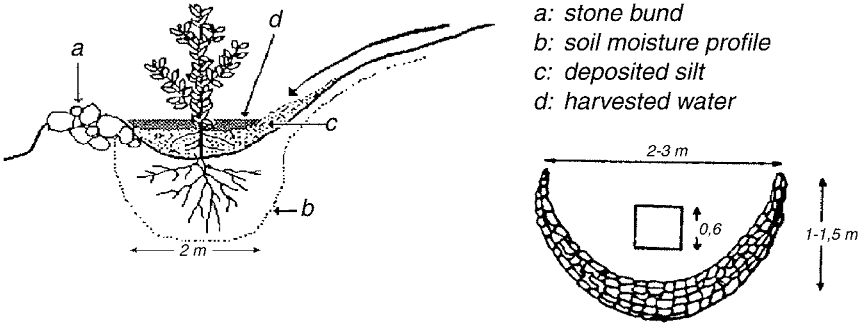


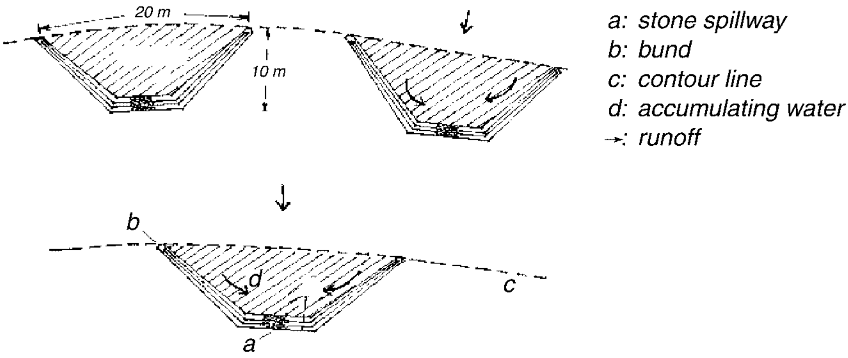
Figure 25: Smaller semi-circular bund seen in section and from above.

C:CA ratio

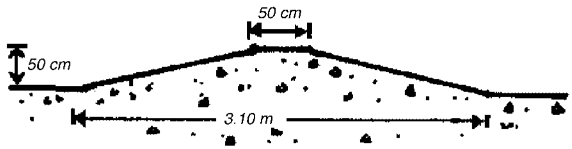
For crops the C:CA ratio can be calculated using the formula in Chapter 3. The size of the cultivated area is the area enclosed by the semi-circular bund and is equal to: $0.5 \times pi \times radius^2$ (pi=3,14).
The size of the catchment area is the distance [e] in Figure 24 multiplied by the distance between the tips of a bund.
For tree growing the runoff water is collected in an infiltration pit The total size of the micro-catchment is estimated on the basis of the tree water requirements.
For rangeland and fodder a C:CA ratio of 3:1 is generally sufficient.
To design a system:

1 Calculate the C:CA ratio, or estimate it, e.g. 3:1.
2 Select the size of the cultivated area, e.g. 10 m². The catchment area has to be 30 m² to obtain a C:CA ratio of 3:1.

The following dimensions are used for semi-circular bunds for crops in Ourihamiza, Niger: they are 2 m wide and are laid out at intervals of 4 m. Rows are spaced 4 m apart, leading to a density of 313 structures per ha and a C:CA ratio of 4:1.



A: Layout of larger structure



B: Cross-section of a larger bund (at the centre)

Figure 26: Layout of larger semi-circular structure and crossection of bund: the trapezoidal shape is a variation on the semi-circular shape.

Ridge design

For the smaller semi-circular bunds (up to a radius of about 6 m) the bunds have a minimum height of 25 cm and side slopes of 1:1 which gives a base width of 75 cm. For structures with a radius greater than 6 m, the tips of the bund start with a low height and gradually increase in height towards the 'bottom' of the structure. E.g., for a semi-circular bund with a radius of 20 m, the tips of the bund are only 10 cm high, which gradually increases to 50 cm at the 'bottom' of the bund. For these larger bunds a more gentle side slope is recommended, for example 3:1. This gives a 10 cm high bund a base width of 70 cm; a 50 cm high bund a base width of 3.10 m. See figure 26 B.

Construction

1 Start by marking out the contour lines on which the tips of the bunds will be located. The distance between the contour lines marked out depends on the size of the structures to be made. Because the structures are free standing, the contour lines need not to be smoothed.
2 Measure the distance between the tips of one structure on the highest contour line. Measure and mark out the distance from one tip to the next structure (on the same contour line), and again the distance between the tips of one structure. Mark out the tips of all the structures on the first contour line in this way. The tips on the second contour line are marked out following the same procedure, but in such a way that the centre point of the structure lies between the tips of two neighbouring structures on the first contour line. In this way a staggered layout is obtained.
3 Mark out the position of the bund of each structure using a string. The string has a length equal to the radius of the structure. Mark out the centre point (the point in the middle of the tips of one structure, on the contour line). Then, holding one end of the string at this point, mark out a half circle from one tip to the other, using the other end.
4 Dig out earth to build the bund from inside the enclosed area. Begin with a small trench, followed by even excavation from the whole enclosed area in order to ensure even distribution of the collected runoff water. It is important that the bunds are constructed in layers of 10-15 cm, compacting each before the next layer is placed on top of it.
5 For the larger structures (radius greater than 6 m) the tips of the bunds made with stones as protection against erosion. Grass planted on the bunds increases the stability.

Maintenance

The critical period is during the first rainstorms after construction. Any breakages must be repaired immediately. If the damage is widespread, a diversion ditch must be dug above the whole system, if this is not already in place. If erosion occurs at the tips of the bunds, the tips can be protected with stones. The structures have to be dug out again after five years. Deposited silt and earth have to be regularly removed from around trees. The catchment area should be kept clear of vegetation.

Planting procedure

The entire enclosed area is planted. When used for rangeland rehabilitation or fodder, trees or shrubs can be planted at the lowest point of the cultivated area. You discover the most by trying out.

Variations

Variations are possible, not only by varying the size of the cultivated area (the radius of the bund) and the location of the individual structures, but also by varying the shape of the bund. 'V'-shaped bunds were already mentioned in the preceding paragraph on closed microcatchments.

Part II: Soil moisture retention

In this second part soil moisture retention techniques to be applied in the cultivated area are described. A distinction is also made here between systems which follow the contour lines of a slope and those which are independent of contour lines. Chapter 7 deals with contour systems to improve infiltration. Chapters 8 and 9 describe water conservation measures, which are not necessarily contour-bound.

7 Contour systems to improve infiltration

Contour farming is a term used to include ploughing, furrowing and planting along the contours of a hill side. The objective of contour farming is to increase infiltration into the soil along the contours and to conserve soil moisture there. Contour farming may reduce runoff and soil erosion by as much as 50%.
The first step in contour farming is to determine a contour guide line. One method for marking out contour lines, the water tube-level, is described in Appendix 3. Several other techniques are described in Agrodok No.6 'Field surveying'.
All subsequent water conservation measures are related to the contour guide lines. Hedges, shrubs or stones may be used to mark these lines. In small fields or on even slopes one guide line may be sufficient. This line should lie about halfway up the slope. On irregular slopes, or in large fields, more guide lines are necessary. In this case the various contour lines should be evenly distributed over the slope.

7.1 Contour ploughing

Contour ploughing ensures that rainfall and runoff water are spread evenly over a field by making furrows parallel to the contours.

Conditions

Contour ploughing may be done on slopes with a gradient of less than 10%. On steeper slopes it is better to combine contour ploughing with other measures such as terracing or strip cropping.

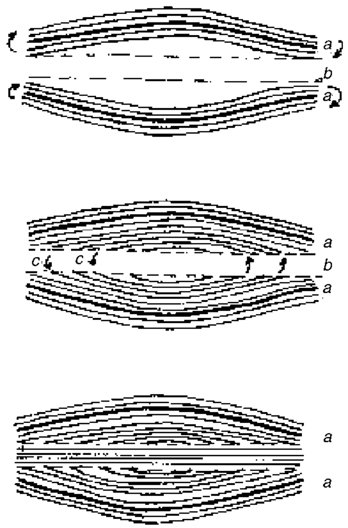
Contour ploughing is practical on fields with an even slope. On very irregular slopes it is too time-consuming to follow the contours when ploughing. Strip cropping (see next paragraph) is then often more effective.

Contour ploughing can be risky when the soil takes up water only slowly (e.g. soils with a high clay content, with impermeable layers or shallow soils). Furrows should not be longer than 100 m and, if they are graded, the slope should be less than 1%.

Procedure

After laying out a contour line, plough the first row along this line. On an irregular slope and other slopes where several guide lines are laid out, ploughing follows the pattern shown in Figure 27.

- Plough parallel to each contour guide line, always taking the nearest contour guide line as a reference point.
- Plough shorter rows each time, leaving a rectangular strip in the middle to turn around. The most suitable number of long rows is 4 to 6 on steep ground, 7 to 10 on more gradual slopes.
- Finally, plough the space used for turning, in straight lines.



a: contour guide line
b: space used for turning
c: turning direction

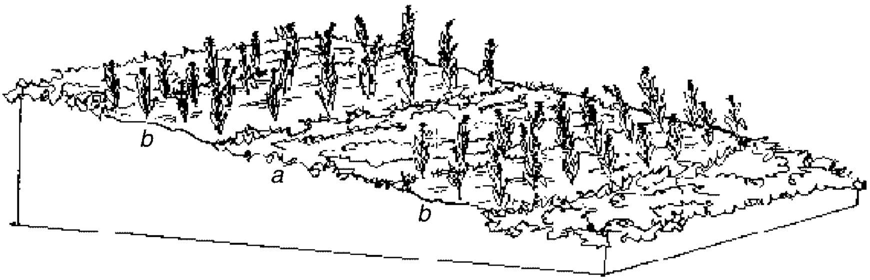
Figure 27: How to plough on a field with several contour guide lines.

Existing gullies on slopes are better left unploughed, because soil erosion might be encouraged otherwise. It is often necessary to construct a spillway to enable excess water to be shed safely.

Furrows may be laid out at a slight angle, e.g. a gradient of 1%, so that runoff water can be collected in a discharge drain. If slopes are less than 15%, simple grassed channels are sufficient, but on steeper slopes more sophisticated structures are required, e.g. a lock-and-spill drain (see Appendix 1).

7.2 Strip cropping

Strip cropping means cultivating different types of crops in strips following the contours (Figure 28). Generally a good ground cover crop is alternated with a crop that provides little ground cover. The ground cover strip slows down the flow of rainwater down the slope and prevents it from washing away valuable topsoil. The water can then be used by the (exposed) crops in the next strip. By tilling only the strips that are to be planted, the farmer saves labour. Strip cropping differs from vegetation strips in that vegetation strips are narrower and permanent, while crops are often rotated in strip cropping.



a: "buffer" strip with crop providing good ground cover
b: strip with arable crop providing little ground cover and/or with different nutrient requirements

Figure 28: Strip cropping.

Conditions
Strip cropping is usually applied to slopes not steep enough to warrant terracing. On its own it can be carried out on slopes with a gradient of up to 5%. If the gradient of the slope is steeper, strip cropping should be combined with other measures such as (tied-)ridging and mulching. On soils where infiltration is difficult (clay soils and soils with a crust), it is better to combine strip cropping with ridging.

Selection of crops
The success of strip cropping depends on careful choice of crops. As far as possible they should not compete with each other for water and nutrients. It is useful to combine crops that differ in their ground coverage, and which have different growth cycles. In this way their peak water requirements and harvest periods will come at different times. Combinations of grasses and legumes are common, as well as of cereals and creeping legumes, e.g. millet and groundnuts (Figure 28). An advantage of many legumes is that they fix nitrogen, which may improve overall fertility of the soil.

Layout
The width of the strips depends on the slope gradient and the infiltration capacity of the soil. Table 9 below gives guidelines for the width of strips on reasonably permeable soils (i.e. soils which are not clayey).

Table 9: Strip cropping: relation between width and slope.

Slope gradient	Width of strip
0-2%	40-50 m
2-4%	30-40 m
> 4%	15-30 m
in very humid climates	10-30 m

Where machinery is used, the width of the strips depends on the size of the machinery. The width of the strip will be an exact multiplication of the width of the machines. If slopes are irregular, the strips with arable crops are kept the same width, while the irregularities of the slope are corrected in the "buffer" strips (the strips with grasses, cover crops, etc.).

Maintenance

Grass strips have to be cut back periodically. The strips with arable crops and those with grasses or cover crops can be rotated to maintain fertility of the soil and to combat pests and weeds.

7.3 Ridging and tied-ridging

Ridging is done by constructing small earth banks parallel to the contours of a slope. The water accumulates above the ridges and is thus allowed to infiltrate into the soil. An alternative to ridges is the construction of small earth mounds.

Conditions

This method of soil moisture conservation is used on slopes with a gradient of up to 7%. Soils should have a relatively stable structure, otherwise the ridges become undermined by runoff and will be destroyed. Ridging requires more labour and capital investment than strip cropping.

Size and shape

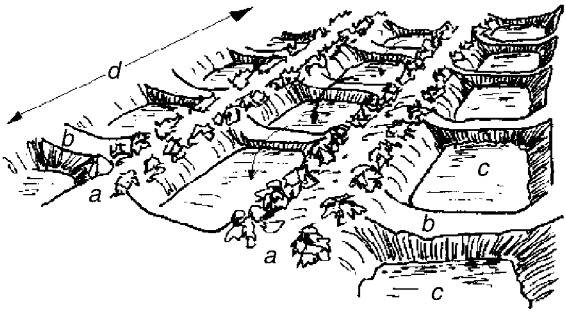
The height of the ridges is usually 20-30 cm. The ridges are as wide as the furrows. The distance between ridges varies from 1.5 to 10 m, and depends on the crop grown, the steepness of the slope and the climate. The distance between ridges can be larger, if combined with strip cropping.

In areas with heavy rainfall, there is a risk of crops becoming waterlogged or the ridges being washed away. This can be prevented by making the ridges sloping a little downwards, at a slight angle to the contour line. In this way the water can be diverted into a drainage channel.

Tied-ridging

A variation on ridging is the partitioned furrow technique, better known as tied-ridging. In this system lower ridges, cross-ties

(15-20 cm high), are made every few metres across the contour furrows, creating mini-basins (Figure 29). In case of light rainfall, the water remains in the mini-basins. When rainfall is heavy, the water runs off over the cross-ties along the contour, because the cross-ties are lower than the ridges and the furrows are built at an angle to the contour. Thus overtopping, i.e. excess water flowing over the ridges, is prevented. The cross-ties reduce the speed of the water flow.



a: ridge
b: cross-tie
c: mini-basin with infiltrating water
d: contour line
→: direction of water flow

Figure 29: Tied-ridging with ridges built at a slight angle to the contour line.

Conditions

Tied-ridging can be used only where rainfall does not exceed the storage capacity of the furrows; otherwise severe erosion may be the result. Tied-ridging is more successful on coarser soils (more sandy), which are less prone to waterlogging, for example on alfisols in the Sudano-Sahelian tropics. Vertisols, black soils with a high clay content, give better overall production yields where broad-bed and furrow techniques are used (see next paragraph).

Planting configuration

Seeds or tubers are placed either near the top of the ridge (to avoid water logging) or towards the bottom of the basin where rainfall and/or soil moisture are limited. The most appropriate site for planting also depends on the water requirements of the crop.

Maintenance

The construction and maintenance of ridges is hard work, especially on heavy (clayey) soil. In order to spread the work out, in the first year the contour ridges can be ploughed using an ox-plough or tractor-drawn implement with a reversible blade, and the cross-ties can be made by hand. Ploughing and ridge making only have to be repeated once every four or five years. This makes total labour input sufficiently low.

7.4 Broad-bed and furrow

The purpose of a broad-bed and furrow system is to increase the amount of water that infiltrates into the soil and that is stored in both bed and furrow. It also makes heavy soils more workable by improving drainage and extending the time of infiltration. When rainfall is very heavy, the (grassed) furrows carry runoff water away, because they slope down with a slight gradient. Another advantage of a broad-bed and furrow system is that it makes mixed cropping or intercropping possible.

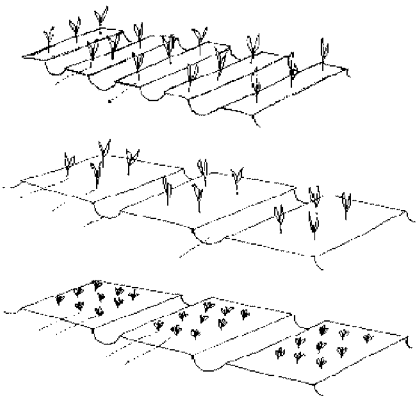
Conditions

This system is mostly used in areas with intense rainfall (a yearly average of 750 mm or more) and on black clay soils (vertisols), where water infiltration is very low. These soils are deep and have a large water storage capacity. Gently sloping land (0.5-3%) is most appropriate. The system is not suitable for red soils (alfisols) or shallower soils.

Size and shape

The broad-bed and furrow system consists of broad beds of approximately 100 cm wide, separated by furrows of about 50 cm wide (Figure 30). Bed width and planting configuration vary according to the cultivation and planting equipment available. Two to four rows of crops are usually planted on one bed. Animal-drawn equipment (a bullock-drawn moulder) can be used to make the beds.

Figure 30 shows a narrow bed and furrow and two variations of a broad-bed and furrow. It is clear that the broad-bed and furrow system makes it possible to combine different crops and planting densities. Planting is carried out in 2, 3 or 4 rows with 75 cm, 45 cm or 30 cm row spacing, respectively. Figure 30A shows a maize crop in a narrow ridge and furrow system (planting distance 75 cm). Figure 30B gives an example of a broad-bed and furrow using the same crop and planting distance. Figure 30C shows a combination of maize and pigeon pea, with a planting distance of 45 cm.
The furrows are often planted with grasses to avoid soil erosion and they slope down at an angle of between 0.4% and 0.8% along their length, depending on the gradient of the slope.



A: Maize in a narrow bed and furrow system

B: Single cropping of maize in a broad-bed and furrow system

C: Intercropping of maize and pigeon pea in a broad-bed and furrow system.

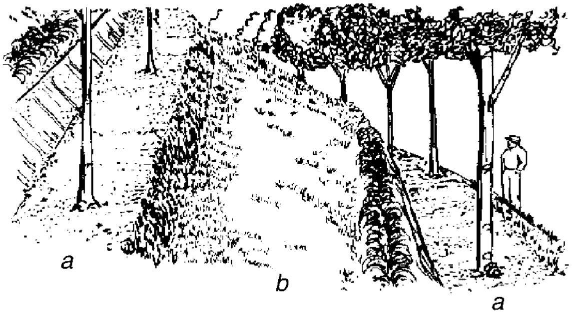
Figure 30: Broad-bed and furrow system using combinations of different crops and different planting densities.

8 Measures to improve infiltration and water storage

Infiltration of water into a soil is improved by making the soil structure looser and the top layer more rough. This can be achieved through the use of cover crops or mulching and tillage. These three measures are described here.

8.1 Cover crops

Cover crops are usually creeping legumes which cover the ground surface between a widely spaced perennial crop, such as young fruit trees, coffee, cacao and oil palms. Cover crops are often combined with mulching. Grass is also used as ground cover between orchard terraces, i.e. narrow terraces for fruit trees, with intermittent uncultivated strips (Figure 31).



a: orchard terrace, planted with fruit trees
b: intermittent terrace covered with grasses

Figure 31: The use of cover crops on terraces.

Cover crops protect the soil from splashing raindrops and too much heat from the sun. They build up organic matter in the soil, they improve soil structure and they may increase soil fertility through nitrogen fixation. Cover crops also suppress weed growth.

Conditions

Cover crops are not very suitable for areas where average annual rainfall is less than 500 mm because competition with the main crop for water might occur. In these areas it may be better to let the weeds stand, provided they do not overrun the main crop.
Legumes are fairly susceptible to disease and often need to be fertilized with phosphorus.

Layout

Cover crops may either cover the whole area between fruit trees (overall covering), or they may be grown in strips (strip covering) between the tree rows. Strip covering is better for young trees. Figure 32 provides examples of both overall covering and strip covering by cover crops combined with mulching.

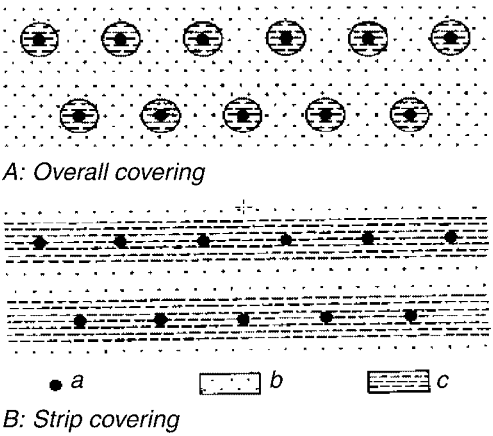


Figure 32: A combination of cover crops and mulching.

Criteria for selecting a cover crop:
1 Easily propagated by seed.
2 Grows rapidly without competing with the main crop.
3 Tolerates some shade and cutting back around the crop.
4 Does not act as a host to pests and diseases attacking the main crop. This risk can be limited by choosing crops from different families.
5 Suppresses weed growth.

6 Has additional productive functions as food (e.g. groundnuts, beans), animal feed, mulch, etc.

Some cover crops are drought resistant, e.g. Centrosema pubescens, Pueraria phaseoloides, Stylosanthes gracilis. Some legumes are also effective pesticides (e.g. Tephrosia candida).

8.2 Mulching

Mulching is done by covering the soil between crop rows or around trees with grass, straw, crop residues or other plant material. When crop residues are left on and in the soil after harvesting, this is called stubble mulching.
The mulch layer is rougher than the surface of the soil and thus inhibits runoff. The layer of plant material protects the soil from splash erosion and prevents the formation of a crust. Where soil is covered by a mulch layer, evaporation is reduced, because the upward movement of soil moisture is hampered. Another effect of a mulch layer is that soil temperature is kept constant, which means that more micro-organisms survive the dry period. Finally, weed growth is also kept down by mulching. Surface rooting crops benefit particularly from mulching, as their roots are found in the partly decomposed layer between soil and mulch.

Conditions

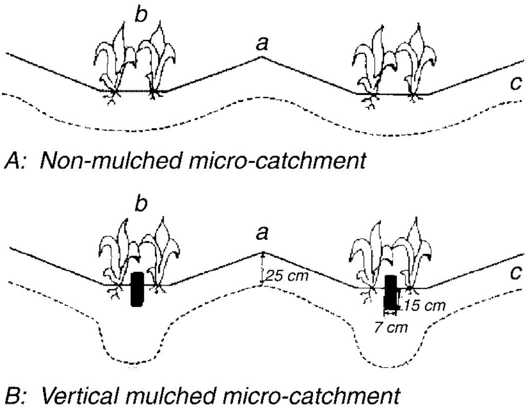
The soils should have good drainage. Areas with marginal rainfall usually respond better to mulching with dead organic material than to cover crops, because mulch does not compete for water and nutrients.

Layout

Mulch can be spread on a seedbed or around planting holes. This is a good practice for trees and crops which require watering. In Senegal mulching of planting holes reduced the watering requirements of tomatoes from once a day to once every three days.
Mulch can also be applied in strips (Figure 32). Alternative row mulching is sometimes preferred to full mulching, because it reduces

the fire risk. The layer should not be too thick; otherwise the soil underneath heats up.
Use a mixture of fast and slow decomposing material. Break or cut large pieces of crop residue before application. Cover crops or grasses in orchards are a readily available source of mulch material. Grass for mulching should be allowed to dry before applying as this not only reduces the weight to be carried, but also the chance of the grass rooting. The mulch may be covered with a layer of soil to protect it against wind. During sowing or planting the mulch is lifted to one side and the planting hole is covered afterwards.

A variation of this technique, used in combination with micro-catchments or tied-ridging, is *vertical mulching*. Straw or stubble are buried in a narrow trench in the topsoil, at the spot of water concentration and in contact with the air (Figure 33). This enables water to be rapidly channelled into the soil by providing slots which are open to the air. Tillage should be avoided.



a: catchment area
b: cultivated area
c: soil moisture profile
d: mulch material buried in the topsoil, in contact with the air

Figure 33: Vertical mulching

Constraints

- Mulching requires a large amount of plant remains, not always available to small-scale farmers in dry areas. Mulch is most effective if applied at the start of the rains, as it intercepts and increases water take-up, but it is frequently more practical to mulch towards the end of the rains when grass is available. In addition, organic mulches decompose rapidly in high temperature climates.

- The constant soil temperature and humidity may enable diseases and pests to survive from one rainy season to the next.
- Mulching of dried grasses may be a fire hazard. This can be reduced by working the mulch into the soil, by alternative row mulching or by making fire pathways around the field.
- In some countries it is customary to burn crop remains just before the rainy season starts. This releases large amounts of nutrients that are available at once for the next crop. When crop remains are used for mulching, these nutrients are released more slowly, so that more manure or fertilizer has to be applied.

8.3 Tillage

There is much discussion about the effect of tillage on soil moisture conservation. Tillage is good for water infiltration and root penetration, as the soil is worked into clods. However, this is only true for stable soils. If the soil is less stable, the clods will disappear rapidly when it rains.

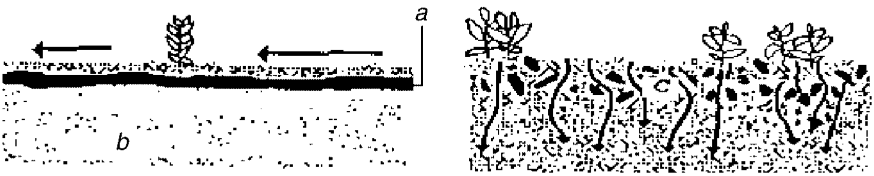
Tillage is required on badly degraded soils or for those that undergo severe hardening during the dry season. Deep tillage (disturbing the soil below 10 cm) has proven beneficial on dense sandy soils in Botswana.

However, repeated cultivation to the same depth may cause a compacted soil layer to form at the bottom of the tilled layer (called a 'plough-pan', or 'hoe-pan' etc.). Plant roots cannot penetrate into this layer and the water storage capacity of the soil is reduced.

In this case, when the clogged layer is several tens of centimetres below the surface, subsoiling is necessary to increase infiltration (Figure 34B).

Some soils become crusted over on the surface when it rains, especially soils containing much clay and silt. This leads to a low infiltration rate and a high rate of runoff.

In this case, with crusted soils, when the soil pores are clogged in the first few millimetres or centimetres, hoeing or superficial ploughing is sufficient to break up the crust and let the water infiltrate (Figure 34A).



A: Superficially crusted soil is broken up by hoeing.

B: Soil compacted in depth is broken up by subsoiling.

a: clogged soil layer
b: dry soil
c: hard crust or clogged layer is broken up
d: water accumulates here

Figure 34: Breaking up clogged soil layers.

Constraints of tillage:

- It can encourage soil erosion and more rapid decay of soil organic matter.
- It may allow more moisture to escape through evaporation.

8.4 Minimum-tillage and zero-tillage

In some situations it may be better to confine soil tillage to a minimum (minimum-tillage) by leaving the stubble after harvesting and only ploughing just before the next crop is planted or sown. It is also possible not to plough at all, but just to make holes to plant the following crop (zero-tillage). Both limit runoff and prevent loose soil material from forming a crust. Moreover they are labour-saving, increase soil organic matter and prevent erosion.

Conditions

Soils should not be susceptible to compaction or crusting. They should be well draining (i.e. not too clayey), have high biological activity, a crumbly consistency and a coarse surface.

Constraints

- The existing vegetation may compete with the crops for water and nutrients.
- These systems often lead to a weed problem.
- Insects may thrive in plant residues.

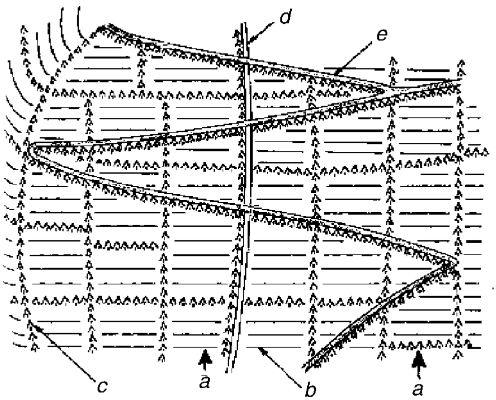
9 Reducing evaporation losses and optimizing the use of soil moisture

9.1 Windbreaks

Windbreaks can be non-living structures such as brushwood and woven palm-frond fences or living hedges such as lines of shrubs, trees or tall grasses. In areas prone to wind they give shelter to crops and *reduce evaporation* of soil moisture because wind low to the ground is prevented. On slopes or fields affected by strong wind, live hedges or windbreaks are effective.
In addition they reduce the speed of run-off and they (living fences) provide organic material to the soil through their leaves. Their roots open up the soil which improves infiltration.

Siting

Windbreaks and live hedges have to be sited at right angles to the most damaging winds (Figure 35). When windbreaks are planted across a hill side, they should follow the contour lines.



a: direction of most damaging wind
b: crop land
c: windbreak
d: drainage channel
e: farm road

Figure 35: Siting of windbreaks.

Planting procedure

Two examples will be given: *Acacia spp.* and *Napier grass*.

- *Acacia spp.* may be established from seeds or seedlings. Seeds are sown in strips or hills. These are spaced at a distance of 0.5 to 1 m within a row, the rows being 1 m apart.
- *Napier grass* is planted by cuttings, in hills which are spaced 20-30 cm apart. The rows are 30-50 cm from each other.

  When you want to set up a tree windbreak, grass strips can be planted on the windward side of the trees in order to protect the tree-seedlings against the wind. Grasses may be retained as ground cover, once the trees are fully grown. Trees with little undergrowth can also be reinforced with loose branches near the ground. Windbreaks should not be too windproof, otherwise damaging whirlwinds may form on the lee side.

Suitable species for windbreaks

Deep rooting species are suitable for windbreaks, because they do not compete for moisture with nearby crops. The use of trees with high evapotranspiration (like eucalyptus) should be avoided. Different types of Acacia and Prosopis give a good windbreak after four or five years. Napier grass is a grass commonly used as windbreak.

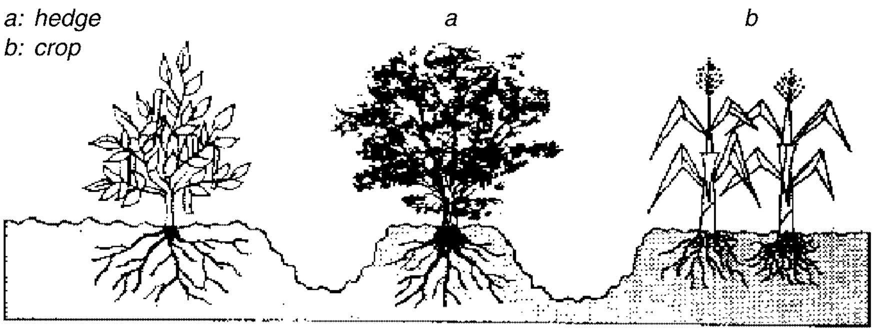


Figure 36: A ditch between hedge and crop to avoid root interference.

Maintenance

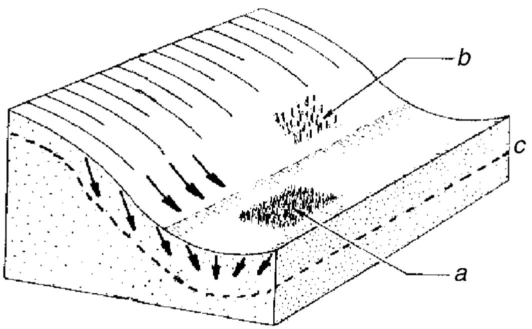
Live hedges have to be regularly pruned to force them to thicken at the base. Prunings can be used as mulch or animal feed. Roots of shrubs and trees can also be trained to grow deeper by regular trimming. Competition in the root zone between hedge and crop can be reduced by digging a ditch between them to force the shrub to grow deeper (Figure 36).

Constraints

- Live windbreaks have to be protected for approximately three years against animals and humans.
- Some species (e.g. *Euphorbia balsimifera*) may provide a shelter to rodents and snakes.
- There is a risk that plant diseases and pests will survive in the living plants of the windbreak during the period in which the crop is not on the fields.

9.2 Dry and sparse seeding

Dry seeding, i.e. sowing in advance of seasonal and unreliable rains, is a widespread means of making the best use of available moisture. It may even be necessary on soils that become difficult to work when wet. There is a risk of premature germination before enough rain falls.



a: crop planted at a density of: 90-120 plants/m²
b: crop planted at a density of: 70-90 plants/m²
c: soil moisture profile

Figure 37: Plant density adapted to moisture availability.

Sparse seeding means that planting or sowing density is adapted to the availability of water at a certain site. It optimizes soil moisture use by giving each plant room to spread its roots and collect moisture. In Morocco farmers traditionally use this principle when planting. In Figure 37 the crop in the furrow or depression is planted at a higher density than the crop planted on the ridge or bank.

9.3 Fallow

Leaving soil fallow means that the land is left uncultivated for a season or for one or more years. Weeds are removed. A fallow period may restore the availability of water in the root zone, as well as soil fertility. The top layer dries out, but subsoil moisture is conserved. More water will then be available for the next crop grown on the soil.

Conditions

Fallow is a suitable practice for some semi-arid areas, but not all. It is particularly useful on cracking clay soils. In areas with more than 500 mm rainfall the usefulness of fallow is subject to debate, as soils cannot hold that much water in their root zone.

Procedure

Fallow is often part of a rotation scheme. It may be best incorporated in a system of sequences of short and long-growth cycle crops and fallow periods. Nitrogen-fixing leguminous shrubs (e.g. *Stylosanthes*), and trees like *Acacia senegal* (gum arabic) are sometimes used to improve fallow land, alternated with periodic crops of millet, sorghum or pulses.

Constraints

The risk of soil erosion is higher on land left fallow, especially on sloping land and where rainfall is heavy. It is therefore advisable to mulch land left fallow.

9.4 Relay cropping and inter-cropping

Relay cropping means that new a crop is planted or sown before the previous one is harvested. This can provide advantages for both crops as one of them may provide nitrogen, shade, support or may discourage pests. Care is needed to ensure that appropriate combinations are selected. Some crops are for example sensitive to shading in their early growth stages.

Mixed cropping

Intercropping or mixed cropping refers to growing a mixture of two or more crops or varieties of one crop at the same time. These crops or varieties have different characteristics, which make them attractive to cultivate together. For example one crop is known to provide high yields, while the other gives lower yields, but is better resistant to drought (or to certain diseases and pests). The latter may provide some harvest if rains are poor, the first maximizes crop yields if there are good rains.
Arable crops may also be interplanted with perennials like trees (agroforestry), shrubs and grasses. Information on this topic can be found in Agrodok No.16 'Agroforestry'.

Intercropping has several advantages, especially to small farmers:

- It allows for a mid-season change of plan according to the amount of rain in the early part of the season.
- A combination of legumes and cereals may increase the nitrogen status of the soil.
- Plants with different rooting patterns (vertical as well as horizontal) need not compete for nutrients and water, as they can take them up from different soil layers. Deeper rooting species may pump up nutrients and make them available to shallower rooting species, when their leaves fall or if their prunings are used as mulch.
- It spreads labour requirements for planting and harvesting.
- Higher yields per unit area are obtained as a result of higher growth rates, fewer losses due to diseases, insects, and weeds, and more efficient use of water, light and nutrients.

- Lower farming risks. The failure of one crop may be compensated for by other crops.
- Soil is less prone to soil erosion, because it is almost continuously covered, especially when perennials are used.

Constraints

- In semi-arid areas nitrogen fixation by leguminous trees and shrubs seems to be low and roots develop horizontally instead of vertically where only a superficial zone is wet by rain.
- Spraying of one crop is difficult.
- Mechanical harvesting is impossible.
- Tillage is difficult. This problem can be overcome by interplanting in rows.

9.5 An example of an integrated contour farming system: SALT

In the Philippines a contour farming system called Sloping Agricultural Land Technology (SALT) has been developed at the Mindanao Baptist Rural Life Centre. It is a way of turning an eroded sloping piece of land into a productive upland farm. Different measures and techniques of soil moisture conservation, described in the previous sections, are combined in SALT. It has the potential to increase a farmer's annual income almost threefold after only five years. It is a system tailored to small family farms which grow both annual food crops and perennial crops.

It involves the following 8 steps, shown in Figure 38:

1. Locate the contour lines and cultivate the ground along them, 4-6 m apart on steep hills and 7-10 m apart on more gradual slopes.
2. Plant nitrogen-fixing shrubs and fodder trees as double hedgerows in two furrows 50 cm apart along each contour line.
3. Cultivate alternate strips between the hedgerows before they are fully grown (thereafter, every strip is cultivated).
4. Cultivate and plant perennial crops (e.g. coffee, cocoa, citrus) in every third or fourth strip.

5 Plant short- and medium-term crops (e.g. maize, mungo, sorghum, upland rice, pineapple, sweet potato) between strips of perennial crops as sources of food and regular income.
6 Trim the hedgerows down to 1 m above ground and use the trimmings as organic manure.
7 Rotate the annual crops to maintain productivity, fertility and good soil formation.
8 Build green terraces by piling stalks, leaves and stones at the base of hedgerows to capture and enrich the soil.

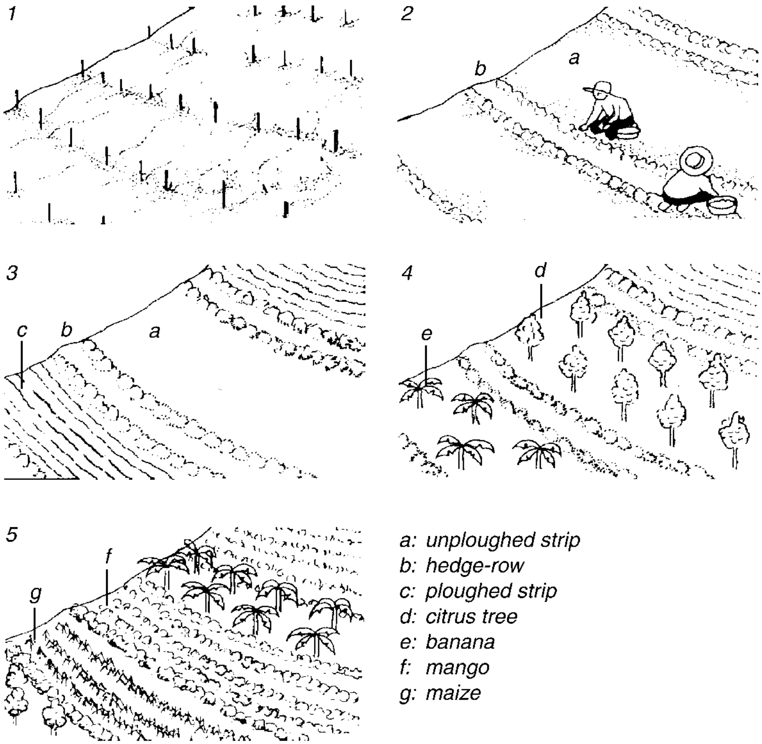


Figure 38: Contour farming according to the Sloping Agricultural Land Technology (SALT).

Glossary

Agro-forestry. The use of woody perennials (trees, shrubs, etc.) on the same land as arable corps, pasture and/or animals, either mixed in the same place at the same time, or in a sequence over time.

Alfisols. Grey, brown or red soils of humid and sub-humid climates, with a white clay layer, agriculturally fairly productive.

Arid. Very dry climate with less than 300 mm average annual rainfall, where cropping is possible only with support of water harvesting or irrigation.

Base-flow. That portion of the discharge of a stream contributed by ground water seepage and interflow.

Contour (line). An imaginary line joining all points of the same height on a land surface, see also Appendix 3.

Cut-off drain. A ditch made to protect cultivated land from external runoff, normally with a gradient of 0.25-0.5%, also called diversion ditch.

Deep percolation. Downward movement of water below the root zone under the force of gravity, eventually arriving at the water table.

Depression storage. Temporary holding of rainfall in hollows and surface depressions.

Ephemeral stream. Flow which occurs for short duration, often in torrents, in a normally dry watercourse.

Evaporation. Process in which water passes from the liquid state into the vapour state.

Floodwater harvesting. A water harvesting system using a stream flow as its source of runoff. C:CA ratios very large.

Horizontal interval. The horizontal distance between two structures.

Infiltration. Absorption and downward movement of rainfall into the soil.

Infiltration capacity. Limiting rate at which falling rain can be absorbed by a soil surface in the process of infiltration.

Interception. Catching and holding of rainfall above the ground surface by leaves and stems of plants.

Interflow. Movement of soil water through a permeable layer in a downslope direction parallel with the ground surface, also called throughflow.

Lock-and-spill drain. Discharge channel with small cross-barriers to reduce the speed of the water flow.

Nitrogen-fixing. The ability of certain small organisms (bacteria, algae) to convert atmospheric nitrogen (a plant nutrient) into a form which can be used by plants. These organisms live near the roots of legumes.

Overland flow. Water flowing over a sloping ground surface to join a stream flow: a form of runoff.

Overtopping. Water flowing over the top of a bund or ridge, leading to erosion.

Perennial (crop). A plant that lives for three or more years and which normally flowers and fruits at least in its second and subsequent years.

Sealing. When soil forms a sort of clay cement after rain, because the finest grains work their way into the soil pores. Also called clogging up.

Semi-arid. Fairly dry climate with average annual rainfall of about 300-700 mm, with high variability in rainfall.

Slope gradient. The angle of inclination of a slope, which may be expressed in degrees or as a percentage (see Appendix 3).

Soil moisture. Water held in the soil and available to plants through their root system, also called soil water.

Soil moisture profile. The depth to which water infiltrates into the soil, also called infiltration boundary.

Spillway. An outlet allowing overflow of excess runoff.

Splash erosion. Soil erosion caused by the direct impact of falling raindrops on a wet soil.

Stoloniferous. Plant which reproduces by putting down runners, e.g. grasses.

Stream flow. Water flow in a stream channel, e.g. a river.

Sub-humid. A humid climate with average annual rainfall of roughly 700-1000 mm.

Surface runoff. See runoff.

Transpiration. Loss of water to the air from small openings in the leaves of plants.

Vertical distance. Spacing between two structures determined on the basis of a fixed difference in ground elevation, also referred to as vertical interval.

Vertisols. Black (sub)tropical soils with a high clay content, developing deep, wide cracks when dry and difficult to till when wet.

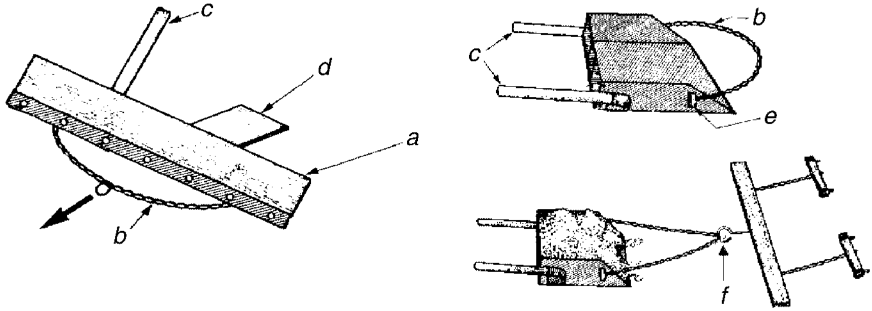
Water table. Upper limit of the ground water.

Water storage capacity. Maximum capacity of soil to hold water against the pull of gravity, also called field capacity.

Appendix 1: Ridging equipment drawn by animals

A mouldboard is a type of plough, which turns over the soil, thus burying surface weeds and trash. The basic type is designed to turn the furrow to the right. In small areas or where a level surface is important, a reversible plough, which has either a right- and a left-hand mouldboard or a reversible mouldboard, is more convenient.

Where a single ridge is required, a bund former can be used, which moves soil to the centre thus forming a ridge or bund. In Turkana, Kenya, animal-drawn scraper boards are used for levelling, and scoops for bund construction (Figure 39). Animal-draught power ensures that bunds are well compacted.



A: Scraper board.

B: Simple earth scoop.

a: board with metal strip joined with bolts
b: chain to tie it to animals
c: handle
d: runner (stage)
e: scoop made of an old oil drum, with bolted wood to hold chain and cutting edge in front
f: swingletree, whiffletree or whippletree

Figure 39: Equipment for levelling and bund construction.

Appendix 2: Height measurements and staking out contour lines

Several methods for surveying contours and measuring height differences exist. They are all described in detail in Agrodok No.6: 'Field surveying'. The line-level is commonly used in East Africa and the water tube-level is often used for water harvesting systems in West Africa. Here the use of the water tube-level will be described, because it is an easy-to-manage and low-cost instrument.

In order to benefit most from the water tube level, observe the following rules:

1 Work while it is cool. Heat causes the tubes to stretch.
2 Refill the water when it spills or when evaporation is high, otherwise the instrument becomes less accurate.
3 Make sure the poles are held vertically.
4 Do not put the poles in hollows or on lumps in the field.

Measuring height differences

A water tube-level is shown in Figure 40A. It consists of:

- At least 20 m of transparent plastic pipe, with an inside diameter of 6-10 mm. The longer the tube, the fewer measurements need to be made.
- Two poles of 1.5 to 2.0 m length. Each pole has a scale on it, marked out in centimetres. A guide mark is made on each pole at 1.5 m height.
- Four rubber straps, wire or twine to attach the pipe to the poles.
- Two tins filled with cement or chopped wood to be used as a base for the poles.
- At least 2 litres of water.

The plastic pipe is tied to the two poles, which are put into the tins. The tube is filled with water by sucking one end of the tube with the other end dipped in water, until the water level reaches the guide mark on the pole at 1.5 m.

The water level in both ends of the tube remains the same, as long as they are standing on two points at the same level. However, when Pole 2 is placed lower down a slope, the water in the tube of Pole 1 will fall, and the water in the tube of Pole 2 will rise (Figure 40B). The difference in height between the two points on the ground is equal to the sum of the drop in water level at Pole 1 and the rise in water level at Pole 2. In the example given in Figure 40B this is 15 + 15 = 30 cm. N.B. If the water tube level is well managed, it is sufficient to note only the difference between the water level and the guide mark on one pole and multiply the result by two.

Usually a slope is too long to measure the difference in height with a water tube level in one step. If this is the case, the following steps have to be taken. Begin as in the example above. After calculating the height difference between the first two points, move Pole 2 down the slope to a position lower than Pole 1. The height difference between Poles 1 and 2 should be measured and recorded. Repeat these steps as many times as it is necessary to cover the whole slope. The total height difference over the whole slope is equal to the sum of all the individual height differences measured.

Marking a contour line

Contour lines can easily be marked out using a water tube-level. Begin at the top of a field and work downslope. Two operators hold the poles, while a third can trace the contour line with a hoe on the ground and/or mark it with pegs.

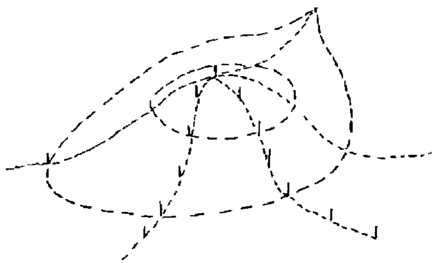


Figure 40: Contour lines.

First measure the total height difference over the whole slope, as described above (the line a-a in Figure 41). Mark these points every few metres with a small stake or peg. These pegs are used as a starting point to mark a contour line. Pole 1 of the tube-level is placed at such a starting point, near a peg.

Pole 2 is moved across the slope as far as possible to a position where the water level is 1.5 m on the scale of both poles. This means Pole 2 is at the same height as Pole 1. After marking the position of Pole 2 with a peg, Pole 1 can be moved, and so on, until the contour line is drawn across the whole slope. Another contour line, further down the slope, can then be staked out (Figure 41).

Defining the slope gradient

The gradient of a slope can be expressed in degrees (a horizontal line being 180°), but it is more common to define it as a percentage. This percentage (**s**) can be calculated by dividing the difference in height between two points, i.e. the vertical distance (**h**), by the horizontal distance (**L**) between these same points, and multiplying this by 100% (Figure 9, Chapter 5).
In the following example the height difference is 5 m over a horizontal distance of 125 m.
Then the slope gradient is equal to:

$$s = \frac{h}{L} \times 100\% = \frac{5}{125} \times 100\% = 4\%$$

It is possible to determine the gradient of a slope using a water tube level. First the vertical distance has to be measured (i.e. the difference in height between two given points), then the distance between these two points over the ground has to be measured, using a metre ruler or a surveying chain. The slope gradient can then be calculated according to the formula given above.

Further reading

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Useful addresses

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IWRA has strived to improve water management worldwide through dialogue, education, and research for over 25 years. Since its official formation in 1972, the organization has actively promoted the sustainable management of water resources around the globe. **IWRA** seeks to improve water resource outcomes by improving our collective understanding of the physical, biological, chemical, institutional, and socio-economic aspects of water.

ADB Water for All (Asian Development Bank-water for all)
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Web-site: http://www.adb.org/Water/default.asp

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IILRI works at the crossroads of livestock and poverty, bringing high-quality science and capacity-building to bear on poverty reduction and sustainable development for poor livestock keepers and their communities. **IILRI** is one of 16 Future Harvest Centres, supported by the Consultative Group on International Agricultural Research (CGIAR).

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The WCA infoNET information system is an Internet-based integrated information platform which merges high quality information resources and expertise allowing direct access to publications, documents, data, computer programs and discussion groups which provide a knowledge base, support and the necessary global platform for decisions on water conservation and use in agriculture

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ISRIC is a Foundation for Documentation, Training and Research on Soils of the World, It is the World Data Centre for Soils of the International Council of Sciences. **ISRIC** is involved in the Green water Initiative, to make accessible, in a simple and user friendly way, to those in close contact with farmers in Sub Sahara Africa, Information on Soils, Climate, Water and Conservation technologies, To stimulate learning and share experiences for Improved Water Use in dryland agriculture.

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ILEIA started in 1984 in response to a concern that mainstream agricultural development - particularly the green revolution - was bypassing the small and marginal farmers in the South, eroding their livelihoods, affecting the environment adversely and leading to widespread losses of agrobiodiversity. **ILEIA** started to identify promising technologies involving no or only marginal external inputs, but building on local knowledge and traditional technologies, where these still existed, and the involvement of the farmers themselves in development. Information about these technologies was exchanged mainly through the **ILEIA** Newsletter..