Irrigation and Hydraulic Structures

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Irrigation

Introduction

Definition

Irrigation may be defined as the process of supplying water by artificial means to agricultural fields for crop production. If water available to the plants from rainfall is not sufficient, it is supplemented by irrigation water.

In order to achieve this objective, an irrigation system is required to be developed that involves planning, design, construction, operation and maintenance of various irrigation works:

- Source: River, Reservoirs
- Control structure: Barrages, Head Regulators
- Distribution system: Irrigation Canals

Types of Irrigation

Different types of irrigation methods can be classified as

- Surface irrigation
- Sprinkler irrigation
- Sub-surface irrigation

Surface Irrigation

Basin Irrigation

Introduction

Basin irrigation is the most common form of surface irrigation, particularly in regions with layouts of small fields. If a field is level in all directions, is encompassed by a dyke to prevent runoff, and provides an undirected flow of water onto the field, it is herein called a *basin*. A basin is typically square in shape but exists in all sorts of irregular and rectangular configurations. It may be furrowed or corrugated, have raised beds for the benefit of certain crops, but as long as the inflow is undirected and uncontrolled into these field modifications, it remains a basin. Usually water is added to the basin through a gap in the perimeter dyke or adjacent ditch.

Advantages

There are few crops and soils not amenable to basin irrigation, but it is generally favoured by moderate to slow intake soils, deep-rooted and closely spaced crops. Crops which are sensitive to flooding and soils which form a hard crust following an irrigation can be basin irrigated by adding furrowing or using raised bed planting. Reclamation of salt-affected soils is easily accomplished with basin irrigation and provision for drainage of surface runoff is unnecessary. Of course it is always possible to encounter a heavy rainfall or mistake the cut-off time thereby having too much water in the basin. Consequently, some means of emergency surface drainage is good design practice. Basins can be served with less command area and field watercourses than can border and furrow systems because their level nature allows water applications from anywhere along the basin perimeter. Automation is easily applied.

Limitations

Basin irrigation has a number of limitations, two of which, already mentioned, are associated with soil crusting and crops that cannot accommodate inundation. Precision land levelling is very important to achieving high uniformities and efficiencies. Many basins are so small that precision equipment cannot work effectively. The perimeter dykes need to be well maintained to eliminate breaching and waste, and must be higher for basins than other surface irrigation methods. To reach maximum levels of efficiency, the flow per unit width must be as high as possible without causing erosion of the soil. When an irrigation project has been designed for either small basins or furrows and borders, the capacity of control and outlet structures may not be large enough to improve basins.

Suitable Crops

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

Other crops which are suited to basin irrigation include: i) pastures, e.g. alfalfa, clover; ii) trees, e.g. citrus, banana; iii) crops which are broadcast, such as cereals and iv) to some extent row crops such as tobacco.

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

Suitable Land Slopes

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

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

Suitable Soils

Which soils are suitable for basin irrigation depends on the crop grown. A distinction has to be made between rice and non-rice or other crops. Paddy rice is best grown on clayey soils which are almost impermeable as percolation losses are low. Rice could also be grown on sandy soils but percolation losses will be high unless a high water table can be maintained. Such conditions sometimes occur in valley bottoms.

Although most other crops can be grown on clays, loamy soils are preferred for basin irrigation so that waterlogging (permanent saturation of the soil) can be avoided. Coarse sands are not recommended for basin irrigation as, due to the high infiltration rate, percolation losses can be high.

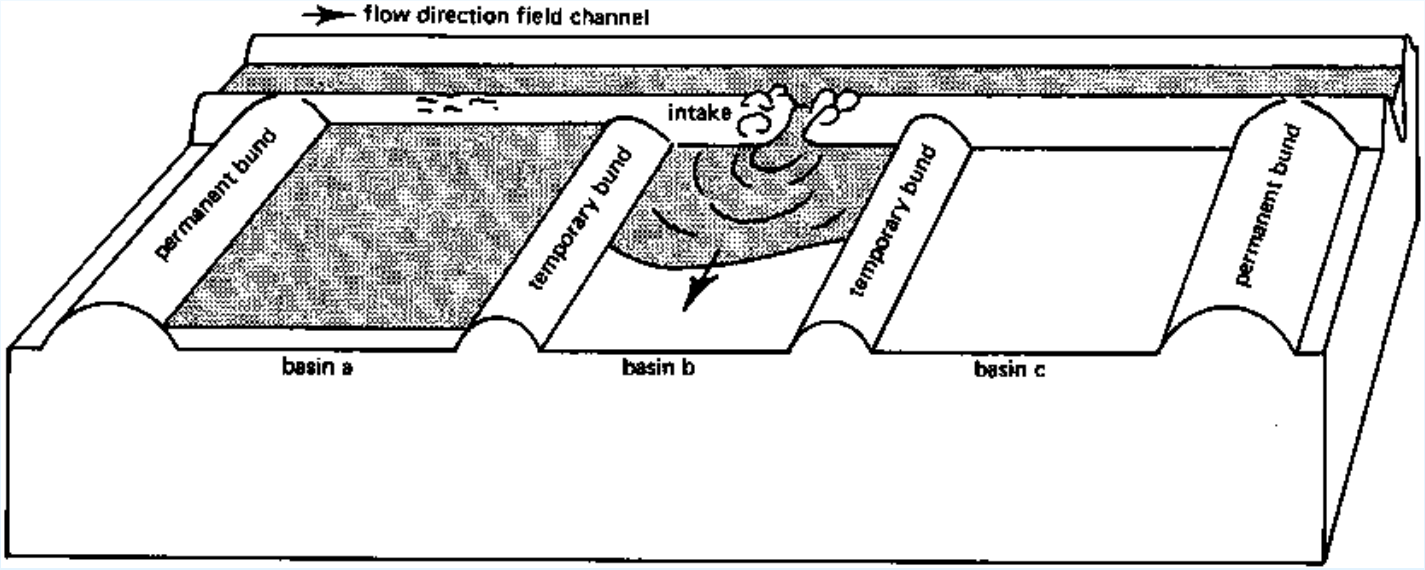
Water Application

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

The direct method

Irrigation water is led directly from the field channel into the basin through siphons, spiles or bundbreaks. In the following figure

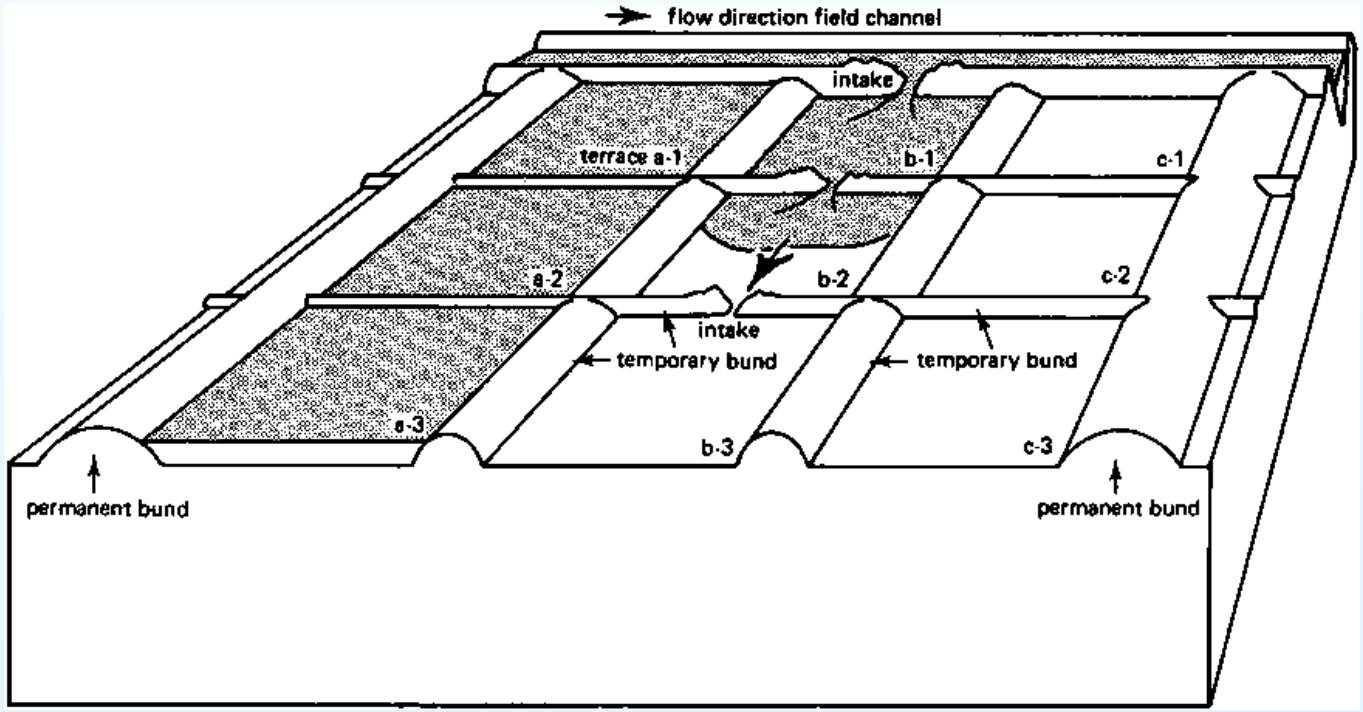
"Basin a" is irrigated first, then "Basin b" is irrigated and so on. This method can be used for most crop types and is suitable for most soils.



Water Application

The cascade method

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



Water Application

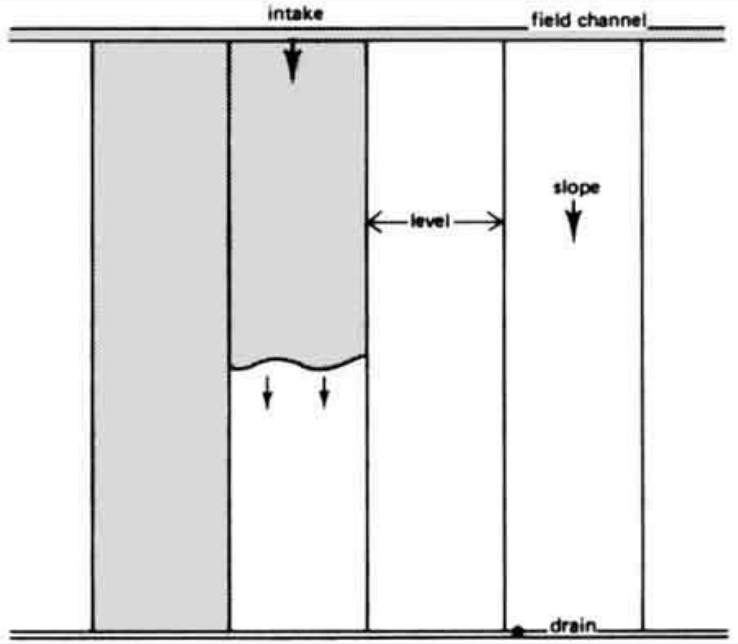
Cascade method is a good method to use for paddy rice on clay soils where percolation and seepage losses are low. However, for other crops on sandy or loamy soils, percolation losses can be excessive while water is flowing through the upper terraces to irrigate the lower ones. This problem can be overcome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

Basin Irrigation

Border Irrigation

Introduction

Border irrigation can be viewed as an extension of basin irrigation to sloping, long rectangular or contoured field shapes, with free draining conditions at the lower end.



Above figure illustrates a typical border configuration in which a field is divided into sloping borders. Water is applied to individual borders from small hand-dug checks from the field head ditch. When the water is shut off, it recedes from the upper end to the lower end.

Advantages

Sloping borders are suitable for nearly any crop except those that require prolonged ponding. Soils can be efficiently irrigated which have moderately low to moderately high intake rates but, as with basins, should not form dense crusts unless provisions are made to furrow or construct raised borders for the crops. The stream size per unit width must be large, particularly following a major tillage operation, although not so large for basins owing to the effects of slope. The precision of the field topography is also critical, but the extended lengths permit better levelling through the use of farm machinery.

Suitability

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

Suitable Slopes

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

Suitable Soils

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

Suitable crops

Close growing crops such as pasture or alfalfa are preferred.

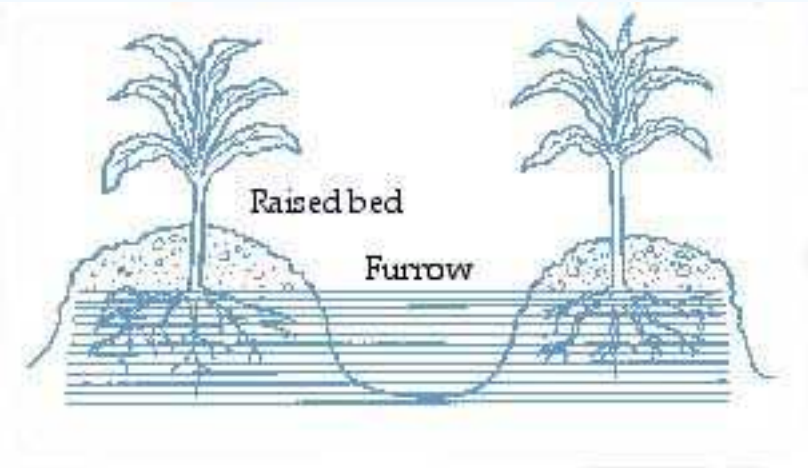
Furrow Irrigation

Introduction

Furrow irrigation avoids flooding the entire field surface by channelling the flow along the primary direction of the field using 'furrows,' 'creases,' or 'corrugations'. Water infiltrates through the wetted perimeter and spreads vertically and horizontally to refill the soil reservoir. Furrows are often employed in basins and borders to reduce the effects of topographical variation and crusting. The distinctive feature of furrow irrigation is that the flow into each furrow is independently set and controlled as opposed to furrowed borders and basins where the flow is set and controlled on a border by border or basin by basin basis.

Advantages

Furrows provide better on-farm water management flexibility under many surface irrigation conditions. The discharge per unit width of the field is substantially reduced and topographical variations can be more severe. A smaller wetted area reduces evaporation losses. Furrows provide the irrigator more opportunity to manage irrigations toward higher efficiencies as field conditions change for each irrigation throughout a season. This is not to say, however, that furrow irrigation enjoys higher application efficiencies than borders and basins.

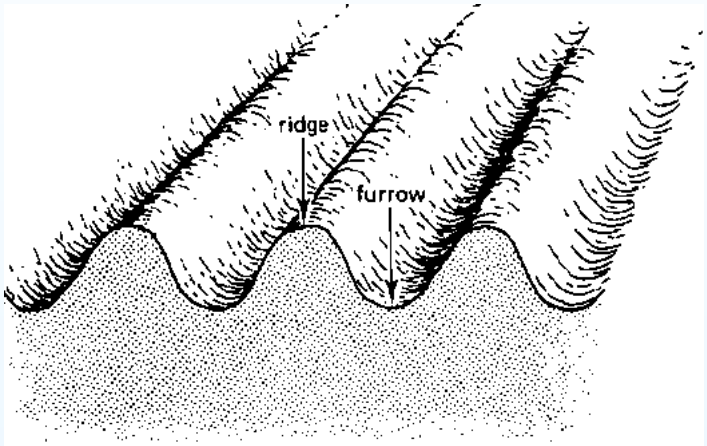


Disadvantages

There are several disadvantages with furrow irrigation. These may include: (1) an accumulation of salinity between furrows; (2) an increased level of tailwater losses; (3) the difficulty of moving farm equipment across the furrows; (4) the added expense and time to make extra tillage practice (furrow construction); (5) an increase in the erosive potential of the flow; (6) a higher commitment of labour to operate efficiently; and (7) generally furrow systems are more difficult to automate, particularly with regard to regulating an equal discharge in each furrow.

Suitable Crops

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



Furrow irrigation is also suited to the growing of tree crops. In the early stages of tree planting, one furrow alongside the tree row may be sufficient but as the trees develop then two or more furrows can be constructed to provide sufficient water.

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

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

Suitable Slopes

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

On undulating land furrows should follow the land contours (figure). However, this can be a difficult operation requiring very careful setting out of the contours before cutting the furrows.

Suitable Soils

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

Furrow Irrigation

Sprinkler Irrigation

Introduction

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

Suitable Crop

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

Suitable Slopes

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

Suitable Soils

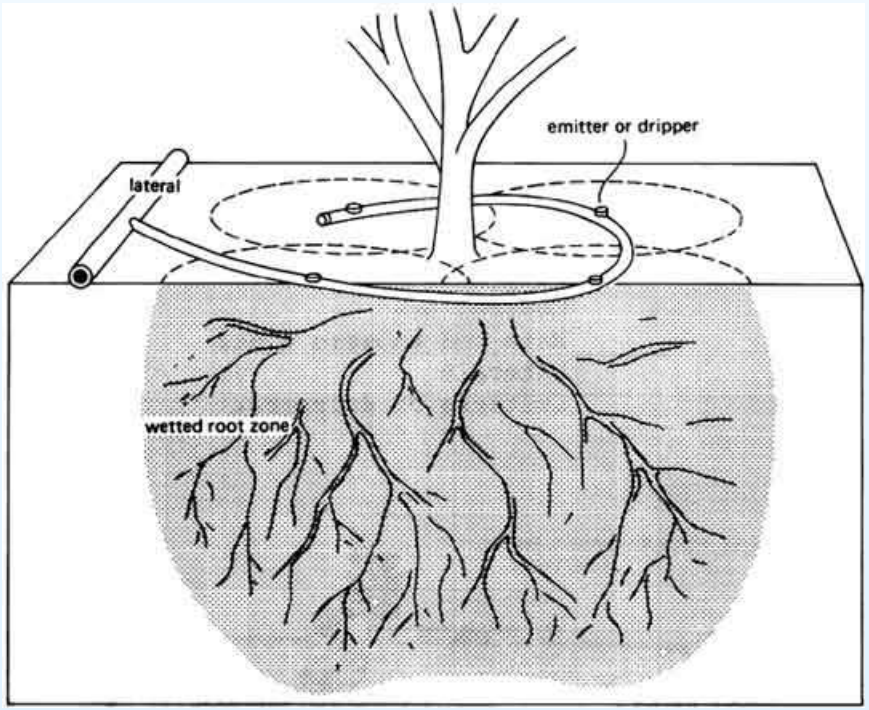
Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils. The average application rate from the sprinklers (in mm/hour) is always chosen to be less than the basic infiltration rate of the soil (see Annex 2) so that surface ponding and runoff can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

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

Drip Irrigation

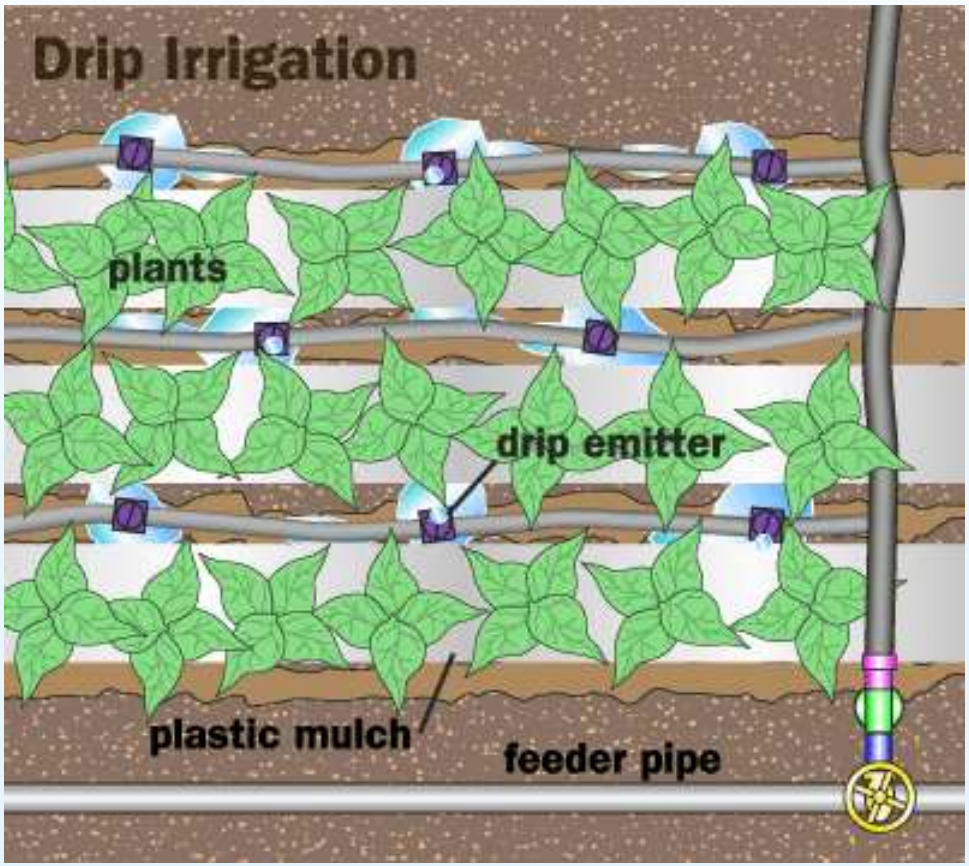
Introduction

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



Suitable Crops

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



Suitable Slopes

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

Suitable Soils

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

Suitable Water

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

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

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

Selection of a Method

Introduction

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

Surface, Sprinkler or Drip

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

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

Natural Conditions

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

Soil type:

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

When a variety of different soil types is found within one irrigation scheme, sprinkler or drip irrigation are recommended as they will ensure a more even water distribution.

Slope:

Sprinkler or drip irrigation are preferred above surface irrigation on steeper or unevenly sloping lands as they require little or no land levelling. An exception is rice grown on terraces on sloping lands.

Natural Conditions

Climate:

Strong wind can disturb the spraying of water from sprinklers. Under very windy conditions, drip or surface irrigation methods are preferred. In areas of supplementary irrigation, sprinkler or drip irrigation may be more suitable than surface irrigation because of their flexibility and adaptability to varying irrigation demands on the farm.

Water availability:

Water application efficiency (see Annex 4, step 8) is generally higher with sprinkler and drip irrigation than surface irrigation and so these methods are preferred when water is in short supply. However, it must be remembered that efficiency is just as much a function of the irrigator as the method used.

Water quality:

Surface irrigation is preferred if the irrigation water contains much sediment. The sediments may clog the drip or sprinkler irrigation systems.

If the irrigation water contains dissolved salts, drip irrigation is particularly suitable, as less water is applied to the soil than with surface methods.

Sprinkler systems are more efficient that surface irrigation methods in leaching out salts.

Type of Crop

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

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

Type of Technology

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

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

Past Experience

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

Required Labour

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

Cost and Benefit

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

Conclusion

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

Basin, Furrow or Drip

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

Factors to be taken into account include:

- natural circumstances (slope, soil type)
- type of crop
- required depth of irrigation application
- level of technology
- previous experience with irrigation
- required labour inputs.

Natural Circumstances

Basin irrigation is most suitable for flat lands, with a slope of 0.1% or less. Little land levelling will be required. If the slope is more than 1%, terraces can be constructed. However, the amount of land levelling can be considerable.

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

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

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

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

Type of Crop

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

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

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

Depth of Water

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

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

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

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

Past Experience

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

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

Required Labour

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

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