3. Use of fertilizers and organic matter. Since fertilizers enhance crop yields, they increase water use efficiency. There is an intimate relationship between soil moisture and nutrient availability. Water use efficiency is increased by a fertilizer which increases dry matter production. Similarly, crop response to fertilizer is generally higher under irrigated conditions than unirrigated conditions. Crop response to frequent irrigation is, in general, enhanced by an increase in the level of fertilizer application, particularly in crops grown for their vegetative parts. Thus, proper management of crop nutrition may also help enhance water use efficiency.

The addition of well-rotted organic matter (like farmyard manure) to a soil, especially sandy soil, increases its water-holding capacity. A soil with high organic matter content will supply more water to the plant than a soil with low organic matter content or none at all. Thus, the addition of organic matter to the soil will enhance the water use efficiency of a crop and thus ultimately increase its yield.

4. Mulching. Cropland loses water at a rate of 2275-45,500 litres of water per acre per day. In hot climates, the rate may exceed 68,000 litres per acre per day (Afzal 1976:62). This huge loss of soil moisture can be minimized by creating a mulch layer by either spreading a thin layer of crop residues on the soil surface or stirring the soil with appropriate implements that leave most of the vegetative portion of a crop on the surface. Mulching reduces both runoff and evaporation losses, and aids infiltration of water into the soil. This leads to better moisture conservation, and hence more efficient water use.

4.9 Irrigation systems

An irrigation system consists of the following components:

1. Main intake structure and pumping station
2. Conveyance and distribution system
3. Field application systems
4. Drainage system

The components of an irrigation system are diagrammed in Figure 4.6.

4.9.1 Main intake structure

The structure built at the entrance of the irrigation system is called the intake structure; it directs water from the original source of supply (lake, river, reservoir, etc.) into the irrigation system (canals, etc.).

In Pakistan, the annual flow of the main rivers in the west (Indus, Jhelum, and Chenab) is 142 maf. Currently there are 20 river diversion structures that divert 92 maf of water annually to the canal irrigation system.

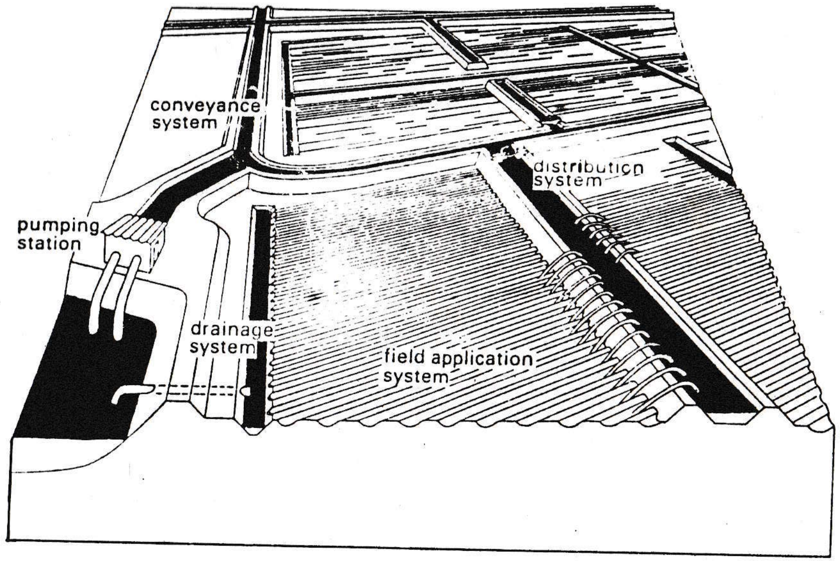

Figure 4.6 Components of an irrigation system (Source: Brouwer et al. 1985:57).

Three large dams (Tarbela, Mangla, and Chashma), with a storage capacity of 21 billion cubic metres, have been built on the western rivers to regularize the seasonal flow of water and to use it for irrigation during winter, when river inflow is only about 19% of summer inflow.

When an irrigation water source lies below the level of an irrigated field, a pump must be used to supply water to the irrigation system. Most canal systems in Pakistan are of the gravity variety, and pumps are used primarily to lift ground water. There are about 200,000 private tubewells and 15,000 public tubewells in Pakistan. The annual total discharge of these tubewells is about 33 maf. Tubewells pump the water directly into water-courses.

4.9.2 Conveyance and distribution system

A conveyance and distribution system consists of canals, distributaries, minors, and field watercourses that transport water from the diversion point to the field head. Pakistan has the world's largest gravity-fed canal irrigation system. It covers a gross area of 16.2 million ha, of which 88% is cultivable. It has 48 principal canals, emerging out of 20 river diversion structures. The cumulative operating capacity of the canals is 7323 cubic metres per second, and the annual conveyance capacity is 231 billion cubic metres. In addition, there are 12 link canals transporting bulk water supplies from the western rivers to the eastern rivers (Sutlej and Ravi). Main canals feed watercourses through distributaries and minors while the tubewells pump water directly into the watercourses. Figure 4.7 (insert) is a schematic and systemic diagram of the Indus Basin irrigation system (Government of Pakistan, Federal Planning Cell 1990).

4.9.3 Field application systems

Once irrigation water reaches the field supply channels (field head), it is important to apply this water as efficiently as possible, since in Pakistan about 25% of the total water available at the field head (56 maf) is usually lost at the stage of field application from the distribution channels, by deep percolation below the crop root zone and runoff. To achieve this objective, selection of an appropriate irrigation water application system is of prime importance.

There are four basic methods of applying water to a field, each of which has its advantages and disadvantages that should be considered when choosing the method best suited to the local circumstances.

1. Surface irrigation
2. Subsurface irrigation
3. Sprinkler irrigation
4. Drip irrigation

1. Surface irrigation. Surface irrigation is the application of water directly to the soil surface by gravity flow from a channel located at the upper reach of the field. Either the entire field is flooded (basin irrigation), or water is fed to small channels (furrow irrigation) or strips of land (border irrigation). High efficiency in surface irrigation methods can only be achieved through proper construction of water distribution systems to provide adequate control of water to the field, and precision land levelling to permit uniform distribution of water over the field.

a. Basin irrigation. In basin irrigation, the entire soil surface is flooded. **Basins** are flat areas of land (plots/beds) surrounded by low **bunds** (ridges). The bunds prevent water from flowing to the adjacent plots (*kiaris*) of the field. This system is quite common in Pakistan and many other countries and is the simplest of all methods of irrigation. There are many variations in its use, but all involve dividing the field into smaller units so that each has a nearly level surface. A plot size of one to two kanals (about 506–1012 m^2) has been suggested, depending on the type of soil and crop to be grown. Bunds are constructed around the areas, forming basins within which the irrigation water is controlled. The basins are filled to the desired depth, and the water is retained until it infiltrates the soil. When irrigating rice or ponding water for leaching salts from the soil, the depth of water may be maintained for a prolonged time by allowing water to continue to flow into

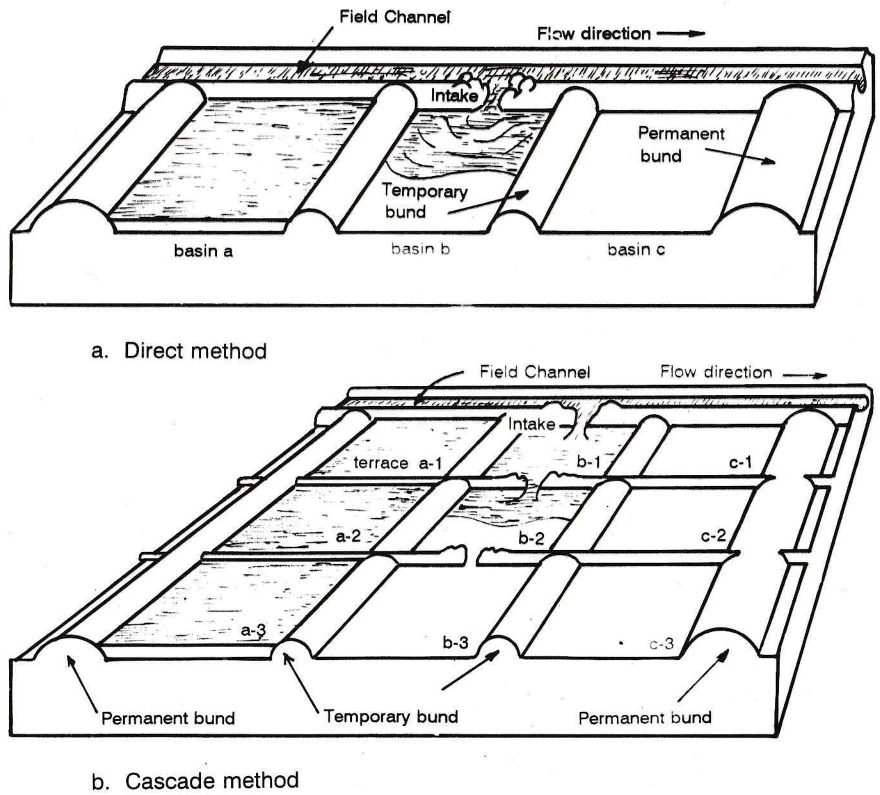

Figure 4.8 Methods of water supply in basin irrigation: (a) direct, (b) cascade. Source: Brouwer et al. (1988:12).

the basins.

In basin irrigation, there are two methods of water supply to plots (basins): the direct method, and the cascade method (Fig. 4.8). Special types of basins are formed for orchards. Usually a separate basin is formed for each tree, but in some cases one basin may be formed for several trees wherever soil and slope of terrain permit. Water is supplied to these basins from a supply ditch. In some cases basins may be interconnected. Figure 4.9a shows the direct method of water supply for orchards, and Figure 4.9b depicts the cascade method of water supply to fruit tree basins.

According to Brouwer et al. (1988), basin irrigation is suitable for many field crops. Paddy rice grows best when its roots are submerged in water, so basin irrigation is the best method to use for this crop. Trees can also be grown in basins, with one tree usually located in the centre of a small basin. Other crops that are suited to basin irrigation include pastures (alfalfa and clover), fodder crops (berseem and shaftal), and cereals.

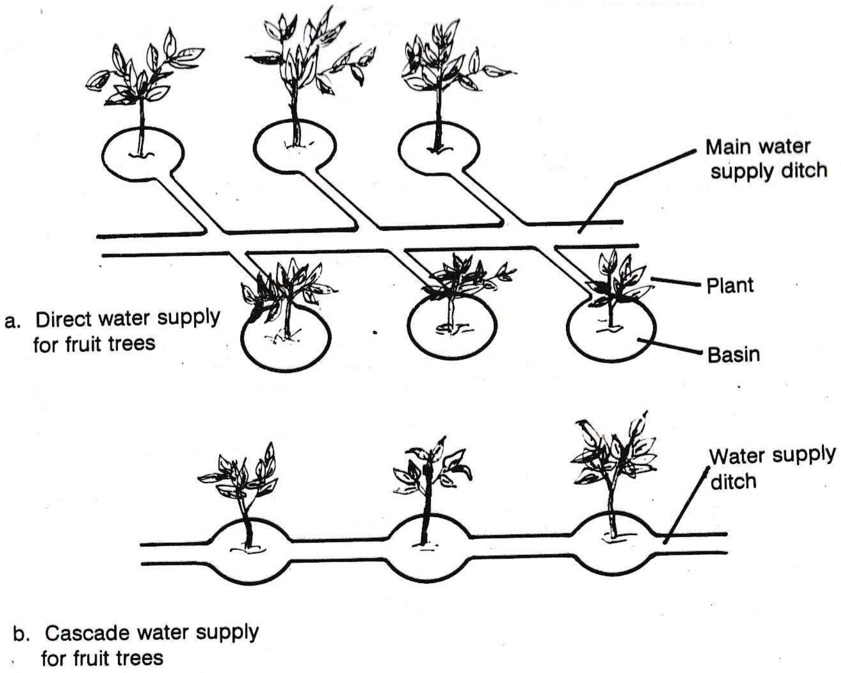

Figure 4.9 Direct (a) and cascade (b) methods of water supply to fruit orchards.

b. Furrow irrigation. Furrows are small, parallel channels or ditches which carry irrigation water to the crop. Crops are usually grown on the ridges between the furrows. The size and shape of the furrow depends on the crop grown, equipment used, and space between crop rows. Water is applied by running small streams into the furrows. Furrows may be straight, like borders laid down on the prevailing land slope, or contoured so that they can carry water across a sloping field rather than down the slope. Typical furrow layouts are shown in Figure 4.10.

Furrow irrigation is suitable for a wide range of soil types (except coarse sands) and crops, especially those grown in rows like maize, sorghum, sunflower, sugarcane, cotton, soybean, tobacco, and groundnut. Crops that are damaged if water covers their stem or crown should be irrigated by furrows. Examples of these crops are tomato, potato, bean, and various other vegetable crops. Fruit trees like citrus and grape can also be irrigated by furrows.

For broadcast crops like wheat, **corrugation irrigation** can be used. This method of irrigation is a modified form of the furrow method. In this irrigation method, smaller and more numerous furrows are created, often with a special corrugating implement. The main difference between a furrow and a corrugation is size. Furrows have a larger cross-section and are used on

flat land, while corrugations have a smaller cross-section and run down the predominant slope. The corrugation method is advantageous when the available irrigation streams are small and the land to be irrigated is of uneven topography.

Figure 4.10 Furrow irrigation: top, without crop; bottom, showing crop planted on ridges.

c. Border irrigation. There are two types of border irrigation, straight and contour.

Straight border irrigation. In this system, the borders are long strips of land which are separated from one another by earthen ridges. The function of the ridges is to guide the flow of water down the slope of the field, not to store water as is the case with basin irrigation. The borders are irrigated by diverting a stream of water from the channel at the upper end of the border. The water flows down the slope (Fig. 4.11). When the desired amount has been delivered to the border, the stream is turned off. It may be turned off even before the water reaches the lower end of the border. There are no specific rules governing this decision; only the **irrigator's** experience enables him to supply the correct amount of water to **each** border.

The length and width of a border are adjusted keeping in view the size of the available water supply. In addition, the size and shape of a border also depend on soil type and slope. In Pakistan, irrigated area is usually divided into acres with dimensions of 220 × 198 feet. The width of a border strip can thus be 10–50 feet. A smaller size is more efficient in water saving (Ahmad and Chaudhry 1988).

SUITABILITY. Straight border irrigation is generally best suited to large, mechanized farms since it is designed to produce long uninterrupted field lengths for ease of machine operations. By contrast, borders are less suited to small-scale farms involving hand labour or animal-powered cultivation methods. Border irrigation is suitable for close-growing crops such as alfalfa, pasture, wheat, barley, or legumes, etc. It is not suitable for rice, which needs standing water for part of its growing season.

Contour border irrigation. Contour border irrigation (CBI) is practised in hilly areas on land having a steep slope or undulating fields, and where levelling is not feasible (Ahmad and Chaudhry 1988:9.5). In CBI, ridges are made across the slope so that the field is divided into a series of strips on the approximate contour. Thereafter, each strip is precisely levelled and is called a contour. Thus, a number of steps (contours) are formed at successive elevations across the slope. Ridges of the contours are constructed high enough to contain heavy rainfall or irrigation water to ensure soil and water conservation.

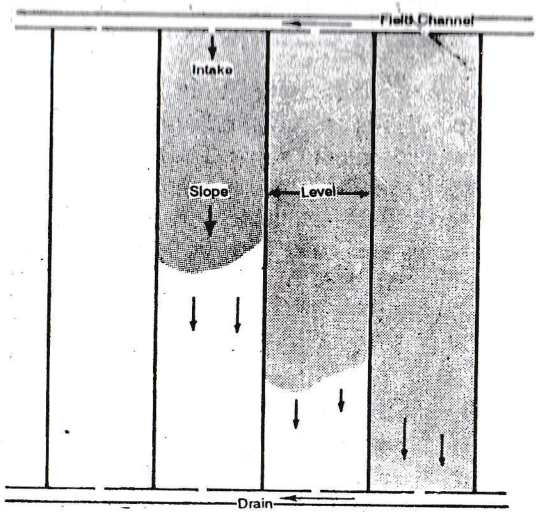

Figure 4.11 Straight border irrigation (Source: Brouwer et al. 1988:29).

Since the vast majority of Indus Basin fields have only a slight slope, only a few sites require contour irrigation. However, CBI is being practised in the hilly areas of Punjab, NWFP, and Azad Jammu and Kashmir (Pakistan).

2. Subsurface irrigation. In the subsurface or subsoil irrigation system, water is applied to a series of field ditches deep down to the impervious layer. Water moves laterally and then vertically through capillaries and saturates the root zone. A continuous supply of moisture in the crop root zone is thus assured from the artificial water table created by the ponding of irrigation water on the impervious layer.

In artificial sub-irrigation, perforated or porous pipes are laid underground in the vicinity of the root zone, and water under pressure is distributed through these pipes. Subsurface irrigation is useful where there is an impervious subsoil at a depth of 2 m or more, a highly permeable loam or sandy loam surface soil, uniform topographic conditions, and moderate slopes. Under such conditions, proper water control to prevent salts/sodium accumulation or waterlogging usually results in the economical use of water, high crop yields, and low labour cost in irrigation. However, the high initial investment and maintenance costs are prohibitive for its adoption. Small grains and root crops can be irrigated by this system provided there is no development of salinity or sodicity due to upward capillary water flow from a shallow water table.

Ahmad and Chaudhry (1988) report that in Europe, particularly France, artificial subsoil irrigation is used to raise cash crops like tomato, pepper, strawberry, cucumber, potato, and sweet corn.

3. Sprinkler irrigation. Sprinkler irrigation is a method of applying irrigation water which is similar to natural rainfall (Ahmad and Chaudhry 1988:9.8, 9.9). Water is distributed through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers so that it breaks

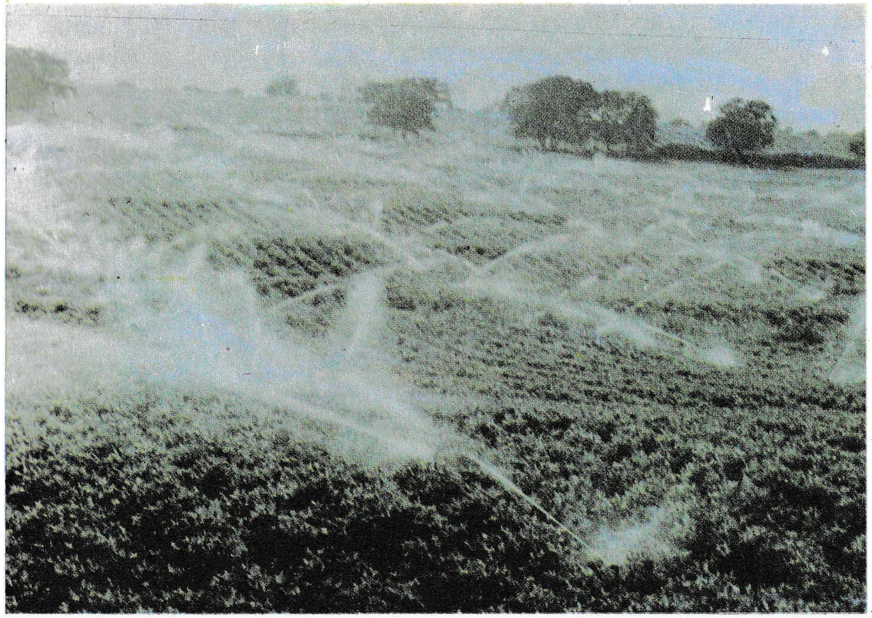
Figure 4.12 Sprinkler irrigation

up into small water drops which fall to the ground (Fig. 4.12). Four types of sprinkler systems are commonly used: permanent, semipermanent, semimobile, and mobile. The pump supply system, sprinklers, and operating conditions must be designed to enable a uniform application of water.

This irrigation method is suited to most row, field, and tree crops. 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 physically damage the crop.

Sprinklers are adaptable to most soils, but they are best suited to sandy soils with high infiltration rates (Ahmad and Chaudhry (1988:9.8). The average application rate from the sprinklers should be less than the basic infiltration rate of the soil, so that surface ponding and runoff can be avoided. However, sprinklers are not suitable for soils which easily form a crust. If sprinkler irrigation is the only method available, then a light fine spray should be used.

The sprinkler irrigation method is more efficient than surface irrigation. However, this method usually requires a much higher initial investment than surface irrigation methods. Power requirements are high and irrigation efficiency is low in hot, dry, and windy areas such as the arid and semiarid areas of Pakistan where surface evaporation losses vary from 180–250 cm per year. Currently, there is little use of sprinkler irrigation in Pakistan, but it could be used to good advantage in still undeveloped, sandy areas like Cholistan, Thal Desert, or Thal Doab provided there is a good ground water source for the sandy soil.

4. Drip irrigation. Drip irrigation is also called **trickle irrigation**. It is one of the latest methods of irrigation, and is becoming increasingly popular in areas with water scarcity and salt problems. Drip irrigation involves dripping water into the soil at very low rates from a system of small-diameter plastic laterals/pipes fitted with outlets called **emitters** or drippers (Fig. 4.13). Water is applied close to the plants so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation

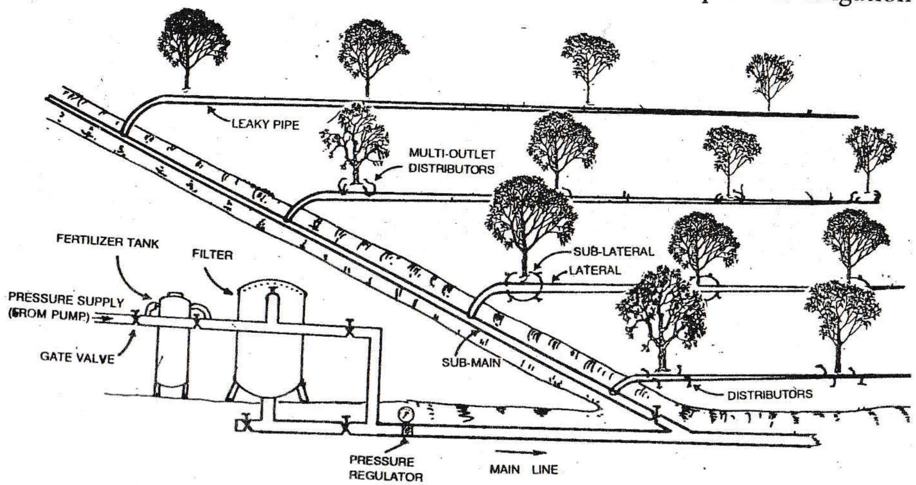

Figure 4.13 A drip irrigation system layout. After Brouwer et al. (1988:40).

which involves wetting the whole soil profile. With drip irrigation, water applications are more frequent than with other methods (usually every one to three days), and provide a very favourable high moisture level in the soil so that plants can flourish. Drip irrigation increases water use efficiency by minimizing water losses through runoff, percolation, evaporation, and conveyance (Ahmad and Chaudhry 1988:9.12).

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

This system of irrigation is suitable for most soils. On clay soils, however, water must be applied slowly to avoid surface water ponding and runoff; and on sandy soils higher emitter discharge rates will be needed to ensure adequate lateral wetting of the soil. This system can be used successfully in deserts and on uneven lands.

The initial cost of drip irrigation equipment is its main limitation for large-scale adoption. Because of its high initial cost, the drip irrigation method has not gained much popularity in Pakistan, but it is now being successfully practised in some parts of Balochistan.

4.9.4 Drainage systems

As water infiltrating from the beds of rivers, canals, distributaries, minors, and watercourses as well as saturated field soils percolates down to lower layers, it feeds the ground water reservoir. As a result, the ground water level (water table) rises. Following heavy rainfall or continuous overirrigation, the ground water table may even reach and saturate part of the root zone. If this situation continues, plants may suffocate or their growth may be adversely affected. Measures to control the rise of the water table are thus necessary. The removal of excess water either from the ground surface or from the root zone is called **drainage** (Brouwer et al. 1985:73).

Drainage can be either **natural** or **artificial**. Many areas have some natural drainage, e.g. excess water flowing from a farmer's field to a swamp, lake, or river. Natural drainage, however, is often inadequate, and artificial drainage is required. There are two common types of artificial drainage: surface drainage and subsurface drainage (Brouwer et al. 1985:74).

Surface drainage. Surface drainage is the removal of excess water from the surface of the land. This is normally accomplished by shallow ditches called **open drains**. These drains discharge into longer and deeper collector drains. In order to facilitate the surface flow of excess water towards the drains, a field can be given an artificial slope by means of land grading.

Surface drains may be needed to prevent or modify saline/alkali conditions in a soil, because most crops do not grow well in such soils. This can be achieved by leaching excess salt from the surface soil. However, excess irrigation water used for this purpose must be drained out from the field by a suitable method to prevent a rise in the water table that would otherwise create **anoxia** (waterlogging). Provisions should be made to drain the excess water present in the crop root zone promptly and carefully to ensure adequate aeration. If land is not naturally well-drained, artificial