TECHNICAL HANDBOOK No. 24

DRIP IRRIGATION

Options for smallholder farmers in eastern and southern Africa

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Chapter 1
Introduction

1.1 Irrigation potential in sub-Saharan Africa

In the dry lands of sub-Saharan Africa, water deficit is the most important environmental factor limiting yields in agriculture. When irrigated, these areas can have a high yield potential because of the high solar radiation, favourable day and night temperature and low atmospheric humidity, conditions that decrease the incidence of pests and diseases compared to areas in temperate zones. The key to maximizing crop yields per unit of supplied water in dry lands is ensuring that as much as possible of the available moisture is used through plant transpiration and as little as possible is lost through soil evaporation, deep percolation and transpiration from weeds.

In recent years there has been growing concern at the performance of conventional irrigation systems in sub-Saharan Africa. The poor performance of irrigation projects seems to have contributed to stagnation in new irrigation development. Available data suggest that irrigation potential in the region is considerable but largely unexploited (Table 1.1).

The anticipated long-term yield increases for irrigated land which earlier depended on unpredictable and unreliable rainfall have not always been achieved. This has contributed to irrigation losing its appeal as an investment strategy. Good performance in irrigation systems is not only a matter of high output but also of efficient use of available resources. For example, the inefficient use of irrigation water in arid areas is not only wasteful but often leads to salinization of the soil profile. Irrigation systems that are to be effective and efficient must ensure that drainage, maintenance of soil fertility and salinity-control measures are employed.

1.2 Major methods of irrigation

Irrigation water is applied to land by three general methods: surface irrigation, sprinkler irrigation and localized irrigation systems. The choice of irrigation method is site specific and depends on topography, the amount of water available, the quality of the water and soils, as well as economic and social considerations. Irrigation systems developed in industrialized countries tend to be complex, energy intensive and dependent

Table 1.1 Estimates (1991) of potential and actual irrigated areas in sub-Saharan Africa

Country	Irrigation potential (ha)	Area under irrigation (ha)	% of potential
Angola	3,700,000	75,000	2
Benin	300,000	10,236	3
Botswana	14,640	1,381	9
Burkina Faso	164,460	24,330	15
Burundi	185,000	14,400	8
Cameroon	290,000	20,970	7
Cape Verde	2,990	2,779	93
Central African Republic	1,900,000	135	0
Chad	835,000	14,020	2
Comoros	300	130	43
Congo	340,000	217	0
Côte d'Ivoire	475,000	72,750	15
Djibouti	1,000	674	67
Equatorial Guinea	30,000	–	–
Eritrea	187,500	28,124	15
Ethiopia	3, 637,300	189,556	5
Gabon	440,000	4,450	1
Gambia	80,000	1,670	2
Ghana	1, 900,000	6,374	0
Guinea	340,000	15,541	5
Guinea-Bissau	281,290	17,115	6
Kenya	353,060	66,610	19
Lesotho	12,500	2,722	22
Liberia	600,000	2,100	0
Madagascar	1, 500,000	1, 087,000	73
Malawi	161,900	28,000	17
Mali	566,000	78,620	14
Mauritania	165,000	49,200	30
Mauritius	20,000	17,500	88
Mozambique	3, 072,000	106,710	4
Namibia	47,300	6,142	13
Niger	270,000	66,480	25
Nigeria	2, 330,510	232,821	10
Rwanda	159,000	4,000	3
Sao Tomé and Principe	10,700	9,700	92
Senegal	340,000	71,400	21
Seychelles	1,000	–	0
Sierra Leone	807,000	29,360	4
Somalia	240,000	200,000	83
South Africa	1,445,000	1, 270,000	88
Sudan	2,784,000	1, 946,000	70
Swaziland	93,220	67,400	72
Tanzania	990,420	150,000	15
Togo	180,000	7,008	4
Uganda	202,000	9,120	5
Zaire	7,000,000	10,500	0
Zambia	523,000	46,400	9
Zimbabwe	388,400	116,577	30

Source: Modified from Hillel 1997.

on expensive, often imported, equipment. These mainly large-scale systems are not directly applicable to the low-capital technological circumstances of the less-industrialized countries where farming is often practised on a small scale and the cost of labour, availability of capital and level of technical skill are very different.

1.2.1 Surface irrigation

The surface method of irrigation involves applying water over the soil surface. The water is conveyed over the soil surface and infiltrates into the soil at a rate determined by the infiltration capacity of the soil. Surface irrigation methods include:

- Basin irrigation where water is applied to a flat area surrounded by dikes. The water ponded in the basin area continues to percolate into the soil some time after the stream has been turned off. Basin irrigation stream sizes are usually 15–240 litres per second depending on soil texture, field size, required depth of irrigation and bund height.
- Border irrigation where water is allowed to flow down a gentle slope (< 0.1%) between bunds. The water advances slowly down the strip and is stopped when sufficient water has infiltrated at the top of the border strip. Border stream sizes are usually 2–15 l/s/m depending on soil type, slope, width and length of border strip and depth of irrigation.
- Furrow irrigation where water is allowed to flow down slope in small channels (furrows) between crop rows. The water is gradually absorbed into the bottom and sides of the furrow to wet the soil. Furrow irrigation stream sizes are usually 0.2–3.0 l/s.

Surface irrigation, however, may not be appropriate for porous soils (final infiltration rates > 7 cm/h) such as sandy soils, or soils with final infiltration rates that are too low (< 0.3 cm/h). Although surface irrigation can be efficient (70% or more), in a typical farmer's situation less than half of the applied water reaches the plant because of poor irrigation practices. Higher efficiencies can be obtained where land characteristics are suitable for surface irrigation with proper design and better water management.

1.2.2 Sprinkler irrigation

In overhead sprinkler irrigation, water is distributed in pipes under pressure and sprayed into the air so that the water breaks up into small water droplets that fall to the ground like natural rainfall. Sprinkler irrigation methods include conventional sprinklers, rain guns, centre pivot and linear move systems. Compared to surface irrigation, sprinkling generally requires less land levelling, can be adapted to sandy and fragile soils and requires less labour. However, higher pumping energy is required to lift the water and create enough pressure to operate the sprinklers. Care must be taken to sprinkle the water at rates lower than the soil's final infiltration rate. This is especially important on heavy soils and sloping land where proper management of the soil is essential to ensure that the soil's infiltration rate is not reduced below the rate at which sprinklers apply the water.

A typical application efficiency is 75%, that is, some three-quarters of the applied water reaches the roots of the plant, while one-quarter is lost through deep percolation, runoff and evaporation losses.

1.2.3 Localized irrigation systems

Localized irrigation systems apply water directly where the plant is growing thus minimizing water loss through evaporation from the soil. Such localized irrigation systems include drip irrigation, porous clay pots, porous pipes, and perforated plastic sleeves.

Drip irrigation

With drip or trickle irrigation the water is applied into the soil through a small-sized opening directly on the soil surface or buried in the soil. By applying water at a very slow rate, drip irrigation is capable of delivering water to the roots of individual plants as often as desired and at a relatively low cost. Because drip irrigation makes it possible to place water precisely where and when needed with a high degree of uniformity and efficiency (90% or more) the method is useful under many field and water situations. Losses to runoff, deep percolation and evaporation are minimal—this means that most of the irrigation water is taken up by the plant. Drip irrigation is often the favoured method of irrigation, for example on steep and undulating slopes, for porous soils, for shallow soils, fields having widely varying soils, where water is scarce, where water is expensive, and where water is of poor quality.

The major part of this handbook (Chapter 4) is devoted to a description of drip-irrigation systems that can be of benefit to smallholder farmers in sub-Saharan Africa.

Porous clay pots

This is a method of irrigation in which water is stored in clay pots buried in the ground, from where it is slowly released to the plants. This method is good for fruit trees. Such use of soil-embedded porous jars is one of the oldest continuous irrigation methods that probably originated in the Far East and North Africa.

The method consists of:

- Clay pots that are placed in shallow pits dug for this purpose;
- Soil is then packed around the neck of the pots so that the necks protrude a few centimetres above the ground surface;
- Water is poured into the pots, either by hand or by means of a flexible hose connected to a water source.

The pots are made of locally available clay with optimum properties of strength (to resist crushing), permeability (to exude water into the soil at an approximately steady rate), and size (to hold enough water for at least one day's supply).

The potential of clay-pot irrigation has not been fully exploited by farmers in the eastern and southern Africa region, even though the technology is suitable for small-scale farmers. There have not been many reports of previous experience in the region.

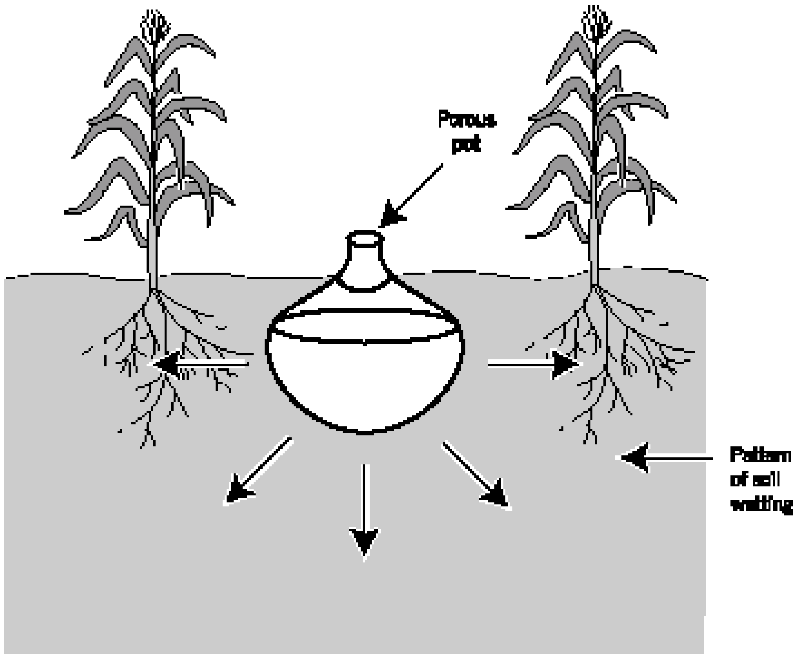


Figure 1.1 *The pattern of soil wetting around a porous clay pot*

Porous clay pipes

Water is spread along a continuous horizontal band in the soil. This method is most suited to closely spaced crops such as vegetables. The locally made clay pipes are approximately 24 cm in length and 7.5 cm in internal diameter, with wall thickness of 2 cm. The pipes are placed at the bottom of a shallow trench (about 25 cm deep) representing the centre line of a 1-m wide bed.

Perforated plastic sleeves

Plastic sheeting has been used to make a sleeve-like casing. The advantage of this is the low cost. However, the method has several distinct disadvantages that restrict the range of its applicability. Since the soft plastic material used for making the sleeve does not retain its shape, the sleeve must be filled with sand before being placed in the soil. The sand filling reduces the capacity of the sleeve by some 50–60%. Moreover, the sand itself tends to retain a significant fraction of the moisture and thus to restrict outflow. Since the plastic casing is essentially impervious, it must be perforated. The difficulty of standardizing the diameter and density of the perforations introduces another variable unto the system. The best configuration must be established by trial and error.

This method has been used with success in Senegal. An interesting variation in Sri Lanka consists of a 50-cm long PVC pipe of standard ˚-inch diameter. The pipe ends in an emitter, a block made from a 1:10 cement/sand mixture. The design was found to be effective in enhancing the survival and growth rate of young fruit trees.

Chapter 2
The soil–water plant relationship

2.1 Introduction

Plant genetics, environmental conditions and crop management affect plant growth. Crop yields, therefore, depend on these general factors. The genetic characteristics of a plant include yield potential and other growth characteristics such as disease resistance and drought tolerance.

Plants grow and develop in direct response to their environment. It follows that some environments are more suited to particular crops or varieties of a certain crop. Environmental conditions considered as the most important in plant growth are:

〈 Climate, especially temperature and radiant energy
〈 Plant available soil moisture
〈 Soil conditions, especially soil aeration, soil reaction (acidity or alkalinity, or pH) and supply of nutrients.

2.2 Environmental conditions

The climatic, soil and water requirements for selected crops are presented in Annex 1. In general, farmers must select the crops that they grow on the basis of environmental conditions prevailing on their land. A good understanding of these environmental conditions is, therefore, of great importance in developing appropriate management strategies.

2.2.1 Climate

Crops respond to radiation from the sun which supplies the heat energy necessary to convert water from the liquid form to gas. This heat energy is called the latent heat of evaporation and is supplied mainly by the sun's direct radiation on the leaf surface and the surface of the soil. Temperature affects the rate of plant growth; air temperature mainly regulates respiration while soil temperature regulates the availability of essential nutrients.

Other variable factors that affect crop performance are relative humidity, wind and the day length. Relative humidity influences the rate of vapour discharge from the stomata and the soil surface in the molecular diffusion process, and wind accelerates water-vapour evaporation. Day length has a positive linear influence on evaporation by influencing the number of hours of radiation. Day length also has an indirect influence on transpiration since the stomata are open when it is light and closed in the dark. If the rate of transpiration at the leaves exceeds the rate of absorption by roots, wilting occurs and growth of the plant is impeded. On the other hand, the available water is not used efficiently if conditions are such as to stimulate excessive transpiration.

The more closely the environment matches a crop's requirements as defined by its genotype, the better the production. The potential to grow a crop on a certain piece of land is generally determined by the environmental factors mentioned above. As water is the major limiting growth factor in arid and semi-arid areas, these croplands tend to be classified as having low production potential. However, if water supply is assured and essential nutrients are available, the arid and semi-arid lands (ASALs) can have very high yields.

2.2.2 Water

Living plants consist of approximately 90% water by fresh weight. This water helps provide rigidity to the plant and is the medium for transporting substances through the plant. Water is also used by plants in the process of photosynthesis in which carbon dioxide is converted to carbohydrate, the basis of the world's food energy cycle. Plant nutrient uptake is regarded indirectly as one of these processes. Nutrients taken up by plant roots are dissolved in water (soil solution). However, the amount of water retained in the plant is small compared with the volume of water that passes through it in transpiration. Water loss by transpiration is the inevitable consequence of the uptake of carbon dioxide through the stomata of the leaves during photosynthesis. However, transpiration also provides cooling to the plant and the pressure gradient that enables transport of dissolved soil nutrients from the root zone to the various parts of the plant. Thus, supply of water both in terms of quantity and quality is vital in the production system.

Approximately 1,000–3,000 litres of water are needed to grow 1 kilogram of marketable crop. In most of the region's ASAL areas, rainfall is low and predominantly occurs as storms, and there are frequent periods of water stress, so-called dry spells, during the rainy season as well as periodic droughts.

The primary challenge for farmers is to ensure that as much as possible of the rain that does fall infiltrates into the soil and is retained in the root zone. By doing this the detrimental effects of dry spells can be reduced. Reducing non-productive soil evaporation losses is also an effective way of ensuring more soil moisture for the crop.

Small-scale farmers can also use water-harvesting systems to store water in the soil, in tanks, ponds and earth dams to enable supplemental irrigation and sometimes off-season irrigation. Surface-water harvesting and ponding have also been used as methods of storing water for drinking. Water is also obtained by pumping from underground supplies, whose recharge also depends on water infiltration. However, care must be taken to avoid depletion of underground supplies beyond the natural annual recharge.

2.2.3 Soil

Soil is essential for plant production as it is the basic resource from which plants derive water and nutrients, and it also acts as a stability medium. However, some soil conditions are better able to support growth of crops than others. If the soil is not in usable condition then it will be necessary to develop the soil into a production resource. The whole crop production system centres on managing the soil through improving its physical condition and fertility. Soils are not necessarily depleted by the continuous growth of either wild plants or cash crops. In natural stands, nutrients are cycled from soil to plants and back, whereas in cultivated fields organic matter and nutrients are diverted to human use. Having thus interrupted these vital avenues of nutrient replenishment, farmers must perform ecosystem management by replacing required material. However, small-scale farmers lack the resources to buy fertilizers and have learnt to practise other methods, for example recycling of organic materials such as manure and crop residues. Other essential practices used in ASAL areas include better timing of planting, use of suitable crop varieties and weeding to reduce competition.

The following are basic factors of the soil environment.

The soil profile

Every soil has a profile—a succession of layers in a vertical section down into loose weathered rock from which the soil was formed. The nature of the soil profile greatly influences the growth of roots, recycling of organic materials, the storage of moisture, and the supply of plant nutrients. Soils range in depth, with some being very shallow and not able to support rain-fed crops because there is insufficient soil for storing water or available nutrients. The depth of the effective system (root zone) depends on both the crop and soil-profile characteristics.

Physical properties

Soil is made up of four major components, which vary with time and from place to place: inorganic particles, organic material, water, and air. Inorganic soil particles occupy about 50% of the total volume of most soils. According to the texture of the soil, inorganic components are further classified into three major classes: sand (2.0–0.05 mm particle size), silt (0.05–0.002 mm) and clay (< 0.002 mm). In general, a good agricultural soil must have a texture, or tilth, that allows moisture and oxygen in adequate proportions to reach the root zone, that stores water and nutrients and allows excess water to drain away. It must be workable to facilitate cultural practices such as tilling and weeding.

Fertility

A soil should be able to supply the essential nutrients that plants need. If the nutrients are not available, they must be added through application of organic materials or fertilizers. At least 16 elements are considered necessary for the healthy growth of plants—carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), sulphur (S), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B), and chlorine (Cl). Plants obtain carbon, hydrogen and oxygen from water and carbon dioxide in the process of photosynthesis, and other nutrients from the soil. The elements nitrogen, phosphorus and potassium are the major elements required by plants. Iron, manganese, zinc, copper, molybdenum, boron and chlorine are required in very small amounts and are known as micronutrients.

Soil must be chemically balanced. The acidity or alkalinity (expressed as a pH value) of the soil may be an important indication of its chemical condition because the availability of certain nutrients to the plant is dependent on the pH. The pH is measured on a scale from 0 to 14, pH 7, the midpoint of the scale, being neutral. A pH below 7 indicates an acid soil with the degree of acidity increasing as the pH value gets smaller. Soil pH values above 7 indicate an alkaline soil with the degree of alkalinity increasing the higher the pH. If the soil is too acid or too alkali then pH must be corrected with such additives as lime for acidity or gypsum for alkalinity.

Another indicator of soil condition is the concentration of soluble salts, as measured by the electrical conductivity of the soil solution. Salt-affected soils are problem soils and require special remedial measures and management practices. Remedial measures include leaching the soils by applying water to the surface and allowing it to pass downward through the root zone. Management practices for the control of salinity include frequent irrigation to maintain a relatively high soil moisture level in the plant root zone.

2.3 Relating crop water use to meteorological data

The amount of water used by plants, or evapotranspiration, is the sum of two processes:

1. Transpiration, which is the water entering the plant roots and used to build plant tissue or passed through the leaves into the atmosphere
2. Evaporation of water from the soil surface, water surfaces (e.g. during a period of ponding), or from the leaves of the plant (e.g. when leaves are wetted by rain or irrigation).

Evapotranspiration is influenced by:

- The evaporative demand of the atmosphere;
- The plant's ability to extract water from the soil and transpire;
- The water content of the soil.

The evaporative demand is, in turn, affected by the following climatic factors:

〈 Temperature: the hotter the climate the more water loss can be expected.
〈 Humidity: the amount of moisture in the air. If the air is humid, less evaporation occurs than under the same average temperature conditions but in drier air.
〈 Wind: high wind normally leads to higher evaporation.

As mentioned earlier, transpiration is an unavoidable effect of CO_2 uptake by the stomata of the leaves. This also means that under constant hydroclimatic conditions, there is generally a linear relationship between crop growth and transpiration. More yield/biomass means more transpiration. The ratio between crop yield (as grain or as total biomass) and water use (expressed as transpiration or evapotranspiration) is linear and defined as the water use efficiency (WUE).

2.3.1 Estimating reference evapotranspiration

To estimate a crop's water requirement, first you must obtain the evaporative demand, which is related to a given climate and expressed as the potential evapotranspiration. Reference evapotranspiration (ET_0) is defined as the rate of water use measured for a large area of short green grass growing under non-limiting conditions. Obtaining accurate climatic data for each environment is time consuming, laborious and expensive, and yet crop water requirement data are needed at short notice for project planning. To meet this need several methods such as the Blaney-Criddle, radiation, Penman, Penman-Monteith and pan evaporation methods are used to calculate ET_0. The choice of method used must be based on the type of climatic data available (Table 2.1) and on the accuracy required in determining water needs. The Penman method gives the best results in terms of accuracy with an error of ±10%. The pan evaporation method (error level ±15%) provides better accuracy compared to the radiation (±20% in hot conditions) and Blaney-Criddle (±25%) methods.

Table 2.1 Climatic data needed for the different methods of estimating ET_0

Method	Temperature	Humidity	Wind	Sunshine	Radiation	Evaporation	Environment
Blaney–Criddle	*	0	0	0			0
Radiation	*	0	0	*	(*)		0
Penman	*	*	*	*	(*)		0
Pan evaporation		0	0			*	*

* Measured data; 0 estimated data; (*) if available, but not essential
Source: Doorenbos and Pruitt 1977.

Before selecting the method to use, a review should be made of the data available from meteorological and research stations in the area you are dealing with. If limited data from several meteorological stations are available near the project area, improved prediction will result from analysis of these data and estimating the climate variables for the project area. The Penman, pan evaporation, radiation and Blaney-Criddle methods are described in Doorenbos and Pruitt (1977). The pan evaporation (Annex 2) and Blaney-Criddle (Annex 3) methods that require data that are relatively easy to obtain are presented for possible application by users of this handbook. Where data are available (those required are altitude, latitude, air temperature, humidity, radiation and wind speed), a more accurate estimation can be obtained by using the FAO Penman-Monteith method, which is described in Allen et al. (1998).

The computation of all data required for the calculation of reference evapo-transpiration is given in Chapter 3.

The calculation of ET_0 can be done by hand with the help of a calculation sheet, or by means of a computer. CROPWAT is a computer program designed to calculate ET_0 (according to Penman-Monteith) and crop water requirement from climatic and crop data. The program can also be used to calculate the water-supply requirement for an entire irrigation scheme. The manual and guidelines for the CROWAT program are contained in Smith (1992).

2.3.2 Estimating crop evapotranspiration

Crop evapotranspiration (ET_c) is the sum of transpiration by the crop and evaporation from the soil surface. The value of ET_c obtained is a measure of the demand from crops that are grown in large fields under optimum soil–water and other environmental conditions, and with excellent management. When there is full ground cover, evaporation is negligible, but immediately following sowing and during the early growing period evaporation from the soil surface may be considerable, particularly when the soil surface is wet for most of the time from rain or irrigation. Empirically determined ET_c/ET_0 ratios, called crop coefficients, relate ET_0 to ET_c.

The crop coefficient (K_c) is crop specific and expresses potential evaporative demand of a particular crop in relation to ET_0. The value of K_c largely depends on the level of ground cover and the frequency with which the soil is wetted by rain and/or irrigation. The K_c values follow a general curve (Figure 2.1).

For most crops, K_c increases from a low value (0.5–0.9) during the initial stages of growth, to a maximum value (0.9–1.2) during the period when the crop reaches full development, and declines again (0.3–0.9) as the crop matures. The K_c values for the initial crop development stage are related to ET_0 and frequency of irrigation or rain.

The crop growing season can be divided into four stages, as follows:

〈 Initial stage: germination to 10% ground cover
〈 Crop development stage: from 10% to 80% ground cover
〈 Mid-season stage: 80% ground cover to start of ripening
〈 Late stage: from start of ripening to harvest.

Average lengths for these crop-growth stages for various crops are given in Annex 4. Crop coefficient values for selected crops can be estimated from Table 2.2.

Finally, crop evapotranspiration is estimated by the following formula:

$$ET_c = K_c \times ET_0$$

where:

ET_c = crop evapotranspiration in mm/day
ET_0 = reference evapotranspiration in mm/day
K_c = crop coefficient.

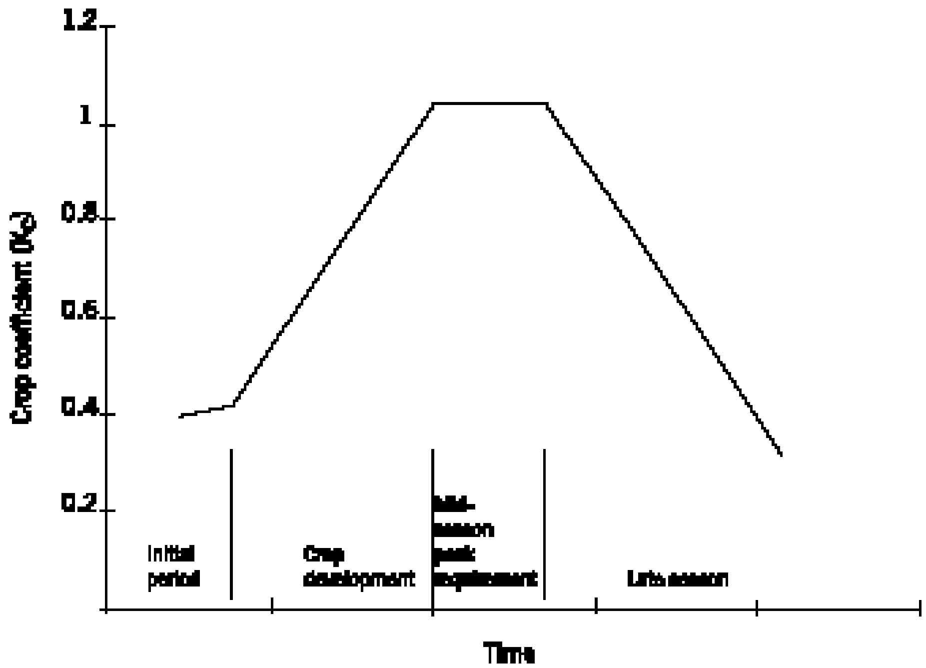


Figure 2.1 *Example of a crop coefficient (K_c) curve.*

Table 2.2 *Crop coefficient data for selected field crops (K_c)*

	Crop development stages			
Crop	Initial stage	Crop development	Mid-season	Late season
Banana (tropical)	0.4–0.5	0.7–0.9	1.0–1.1	0.9–1.0
Bean (green)	0.3–0.4	0.7–0.8	1.0–1.1	0.9–1.0
Bean (dry)	0.3–0.4	0.7–0.8	1.1–1.2	0.7–0.8
Cabbage	0.4–0.5	0.7–0.8	1.0–1.1	0.9–1.0
Cotton	0.4–0.5	0.7–0.8	1.1–1.3	0.9–1.0
Grape	0.4–0.6	0.6–0.8	0.7–0.9	0.6–0.8
Maize	0.3–0.5	0.7–0.9	1.1–1.2	1.0–1.2
Onion	0.4–0.6	0.7–0.8	1.0–1.1	0.9–1.0
Pea	0.4–0.5	0.7–0.9	1.1–1.2	1.0–1.2
Pepper	0.3–0.4	0.6–0.8	1.0–1.1	0.9–1.0
Potato	0.4–0.5	0.7–0.8	1.1–1.2	0.9–1.0
Sugarcane	0.4–0.5	0.7–1.0	1.0–1.3	0.8–0.9
Tomato	0.4–0.5	0.7–0.8	1.1–1.3	0.8–1.0
Watermelon	0.4–0.5	0.7–0.8	1.0–1.1	0.8–0.9

First figure: under high relative humidity (> 70%) and low wind (< 5 m/sec)
Second figure: under low relative humidity (< 20%) and high wind > 5 m/sec)

Source: Modified from Doorenbos and Kassam 1986, Table 18.

2.3.3 Actual crop evapotranspiration

The ET_c calculated above predicts crop evapotranspiration under non-limiting field conditions, whereas the conditions encountered in the field are often limiting, especially for resource-poor farmers. Lower than predicted evapotranspiration, actual crop evapotranspiration (ET_{ca}), and therefore crop production, will result from influences such as inadequate soil fertility, moisture deficit, soil salinity, waterlogging, and incidence of pests and diseases.

Reduction in crop yield under stress caused by a shortage of water (Doorenbos and Kassam 1986) and influence of salinity (Ayers and Wescot 1976) can be estimated using the following relationships.

Yield response to water

The response of yield to water supply is quantified through the yield response factor (K_y) which relates relative yield decrease ($1–Y_a/Y_m$) to relative evapotranspiration deficit ($1-ET_{ca}/ET_c$).

$$1 - Y_a/Y_m = K_y(1 - ET_{ca}/ET_c)$$

where

Y_a = actual yield of the crop
Y_m = maximum harvested yield in the absence of environmental or water stresses
K_y = yield response factor
ET_c = crop evapotranspiration under non-limiting conditions
ET_{ca} = crop evapotranspiration under prevailing environmental and water stress.

Yield response to salinity

The response of yield to soil salinity is quantified through the following equation:

$$Y = 100 - b\,(EC_e - a)$$

where

Y = relative crop yield in %
EC_e = salinity of the soil saturation extract (mmhos/cm)
a = salinity threshold value for the crop representing the maximum EC_e at which 100% yield can be obtained
b = yield decrement per unit of salinity, or percentage yield loss per unit (EC_e) between the threshold value (a) and the EC_e value representing the 100% yield decrement.

Crop tolerance tables presenting expected yield decrements for certain crops due to salinity of irrigation water are also found in Ayers and Wescot (1976).

Chapter 3

Drip irrigation

3.1 Historical perspective

Irrigation has been credited with the rise and flourishing of civilizations such as those in ancient Mesopotamia, Sumeria and Babylon. In Mesopotamia, irrigated agriculture began in about 4000 BC when a band of adventurous farmers migrated into the plains between the Euphrates and Tigris rivers in present-day Iraq. These settlers first depended on planting on the floodplains after the Euphrates river flood water had receded. They improved this practice by digging ditches to divert some of the river flow to water their crops during the dry season. In this way, the plains of Mesopotamia and the ingenuity of its early settlers gave rise to irrigation. In Egypt, basin irrigation introduced along the Nile in about 3300 BC still plays an important role in Egyptian agriculture. In China, water-control activities that began about 2200 BC are still practised today. The dominant methods of irrigation from these early times have been surface and sprinkler irrigation.

Developed economies now exist in some regions of the world solely because of irrigation. In Egypt, whose agriculture is highly dependent on irrigation, more and more desert land continues to be put under irrigated agriculture. Israel has developed the Negev Desert to produce food in an area where the annual rainfall could hardly sustain a crop for more than 10 days. The more recently developed drip irrigation methods have played a big role in this agricultural development in the Negev Desert where settlement of people would not have been possible without irrigation.

The first drip irrigation experiments are reported to have began in Germany in 1860. Subsurface clay pipes were used in combination with irrigation and drainage systems under which irrigation water was pumped into the underground drainage system to soak into the soil. As a result, crop yields doubled. In the United States, around 1873, Nehemiah Clark obtained a United States patent for the first known drip emitter that was a simple hole. Experiments with perforated pipes were introduced in 1920, providing an important breakthrough and leading to the development of entire irrigation systems using perforated pipes made of various materials.

The development of plastics during and after the Second World War meant that plastic pipes and other components of such water-supply systems could be produced easily and cheaply, and this helped to speed up the use of drip irrigation systems. In Germany, extensive work was done with underground irrigation using perforated plastic pipes. Irrigation of plants through narrow openings in plastic pipes can also be traced back to greenhouse operations in the United Kingdom in the late 1940s.

Current drip irrigation technology was developed in Israel, Denmark and the United States. In Israel in the early 1960s, Engineer Symgha Blass developed the first planted drip irrigation system using a micro-tube extending from a plastic main to irrigate trees. This was based on his observation that a large tree near a leaking tap exhibited more vigorous growth than other trees in the area. About the same time, Volmer Hansen in Denmark used the same kind of tube to water flower pots, and then developed his system for greenhouses. Each of these people was working independently and did not know of the other's work at the time. Blass continued work to develop the spiral emitter. In the United States, S. Davis installed the first field experiment with a subsurface drip irrigation system on a lemon orchard at Pomona, California in 1963. In 1964, Richard Chapin developed a drip tape for vegetable crops. Chapin's drip tape was first used on a crop of cantaloupe melon by Norman Smith on Long Island, N.Y., in combination with plastic mulch. The development of good filters and screens helped to solve the problem of clogging of emitters that was associated with drip irrigation.

By the late 1960s use of drip irrigation was expanding rapidly and spread rapidly throughout the semi-arid regions of Australia, Israel, New Zealand, Mexico, United States and South Africa, all areas where there was a pressing need to make efficient use of limited water supplies. By the 1970s, equipment development and manufacture tended to overshadow basic research studies directed towards an understanding of the optimum design, management and maintenance of this new method.

Drip irrigation technology has continued to undergo intensive research and new development over the past 30 years. Advances in drip-tape technology made it possible to develop simple drip irrigation systems that poor families could afford. In 1974, the aid organization Catholic Relief Services asked Richard Chapin to help set up a small irrigation system for vegetables in Senegal. He used a system in which a 50-gallon (189 litre) drum was mounted 1.5–2 m above the level of the soil and drip lines were connected to the drum. This worked very well but was, however, still too complicated and expensive for poor people with small kitchen gardens.

The development of new and better drip irrigation tapes in the 1980s made it possible to use a bucket mounted only 1 m above the soil to irrigate two rows of vegetables 15 m long. These simple irrigation kits could be produced economically and shipped anywhere in the world. International Development Enterprise (IDE), based in Denver, Colorado, has also designed and field tested several drip irrigation systems that are more affordable and appropriate for smallholder farms and have been used in various parts of India. In Israel and parts of Africa, middle-range low-pressure systems comprising a 200–1,000 litre drum connected to a network of drip irrigation pipes have emerged, especially in the 1990s.

3.2 Principles of the drip irrigation method

Drip irrigation involves dripping water onto the soil at very low flow rates (0.2–20 l/h) from a system of small-diameter plastic pipes fitted with outlets (drip emitters). The basic concept underlying the drip irrigation method is to supply the amount of water needed by the plant within a limited volume of soil and as often as needed. Water is applied close to the plant so that only that part of the soil immediately surrounding the plant is wetted. The volume of soil irrigated by each drip emitter and the water flow along the soil profile are a function of the characteristics of the soil (texture and hydraulic conductivity) and the discharge rate of the drip emitter. Applications are usually frequent (every 1–3 days) to provide a favourable moisture level for the plants to flourish. Compared to the sprinkler and furrow-irrigation methods (with efficiencies of 60–70% in high-management systems), drip irrigation can achieve 90–95% efficiency. Table 3.1 gives comparative irrigation requirements for meeting crop demand with the different irrigation methods.

Table 3.1 *Comparison of typical irrigation requirements under well-designed and managed drip, sprinkler and furrow irrigation systems (mm/day)*

Net crop water demand	Irrigation requirement (drip method)	Irrigation requirement (sprinkler method)	Irrigation requirement (furrow method)
3.0	3.3	4.3	5.0
3.5	3.9	5.0	5.8
4.0	4.4	5.7	6.7
4.5	5.0	6.4	7.5
5.0	5.6	7.1	8.3
5.5	6.1	7.9	9.2
6.0	6.7	8.6	10.0

3.3 Advantages of drip irrigation

3.3.1 More uniform and higher crop yields

With a drip irrigation system, irrigation takes place on a frequent basis, enabling the water manager to maintain the soil moisture at an optimum level. A well-designed, well-maintained drip irrigation system can also apply water more evenly than other irrigation methods. These features lead to more uniform and higher crop yields per land unit.

3.3.2 More efficient use of available water

Precise water application with drip irrigation is possible making irrigation much more efficient, an attribute that makes the drip irrigation method especially attractive if water is scarce or expensive. Direct evaporation from the soil surface and water uptake by weeds are reduced by not wetting the entire soil surface between rows or trees. Sprinkler irrigation is subject to water loss by wind drift, increased evaporation, or poor application uniformity, especially with strong winds. Drip irrigation can reduce or eliminate runoff and deep percolation, making it possible to manage difficult soils ranging from crusting soils to porous sandy ones.

3.3.3 Reduced cost for fertilizer and other chemicals

Precise application of nutrients is possible using drip irrigation. Fertilizer costs and nitrate losses can be reduced considerably when the fertilizer is applied through the irrigation water (termed fertigation). Nutrient applications can be better timed to coincide with plant needs since dressing can be carried out frequently in small amounts and fertilizers are brought to the immediate vicinity of the active roots. Besides fertilizers, other water additives such as herbicides, insecticides and fungicides can be supplied to improve crop production.

3.3.4 Reduced labour costs

Cultural practices such as weeding can be performed when the plants are being irrigated. A drip irrigation system can be automated so that water is automatically switched on to irrigate and automatically turned off after the pre-set depth of irrigation has been attained. Labour and operational costs can be reduced by simultaneous application of water, fertilizer, herbicide, insecticide or other additives through the drip system.

3.3.5 Low energy requirement

A drip irrigation system requires less energy than a conventional pressurized system as it increases irrigation efficiency and therefore requires less water to be pumped. Compared to other pressurized systems, savings are also made because of the lower operational water pressure required for drip systems.

3.3.6 Reduced salinity hazard

When the drip lines are placed close to a row of plants, the root zone tends to be relatively free of salt accumulations as the salts always accumulate towards the edge of the wetted area. The accumulation of salts on a surface-irrigated field tends to be right in the middle of the root zone. With drip irrigation, the distribution of water during the infiltration process is governed by the soil’s hydraulic properties and emitter discharge. Since the drip irrigation system can supply water frequently, the irrigation regime leaves a zone of wetted soil with a lowered salt content, which is beneficial for root activity. Furthermore, applying water directly on the soil surface eliminates the opportunity for salts to be absorbed through the leaves, as may occur in sprinkler irrigation.

3.4 Disadvantages associated with drip irrigation

3.4.1 Cost

Conventional drip irrigation systems typically cost US$ 5,000–10,000 per hectare, or much more, installed in East Africa. However, recent advances have introduced some adaptations in the systems that are making them accessible to small-scale farmers. In Chapter 4, we describe simple drip irrigation systems which would cost a farmer US$ 15 to cover 15 m^2, or US$ 200–400 for a bigger system covering 500 m^2.

3.4.2 Technical limitations

A higher level of design, management and maintenance is required with drip irrigation than other methods. Good water management under drip irrigation is essential as irrigating with more water than the plants require will result in the loss of most of the benefits of drip irrigation. Over-irrigation will also make the soil excessively wet and therefore promote disease, weed growth and nutrient leaching. However, smallholder farmers generally are quick to learn and adopt drip irrigation technology in the light of their practical experiences in using the various methods.

3.4.3 Clogging of emitters

Clogging of emitters is the most serious problem associated with drip irrigation. Clogging causes poor water distribution along the drip laterals and this affects plant growth. Research has resulted in the development of emitters with specific properties that minimize the opportunity for clogging. To prevent blockage, care should be taken to filter the water properly before use, depending on the particular particle size and type of suspended material contained in the irrigation water.

3.4.4 Restricted root zone

Particularly in regions of low rainfall, plant root activity is limited to the soil zone wetted by the drip emitters—usually a much smaller soil volume than that wetted by full-coverage sprinkler or surface irrigation systems. Thus, if a drip irrigation installation fails, the crops will suffer even more from drought than crops watered by sprinkler or surface irrigation. This is because under drip irrigation the confinement of roots to a relatively shallow profile means less available soil water storage for the plants.

3.4.5 Salt accumulation in the root zone

Unlike surface and sprinkler irrigation systems, which can flush out salts below the crop root zone, surface drip irrigation systems tend to move salts to the outer edge of the wetted volume of soil and soil surface. Careful management is therefore necessary to ensure that the salts do not migrate back to the active root zone. If rainfall is insufficient to totally leach the salts from the root zone, this rainfall can move the salts into the root zone and cause damage. This is very common in areas with annual rainfall less than

100 mm. Growers who have a build-up of salts on the outer edge of the wetted pattern, will often turn on their drip irrigation during the first rain of the season to keep the salts from soaking back into the relatively salt-free root zone. However, in regions where the annual rainfall is more than 100 mm, salt accumulation in the upper layer of the soil is occasionally leached thus limiting the damage to plants. If the need to leach salts from the root zone becomes necessary, a sprinkler or surface irrigation system may have to be used.

3.5 Components of a drip irrigation system

There are different kinds of drip irrigation systems varying in detail (as described in Chapter 4). However, the basic components of any drip irrigation system (Figure 3.1) are:

- Water source—to provide the amount of water required at the necessary pressure to distribute and push water out of the drip emitters;
- Control valve—to open and shut off the water;
- Injection equipment—to apply fertilizers and other additives through the system;
- Flow meter—to measure the amount of water moving through the system;
- Filter—to remove particles from the irrigation water that may clog the drip emitters;
- Pressure regulator—to regulate water pressure;
- Main and submain lines—to carry and distribute water to the drip laterals;
- Drip laterals—to carry the water and distribute it to the drip emitters;

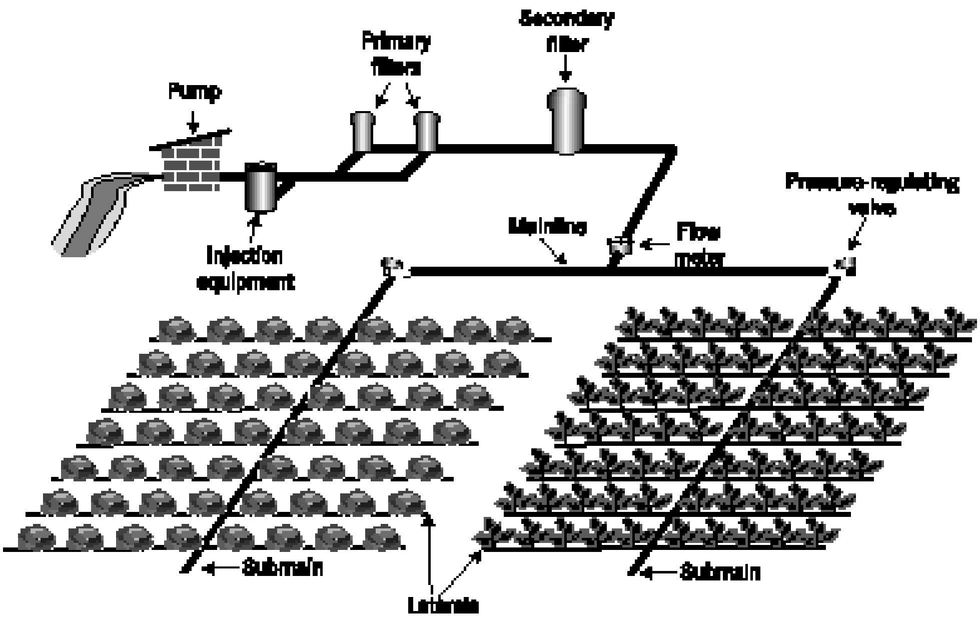


Figure 3.1 *A typical drip irrigation system.*

- Emitters—to control the flow of water from the laterals into the soil;
- Flushing manifold—to wash sediments from the lateral lines.

3.5.1 Water source

Drip irrigation systems operate within certain pressure ranges, depending on the operational pressure of the drip emitters. A drip system should therefore be designed to meet the required demand in terms of water flow and pressure. Pressure gives the driving force for the water to be released from the emitters into the soil. For water at rest in a container the maximum pressure (pressure is also referred to as "head") is the relative height of water above the point of measurement. An operating irrigation system has water flowing through the pipes, valves and other components resulting in continuous pressure loss as distance from the source increases. Therefore, it is necessary to compute the total head required for the drip irrigation system. For a water source situated at a higher elevation than the irrigated field, no pump is required if the available head is more than or equal to the total head required for the irrigation system. Where it is less, a pump is required to give the necessary pressure.

Common irrigation pumps are the centrifugal or piston types. They may be power driven by electrical motors or by an engine or manually.

3.5.2 Valve

Control valves are an important part of a drip irrigation system to regulate the water flow.

3.5.3 Flow meter

Flow meters can be used to measure the water flowing on to the fields. Some flow meters turn off the water automatically when a certain amount of water has been applied.

3.5.4 Injection equipment

Injectors are used to apply fertilizer and other materials to the water in the drip lines. These injectors may be dependent on the water pressure, such as a pressure drop across an orifice, to draw material from a tank, or may require their own piston-type, motor driven, injecting equipment.

3.5.5 Filters

The water to be used in drip irrigation must be cleaner than drinking water. The relative sensitivity of a particular emitter to clogging is influenced by the dimensions and configurations of the flow passages. Inorganic material such as sand, silt, clay and chemical precipitates, or organic material such as algae and bacterial slimes, can clog the passage ways. A guide for classifying the relative clogging potential of various types of irrigation water is given in Table 3.2.

Table 3.2 *Relative clogging potential of water used in drip irrigation systems.*

Type of problem	Minor	Moderate	Severe
Physical			
Maximum suspended solids (mg/l)	< 50	50–100	> 100
Chemical			
pH	< 7.0	7.0–8.0	> 8.0
Maximum total dissolved solids (mg/l)	< 500	500–2,000	> 2,000
Electrical conductivity (dS/m or mmhos/cm)	< 0.8	0.8-3.0	> 3.0
Maximum manganese concentration (mg/l)	< 0.1	0.1–1.5	> 1.5
Fe concentration (mg/l)	< 0.2	0.2–1.5	>1.5
H_2S concentration (mg/l)	< 0.2	0.2–2.0	> 2.0
Biological			
Bacterial population (maximum number per ml)	< 10,000	10,000–50,000	> 50,000

Sources: Modified from Hillel 1982 and Hanson et al. 1994.
Notes:
Electrical conductivity (EC) is a measure of the total dissolved salts (TDS). Approximately the relationship is: TDS (mg/l or ppm) = 640 x EC (dS/m or mmhos/cm).

Irrigation water must therefore be filtered if it is to be used in a drip system. To do this, various types of filters are used individually or in combination. Filters may be cartridge, screen or disc, suction screen, centrifugal separator, gravity flow or sand/gravel filters. The filters may be used separately or in combination, depending on the quality of the irrigation water and the level of filtration required. Filters that remove heavy loads of fine sands and organic material are known as primary filters (suction screen, centrifugal separator, gravity flow or sand/gravel filters). After primary filtration, a secondary filter (cartridge, screen or disc filter) is used to remove the smaller particles from the irrigation water. The various filters are described by the respective product manufacturers and will not be discussed in detail in this handbook. The best type to use depends on the type and size of particles suspended in the water to be used for irrigation. Table 3.3 provides an example as a filtration guideline.

Filtration can also be done by using a simple filter placed between the source of water and the irrigation lines. For example, the filter used in the Chapin bucket drip irrigation system (described in Chapter 4) is made from mesh screen and rubber material and costs less than US$ 1.5 (Figure 3.2). The mesh screen serves to filter suspended material from the irrigation water. The rubber has a tapered screen end to fit into a ʃ-inch socket, while the other end has two outlets for header tubings. The header tubings act like submains to distribute water into the drip laterals. Another method is to tie a clean piece of cloth over the bucket and pour the water through it.

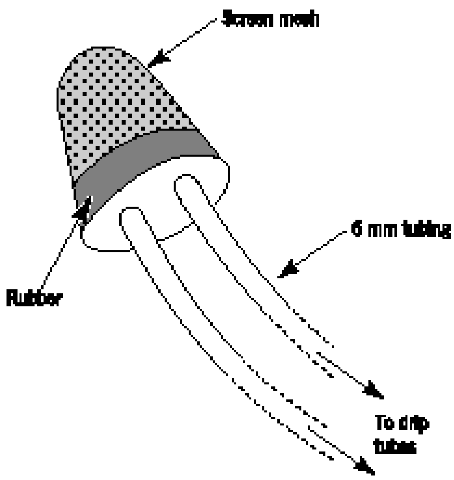


Figure 3.2 *Simple filter screen.*

Table 3.3 *Filtration guidelines.*

Flow rate	Concentrations		Required type of filter
	Inorganic	Organic	
Less than 11.4 m^3/h	L	L	A
	L	M	D + A
	L	H	D + A
	M	L	C + A
	M	M	C + D + A
	M	H	C + D + A
	H	L	C + A
	H	M	C + D + A
	H	H	C + D + A
11.4–45.6 m^3/h	L	L	B
	L	M	D or B
	L	H	D + B or F
	M	L	C + B
	M	M	C + D or F
	M	H	C + F or E
	H	L	C + B
	H	M	C + D + F or C + F
	H	H	C + D + F
More than 45.6 m^3/h	L	L	B
	L	M	D + B or D + F or E
	L	H	D + B or D + F
	M	L	C + F/E
	M	M	C + F/C + D or E
	M	H	C + D + F
	H	L	C + F/E
	H	M	C + D + F or C + E
	H	H	C + D + F

Source: Modified from Hanson et al. 1994.
L = < 5 mg/l
M = 5–50 mg/l
H = > 50 mg/l

A = cartridge filter
B = screen/disk filters
C = suction screen filter
D = centrifugal separator
E = gravity filter
F = sand media filter

3.5.6 Pressure regulator

This is a mechanical valve required to maintain the system near design pressure, depending on the emitters. A pressure regulator is installed immediately downstream of the secondary filter to reduce the pressure to the required head.

3.5.7 Main and submain lines

Main and submain lines carry water to the drip laterals. They are usually made of plastic, although steel pipes are also used. The size depends on the required water flow in the laterals served. Large main lines are connected to smaller submains, which are in turn connected to the drip laterals.

3.5.8 Drip lateral lines

Drip lines are made from polyethylene tubes with diameters of 8–25 mm. The most common drip line sizes are in the range of 12–20 mm in diameter. Flow rates along the drip line tend to drop and therefore there is a higher risk of clogging of the drip emitters by particles carried by the water. Specifications by manufacturers, results of research and local experience will guide you as to the appropriate size and length of drip laterals required. The longer the lateral the greater the amount of water required to fill the tube to generate the pressure required to regulate the discharge rate.

The density of plants in the field usually determines spacing between emitters; only after this is the soil type and water quality considered. Available emitter spacing for integral drip lines range from 5 cm to 90 cm, with 30 cm being quite common for field crops and the 90 cm spacing being most common for orchard irrigation. When the soil allows for lateral spread of water and the quality of water is good, it is possible to install a single drip line between plant rows. For porous soil like a sandy soil, each plant is planted next to the drip emitter.

3.5.9 Drip emitters

The drip emitter controls the flow from the lateral into the soil. Common drip emitters have flow rates in the range 0.5–15 l/h at the standard pressure of 1 atmosphere. Drip emitters should be suitable for the drip irrigation system in question. In particular they must distribute the water uniformly. The variation in discharge between the emitters in the whole field, that is, the average differences in emitter discharge rates between individual emitters and the average discharge for the system should not exceed 20%. Along a drip lateral, the average difference in emitter discharge rates between individual emitters and the average discharge for the lateral should not exceed 10%. Another important aspect is resistance to clogging at the water pressure operational for the system. Some emitters are self-cleaning and others can be opened for cleaning. Information on the emitter's resistance to clogging is supplied by manufacturers but should be supported by research data and local experience.

Frequent inspection of emitters to identify clogged ones is necessary. This does not take long and can be done once a week. A clogged emitter can be repaired by rubbing it vigorously with the fingers or against itself, blowing in it, or trying to force water out of the outlet.

Three types of drip emitters are available:

1. In-line drip emitters

In this type individual emitters are already installed inside the drip tubing as part of the tubing flow path with drip emitter ends on either side. The drip emitter ends are connected to each other by a lateral segment to produce the required drip line. In-line drip emitters are suitable for field crops as well as orchards and landscape irrigation.

2. Integral drip emitters

In the integral type the drip emitters are welded to the inner wall of the tube and come as continuous rolls (integral drip lines) with outlets at predetermined intervals. Drip lines are available in various diameters, wall thickness and emitter spacing. Integral drip lines are mainly used in field crops and orchard irrigation.

3. On-line drip emitters or button-type emitters

In this type the drip emitters are designed to be inserted directly into the wall of the tube or through 5-mm micro-tubes, either at predetermined intervals or in clusters. The button-type emitters are mainly used in orchard, pot plant or landscape irrigation.

3.5.10 Flushing manifold

Flushing the drip lateral lines provides a cleansing action for the drip system. To flush the lateral, water is allowed to flow freely out of the end of the lateral line. This momentarily increases the velocity of water inside the lateral thus flushing sediments from the lateral line. The lateral lines can be provided with individual flushing units at the ends or connected through a flushing manifold to flush several lateral lines at once.

3.6 Simplified drip systems

Modifications are constantly being made to simplify drip irrigation systems and make them more affordable. These systems attempt to simplify the equipment design while maintaining the basic high-frequency, high-efficiency and low-volume irrigation advantages of drip irrigation. Some of these modifications are:

- Improvization of drip emitters
- Low hydraulic pressure systems.

3.6.1 Home-made drip emitters

Simple drip emitters can be made by punching holes manually in the lateral tubes. To make such perforations as uniform as possible, a standard hole puncher is used. To prevent excessive flow or blockage of the perforations, the holes can be covered with tight-fitting collars made by slitting short sections of the same tube that is used for the laterals and slipping them over the holes (Figure 3.3). With experience, a user can make adequate emitters for a fraction of the cost of commercial emitters.

Another way to make emitters is to insert sections of micro-tube into holes punched in the lateral tubes, then adjusting the micro-tube length to provide the desired discharge rate.

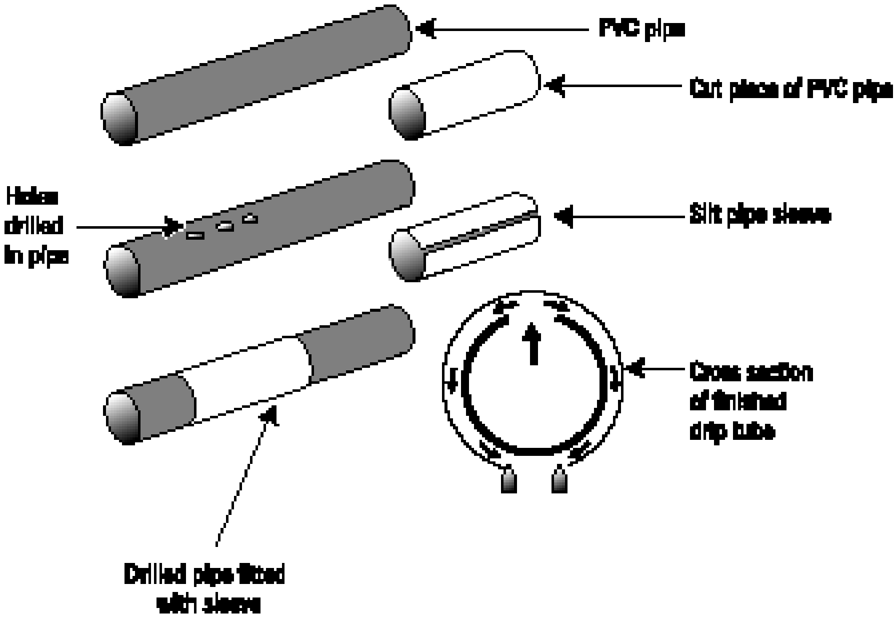


Figure 3.3 *Simple drip emitter: a hole and collar.*

3.6.2 Low hydraulic pressure systems

Low hydraulic pressure systems can be devised that do not require mechanical pumps. Elevating the reservoir just a few metres above the land to be irrigated creates a gravitational head sufficient for drip irrigating a small area.

Table 4.1 *Characteristics of different categories of drip irrigation system.*

System type	Pressure requirement (m)	Area covered by individual system (m^2)	Systems used in ESA	Systems used elsewhere
Bucket kits	0.5–1	< 20	Chapin Waterboys	IDE
Drum kits	0.5–5	20–1,000	KARI–Chapin Waggon Wheel Family drip Plastro	Micro-Tal IDE
Farm kits	5–25	> 1,000	Chapin, IIS, KARI	WTC

4.2 General features and management aspects

4.2.1 General features

Drip irrigation systems consist of water storage, water filtration, water conveyance and distribution, and water application sub-systems. Details of some of these drip irrigation systems available on the market are presented in this chapter. Common preparation requirements and features are as follows:

〈 Prepare the area to be irrigated. This could be simple land preparation or involve the formation of planting beds (see box).
〈 For best results, drip systems are used to irrigate level beds. If the drip tubes go uphill, downhill or around corners, the system will not give equal water flow from each dripping outlet.
〈 Construct the water container stand. Ensure that it can support the weight of the container and water when full.
〈 Mount the water container on the stand so that the water outlet is at the height necessary to provide the water pressure required to operate the system.
〈 Mount the container water outlet, water filtration and flow regulator fittings.
〈 Lay the water distribution system components that connect the water container to the individual drip lines. Make sure that the open ends are closed to avoid foreign material entering the pipe.
〈 Unroll the drip lines and lay them along the full length of each row of plants to be irrigated.
〈 Connect the drip lines with the water distribution system (header pipes).
〈 Flush the system to remove any foreign matter that may have entered the pipeline.
〈 Close the end of the drip lines.

It must be emphasized that any training or advice on the use of drip kit systems should not only cover actual kit installation and maintenance, but also all aspects of growing vegetables under drought conditions since the purpose is to increase farmers' yields. Thus training and advice should include lessons about bed preparation and composting, transplanting, irrigation-water management and pest and disease control.

Preparation of a planting bed

1. Lay out the planting bed depending on the length, spacing and number of the drip lines.
2. Excavate shallow trenches (15–30 cm deep) lengthwise where the row crops will be planted.
3. Place plant stover or green material in the trench to a depth of about 15 cm.
4. Add a 5–10 cm layer of fresh manure on top of the green material.
5. Cover the trench and level the ground to form a raised bed 10–20 cm above the aisles.

4.2.3 Maintaining the system

- Ensure that only clean water is used in order to minimize the chances of clogging the filtration system. A filter screen will keep coarse particles from entering the drip lines. If there is fine silt in the water, or blowing sand in the air, a piece of cloth can be tied over the top of the bucket. Water can be poured through the cloth to keep the fine particles from entering the bucket.
- Clean the filtration system at least twice a month.
- Inspect the emitters to identify clogged emitters at least once a week and unblock or replace any clogged emitters. Clogged drip emitters cause non-uniform application of water and result in non-uniform growth of the plants
- Flush the system at least once a month. The frequency can be increased or reduced depending on the amount of impurities in the irrigation water.
- Check and repair leaks frequently.
- Take extra care during field operations, particularly weeding, to avoid cutting the drip lines.
- Take precautions to minimize the destruction of drip lines by termites and rodents.
- When no longer in use uninstall the components of the system and store them in a safe place.

4.2.4 Water management tips

- Maintain an optimum soil-moisture regime by applying the required amount of water at the right frequency. Shallow sandy soils require more frequent (1–2 day interval) irrigation; deep clay loam soils allow less frequent (3–7 day) irrigation.
- During the early stages of crop growth the plant roots are shallow and therefore there is a need for more frequent irrigation and less water per irrigation event.
- During the flowering or late vegetative stage of the crop, water consumption is highest and an adequate water regime is vital. Ensure that the crop does not experience moisture stress during this period.
- Crop water use will vary from 3 to 7 mm/day. Ensure that adequate amounts (depending on the area and crop growth stage) are applied.
- All leaks should be mended quickly to prevent water wastage.

4.2.5 Planting tips

- To ensure that the plants are planted where they will benefit most from the water supplied by the emitters, irrigate the field before planting and plant seedlings on the wetted circle.
- Most crops require manure at a rate of 1–2 handfuls and/or 1 tablespoon of double super phosphate per planting hole.

4.3 Bucket systems

In bucket kit drip irrigation, water flows into the drip lines from a bucket reservoir placed 0.5–1 m above the ground to provide the required water pressure. The efficient use of water that is possible with drip irrigation enables a farmer to grow vegetables using 30–60 litres of water daily during the crop growing season.

A bucket kit system comprising two 15-m long drip lines can be used to grow 50 plants such as tomato, egg plant and similar crops requiring a spacing of 60 cm along the plant rows; 100 plants of spinach, cabbage, kale, pepper and similar plants requiring a spacing of 30 cm along the plant rows; or 300 plants of onion, carrot and similar plants requiring a spacing of 10 cm.

The standard bucket kit system consists of two drip lines placed 0.5 m apart on a bed with a width of 1 m. A bucket is placed on a stand at one end of the bed and connected to the drip lines. These bucket kit systems can irrigate 10–20 m^2, depending on the length of the drip tube and plant spacing.

The bucket should be filled once in the morning and once in the afternoon to supply 30–60 litres of water to the crop per day. The actual amount of water depends on crop water requirements and rainfall. In very dry areas and during the dry season 60 litres of water will be required per day.

There is a growing demand for bucket kits. For example, Chapin bucket kits are reported to be in use in over 80 countries world wide and the demand is growing fast. By 2001, more than 5,000 kits had been sold by KARI to Kenyan farmers who have adopted the bucket drip irrigation system. Non-governmental organisations (NGOs) and community based organizations are using drip irrigation kits as a poverty eradication tool. Despite their simplicity, bucket systems are extremely successful, saving precious water often fetched up to a mile away, and the labour needed to water each plant individually. Furthermore, it has been shown that plants that are watered using the bucket system have higher yields.

Three examples of bucket kits (Chapin, Waterboys and IDE) are described in this section. Each bucket kit comes with instructions on how to assemble it, to make the raised beds and how to manage them.

The average cost of a bucket kit is US$15.

4.3.1 Chapin system

Description of the system

Chapin bucket kits were developed by Richard Chapin of Chapin Living Water Foundation. This drip irrigation system (Figure 4.1) consists of a 20-litre bucket mounted 1 m above the ground and 30 m of drip tape.

Assembly instructions

1. Prepare the field to be irrigated.
2. Mount a 20- or 30-litre bucket (supplied by the farmer) with a ʃ-inch hole cut at the bottom 1 m above the ground.
3. Assemble the outlet from the bottom of the bucket by connecting the male adapter, rubber washer and female adapter.
4. Install the filter screen at the bottom of the bucket.
5. Install the two supply tubes running from the filter to the barb fittings.
6. Connect the 15-m drip irrigation tape through the drip lock fittings.

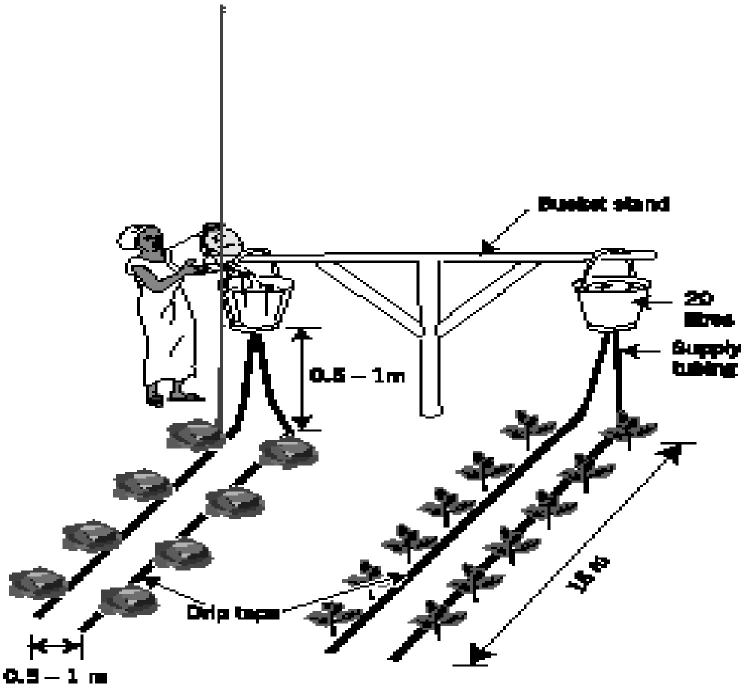


Figure 4.1 *Layout of Chapin bucket system with two drip lines.*

System components

〈 20-litre bucket 〈 Timber and nail for bucket stand 〈 2 pieces x 15 m drip tape 〈 2 pieces x 1.5 m supply tubing 〈 Filter screen 〈 Washer 〈 2 barb fittings 〈 Male adapter 〈 Female adapter

How to adapt the system to more than two drip lines

The contents of a Chapin bucket kit enable one to set up 2 x 15 m (two drip lines each 15 m long) or, by using the submain pipe, the kit can be used for 4 rows 7.5 m long or 6 rows 5 m long, depending on the size of the garden. To do this you need the piercing tool, the submain (4.6 m long) and the 3-m micro-tubing included in the kit. This is achieved by:

1. Cutting each drip tape twice (to make 4 lines), or three times (to make 6 lines);
2. Cutting 4–6 pieces of the micro-tube, depending on the number of drip lines;
3. Piercing a hole through the submain using the piercing tool;
4. Connecting each drip line to the submain using the micro-tubes.

For further information contact Chapin Living Waters Foundation and the Small Scale Drip Irrigation Project at Kenya Agricultural Research Institute (KARI).

4.3.2 Waterboys system

Description of the system

Waterboys (U) Ltd. have adapted drip irrigation technology and developed a bucket kit for smallholder farmers in Uganda (Figure 4.2). The kit comprises of one 30-litre bucket (the bucket is part of the kit), and 2 x 10 m of drip tubes connected to a water distribution manifold. The drip outlets in the standard kit are spaced at 30 cm. No filter is included in the Waterboys kit.

Assembly instructions

1. Prepare the planting bed 1-m wide x 10-m long.
2. Construct a bucket stand.
3. Lay the pipes. Since all the pipes are already connected, you only need to lay them out on the bed.
4. Mount the bucket on its stand.
5. Connect the manifold to the bucket with a snap-in collar.
6. Connect the two drip lines to the tee.

Dealing with filtration

Since a filter is not included in the kit, the Waterboys bucket kit system requires water that has already been filtered for irrigation. This may not be the case in many rural areas and even in some urban centres. Thus, if the water requires filtration, tie a clean cloth on the mouth of the bucket and always pour the water required for irrigation through it.

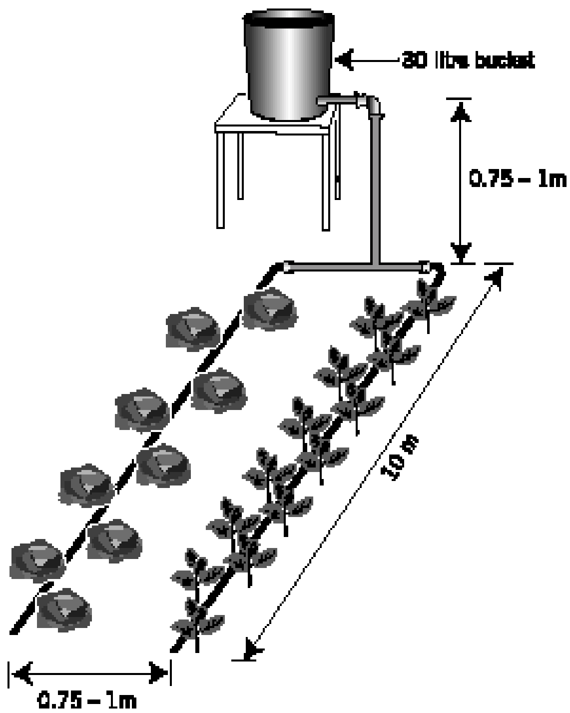


Figure 4.2 Layout of Waterboys bucket system.

System components

〈 30-litre bucket 〈 2 x 10 m complete drip line 〈 Manifold to connect 2 drip lines.

For further information contact Waterboys (U) Ltd.

4.3.3 IDE bucket kit

Description of the system

The International Development Enterprise (IDE) of the USA has also designed and tested a bucket system. The IDE bucket drip irrigation system (Figure 4.3) consists of a bucket, a valve, a filter, an end cap and a 10-m long 12-mm diameter lateral line fitted with 26 micro-tubes, 13 on each side. All the pipes are pre-fitted and packed in a small box. The 13 micro-tube connections are spread over the length of the drip lateral at a spacing of 0.75 cm. Water from the bucket flows out like a small stream from all 26 micro-tubes and spreads out in a circular pattern. Four plants are planted in each of the circles and therefore a total of 104 plants can be watered by the IDE bucket system. The valve is used for flow regulation—giving the advantage that the bucket can be filled beforehand and irrigation started when required. The end cap is used to close the end of the lateral line.

Assembly instructions

1. Prepare the planting bed.
2. Construct a bucket stand such that the bottom of the bucket is at a height of at least 0.5 m.
3. Unroll all the pipes and lay them on the ground.
4. Connect to the bucket with the snap-in collar provided at the bottom of the bucket.

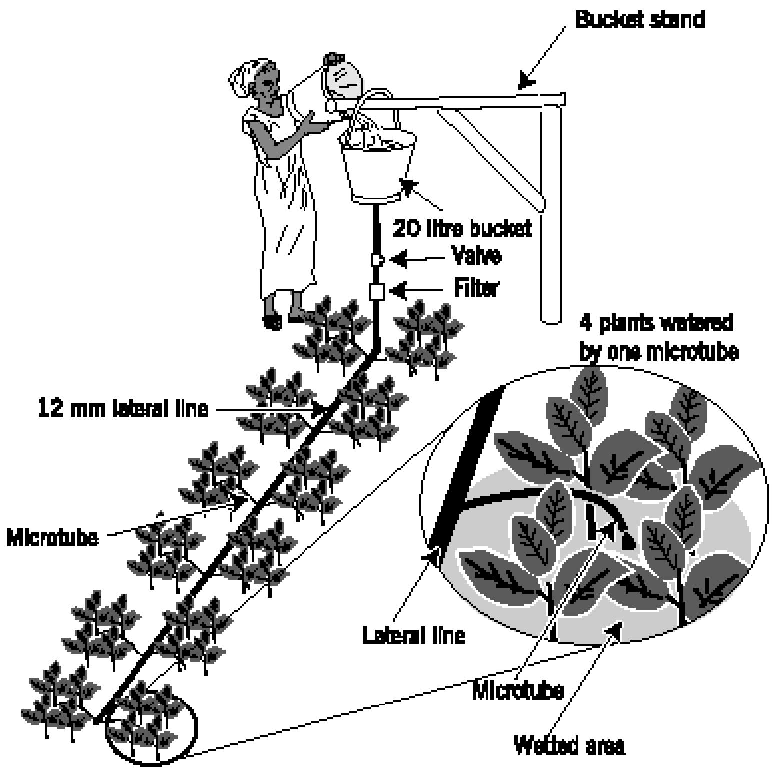


Figure 4.3 Layout of IDE bucket system.

System components
〈 20-litre bucket 〈 Regulating valve 〈 Line filter 〈 10-m long PE lateral fitted with 26 micro-tubes 〈 End cap.

For further information contact International Development Enterprises.

4.4 Drum systems

Drum systems operate under a low pressure head of water (0.5–5 m). Mounting the drums on block supports raised at least 1 m above the planting surface is recommended. The higher the drum is placed the greater the area that can be irrigated. An area of up to 1,000 m^2 can be covered by a drum system.

The main advantage of drum systems is the bigger area that can be covered compared to the bucket system. This presents an economic advantage because of the number of plants per drum system. A drum system covering 5 beds each 1 m wide and 15 m long can be used to grow 250 plants (tomato, egg plant and similar plants requiring a spacing of 60 cm along the plant rows); 500 plants (spinach, cabbage, kale, pepper and similar plants requiring a spacing of 30 cm along the plant rows); or 1,500 plants (onion, carrot and similar plants requiring a spacing of 10 cm). The drum system also offers water storage and control through a control valve, making it possible to fill the drum for irrigating at another time.

The standard drum kit system comprises a drum, control valve, a manifold and drip lines. The drum should be filled with the valve in the closed position. To irrigate it is important to open the valve fully. This allows the water to be distributed quickly through the drip lines and allows for good water distribution.

Six examples are presented: the KARI drum system from Kenya, the Waggon Wheel system from South Africa, the Family, Plastro and Micro-Tal systems from Israel, and the IDE drum used in India.

4.4.1 KARI-drum kit

Description of the system

This is a variation of the Chapin bucket kit and involves using a drum of about 200-litre capacity or the equivalent of five bucket drip irrigation systems. The development of this adaptation is credited to a farmer in Eldoret in the Rift Valley Province of Kenya who, after working with the bucket drip kits, connected an old drum to supply four drip lines. KARI improved on the drum adaptation (Figure 4.4) by designing the manifold with 4 or 5 openings each serving two drip lines.

Assembly instructions

1. Prepare a rectangular area 7.5 wide x 16 m.
2. Peg out the position of beds and paths to accommodate 5 beds each 1-m wide x 15-m long. Leave a 20 cm space between the beds.
3. Connect the manifold by cutting the pipe into 3 pieces each 1.25 m long. These are connected to the 3 tees and the 2 bends connected at the ends. The 3 tees and 2 bends on each side of the PVC pipe are designed to be centrally located on the five planting beds. Depending on the location of the drum, a tee is connected to channel the water from the drum to the manifold.

4. Use PVC glue for leak-proof fitting and wait for the required duration to allow bonding.
5. Lay out the drip tapes on the beds, two lines per bed, and insert the filter plugs into the open ends of the outlets in the manifold.
6. Finally, connect one end of the connector tubing to the filter plug and insert the barb fitting to the other end. Connect the drip tube to the drip lock fitting.

To install a drum system costs about KSh7,500 (US$100) in Kenya.

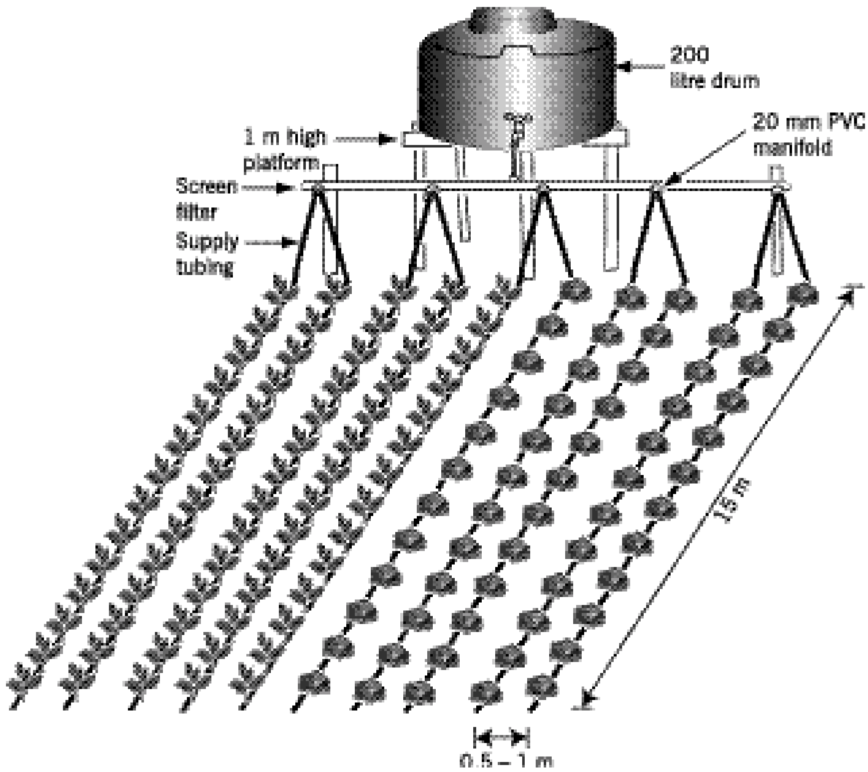


Figure 4.4 *Layout of a drum system adapted from Chapin's bucket kit.*

System components
〈200-litre drum with opening at one end or cut open 〈ʃ" gate valve (control valve) 〈ʃ" x 6 m plastic water pipe 〈4 x ʃ" PVC tees 〈3 x ʃ" PVC bends 〈5 filter plugs 〈10 x 0.5 m lengths of flexible tubing 〈10 barb x drip lock fittings 〈10 x 15 m drip irrigation tubes 〈10 drip tube end closures.

For further information contact the Small Scale Drip Irrigation Project at Kenya Agricultural Research Institute.

4.4.2 Waggon Wheel system

Description of the system

The Waggon Wheel system was developed in South Africa by Dr Gerrie Albertse in 1995. It has been used to grow vegetables and grapes in the very harsh conditions of arid South Africa. The Waggon Wheel irrigation system (Figure 4.5) uses a circular arrangement of 6 drip lines radiating out from the central reservoir drum (210 litres)—hence the name Waggon Wheel. The length of each drip line is 6 m.

Assembly instructions

1. Drill an outlet hole on the side of the drum about 10 cm from the bottom.
2. Install a back nut, nipple and control valve on the outlet.
3. Cut 6 pieces each 30 cm long from a 2-m PE pipe to be used in constructing the circular manifold.
4. Using 6 tee connectors construct a circular manifold by connecting the tee connectors to the PE pieces, as shown in the diagram.
5. Make a platform from an old drum cut in half.
6. Make the drip lines by cutting six 7-m lengths of 15-mm PE and mark the positions of the holes on the pipe (30 cm apart). Heat a 50-mm nail and burn a hole through both walls of the pipe. Cut 10-cm pieces of string and thread the string through the two holes. Tie a knot on each side. Close the drip line at the end by bending the pipe and tying it with a piece of wire.
7. Connect the drip lines to the manifold and the manifold to the drum outlet.

A typical cost of the home-made Waggon Wheel system is US$ 16 in South Africa.

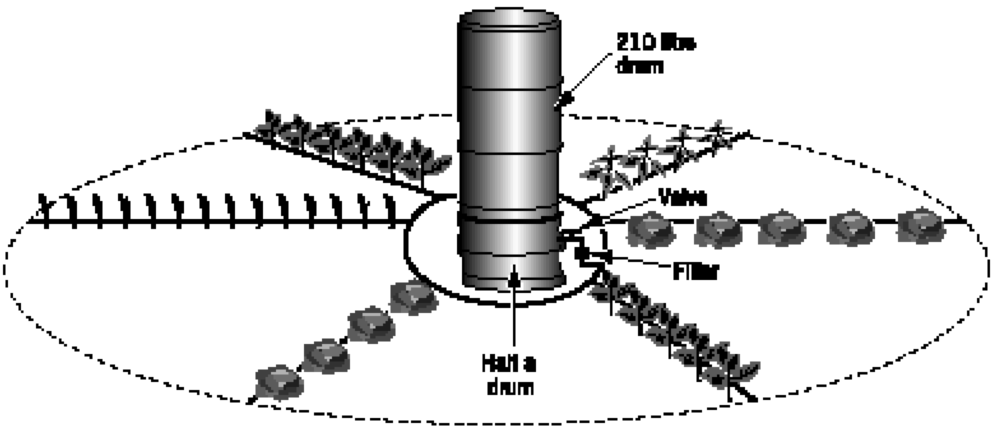


Figure 4.5 *The Waggon Wheel system.*

System components

〈 210-litre drum 〈 42 m 16 mm polyethylene pipe 〈 7 pieces 15 mm tee connectors 〈 1 unit 100 mm x 15 mm nipple with 2 back nuts 〈 15 mm control valve (tap) 〈 1.5 m 16 mm polyethylene pipes (manifold) 〈 3.6 m 1.5 mm nylon braided string.

For further information contact Gerrie Albertse.

4.4.3 Family drip system

Description of the system

The Family drip system, developed by Netafim Irrigation Equipment and Drip Systems company in Israel, is a low-pressure system intended for a family plot. Similar to the drip systems discussed above, no central pressurized water system or power source is required, and the technical level is such that it is easy to understand (Figure 4.6). The drip tube is made from heavy-duty polyethylene pipes (inside diameter 6 mm, outside diameter 8 mm) for low-pressure performance giving a drip emitter flow rate of 0.65 l/h at 1 m pressure. The drip outlets are spaced at 30 cm.

This system has been used in Israel and China. Plans are under way to make it available in many countries of the world through the Netafim distribution network of companies.

Assembly instructions

1. Order material from your supplier according to the area to be irrigated.
2. Construct a stand from locally available material.
3. Level the plots and install the irrigation system as per instructions.

In Kenya you can obtain further information or buy a complete system to irrigate 500 m^2 (for US\$ 470) from Amiran (K) Limited.

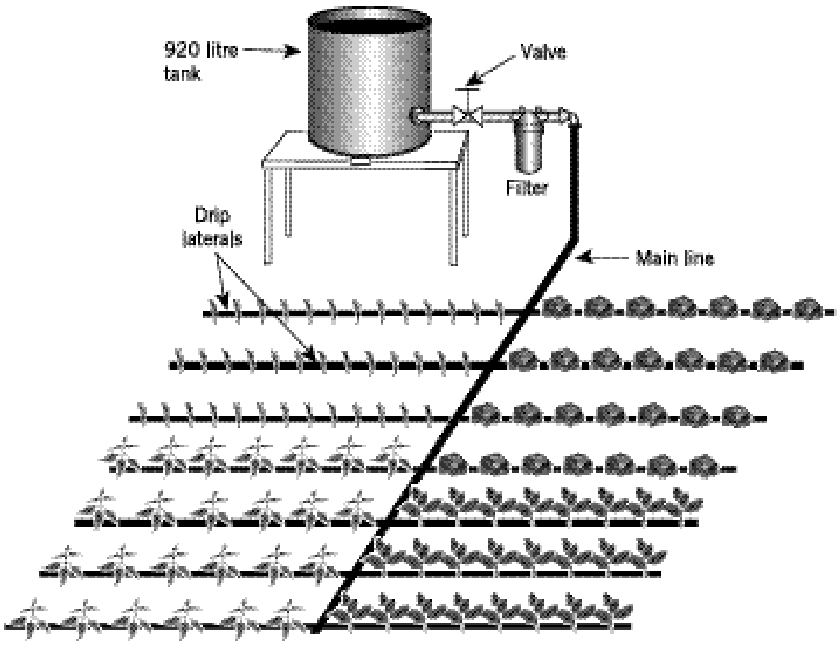


Figure 4.6 *Family drip system.*

System components

〈920-litre plastic water tank 〈1-inch screen filter (120 mesh) 〈Control valve 〈20 m x 40 mm PE pipe 〈14 dripline start connectors for PE pipe 〈14 insert connectors for dripline 〈14 dripline end closures 〈800 m x 8 mm dripline.

4.4.4 Micro-Tal system

Description of the system

The Micro-Tal system was developed by Ein-Tal Micro Drip Irrigation Ltd. in Israel. It is a gravity system that is adapted to take advantage of the benefits of the drip irrigation method without requiring an expensive water pressure system. The main feature of the Micro-Tal drip system (Figure 4.7) is the low flow rates of 0.1–0.5 l/h per emitter under low gravity pressure controlled by water heads up to 1 m. The very low flow rate (one-tenth of that of the ordinary drip) means that it takes 6–10 hours to supply the daily amount of irrigation water to a plant through the drip emitter. Another major difference with systems discussed earlier is the drip line, which is assembled by connecting in-line emitters with segments of 4-mm tubing. The gravity filter used in this system is also unique to the Micro-Tal.

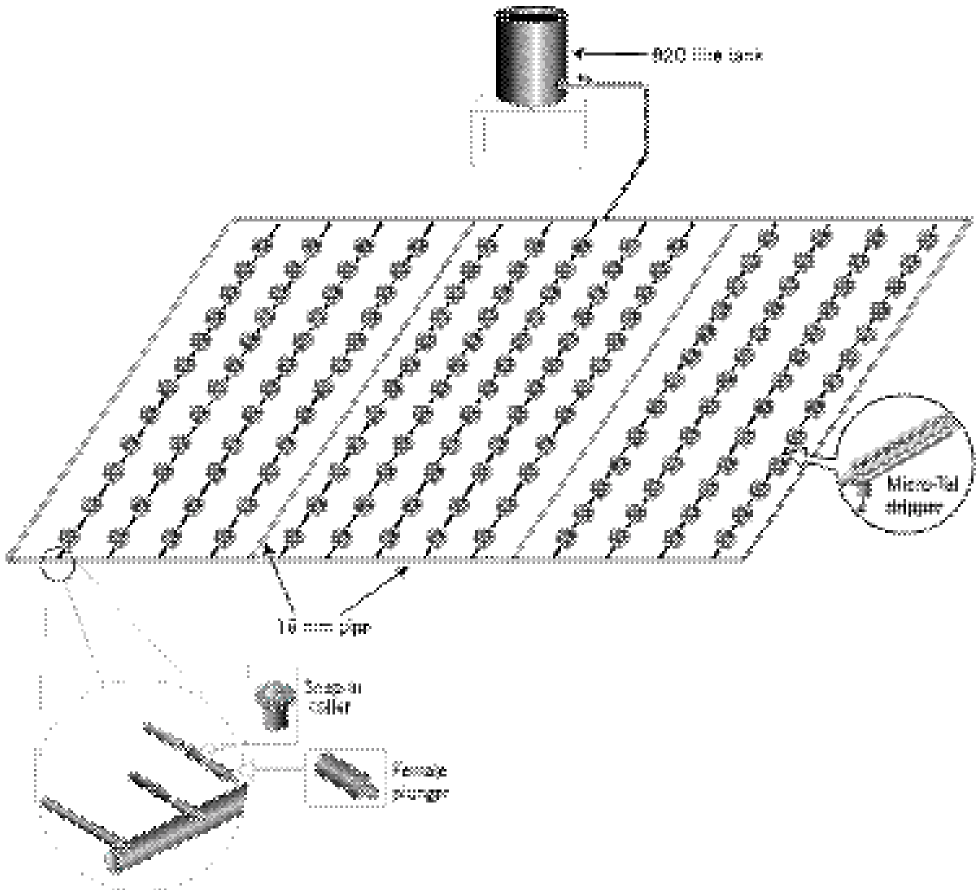


Figure 4.7 *Micro-Tal drip system.*

System components

- 920-litre drum
- Gravity filter
- Capillary micro-tube with 4 mm outside diameter
- Low flow in-line drip emitters
- 16 mm PE pipe
- 16 mm x 4 mm connectors.

Assembly instructions

1. Prepare a 60 m x 20 m garden to be irrigated by making planting beds as required.
2. Lay out a 16-mm PE pipe along the longer sides of the garden (feeder lines) and every 20 m connect the feeder lines with 16 mm pipe. This makes a network water delivery system that essentially divides the garden into three 20 m x 20 m units.
3. Locate the tank at the upper end of the garden. Unroll 20 m lengths of the 4 mm capillary micro-tube along the length of the garden.
4. Cut the 4 mm micro-tube according to crop spacing and connect the in-line Micro-Tal drip emitters.
5. Connect drip lines to feeder lines with female connectors using the snap-in collar.
6. Connect the set to a drum on a platform 0.5–1 m high.
7. Connect the gravity filter inside the drum.

For further information contact Ein-Tal Micro Drip Ltd.

4.4.5 Plastro system

Description of the system

The Plastro system (Figure 4.8) was also developed in Israel as a low-pressure drip irrigation system with high water efficiency, clogging resistance and durability. For further information contact Plastro GVAT in Israel, or ATIF (K) Limited.

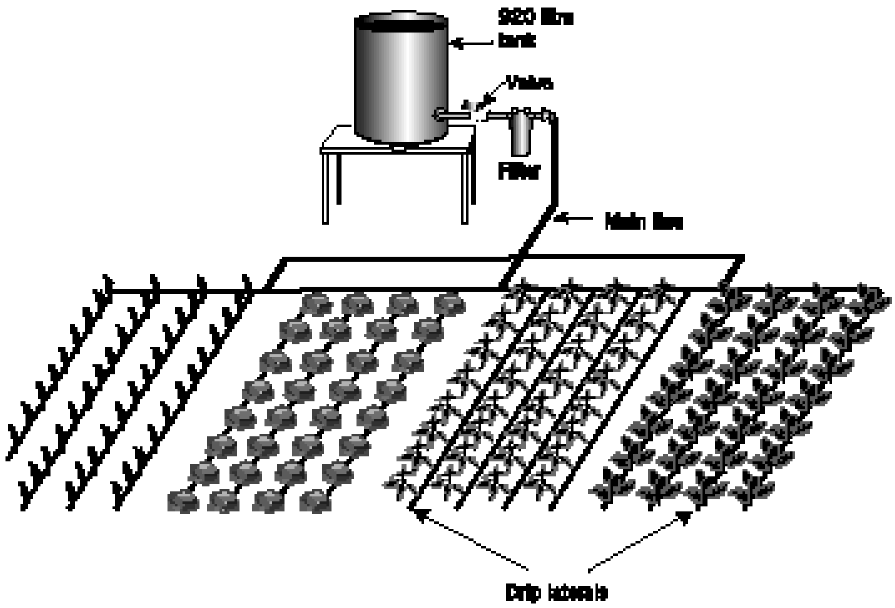


Figure 4.8 *Layout of Plastro system.*

System components

〈 920-litre plastic water tank 〈 Screen filter (120 mesh) 〈 Control valve 〈 24 m x 32 mm PE pipe 〈 2 x 32 mm bends 〈 2 x 32 mm equal tees 〈 16 dripline start connectors 〈 16 dripline end closures 〈 600 m standard 16 mm drip tube.

4.4.6 IDE system

Description of the system

International Development Enterprises of Colorado, USA, designed and tested a drum kit system which can irrigate 520 vegetable plants (Figure 4.9). The drum kit consists of 130 pipes (1-mm diameter) called micro-tubes, fitted to 5 rows of 12-mm diameter PE laterals. Water from the drum flows out in a small stream from all 130 micro-tubes. The water then spreads out in a circular pattern to about 0.5-m radius. Four plants are planted in each of the circles. Field tests are reported to have been carried out on vegetables in the hill areas of Nepal and in Andhra Pradesh, India.

Assembly instructions

1. Prepare the area to be irrigated.
2. Mount the drum.
3. Connect laterals to a 200-litre drum of water by a 16 mm-diameter pipe (submain).
4. Unroll all the pipes, lay them on the ground and connect to the drum. A manual is provided with the kit as a pictorial guide to correct installation and planting.

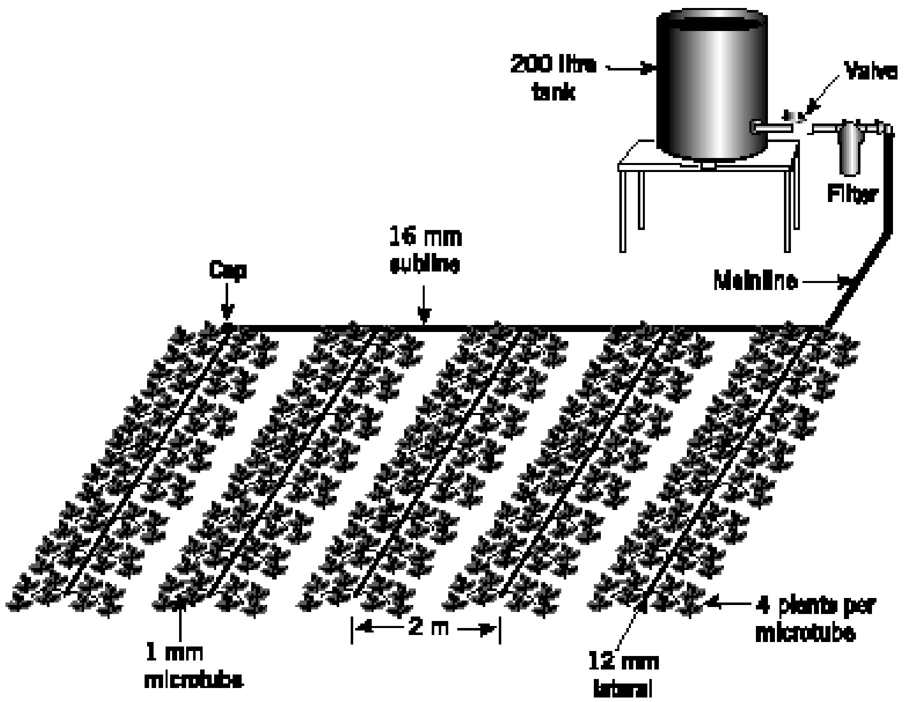


Figure 4.9 *Layout of IDE drum system.*

System components

〈 200-litre drum 〈 Tap 〈 Line filter 〈 16 mm submain pipe 〈 5 x 10 m PE laterals (12-mm diameter) fitted with 26 micro-tubes (1-mm diameter) 〈 5 end caps.

For further information contact International Development Enterprises.

4.5 Farm kits

In farm kit drip irrigation, water is connected directly to a pressurized water supply. This water supply could be pumped or gravity fed. The minimum pressure required is usually a 5-m head (0.5 bar). Water flows through a screen filter into a submain pipe then flows into the drip lines. The irrigated area can vary from 500 m^2 to more than 10,000 m^2. Several small kit systems can be laid out on a farm to cover a larger area. The drip tapes are placed on a prepared soil surface and plants are planted near the drip outlets to receive maximum benefit.

Four examples of such farm kits (Chapin, IIS, KARI and WTC) are described in this section. The Chapin and IIS systems are marketed as complete kits. The KARI and WTC systems are demonstrated by the organizations concerned and the components bought by the farmer from suppliers of drip irrigation equipment.

The average cost of a farm kit is US$ 200 for a system covering 500 m^2.

4.5.1 Chapin system

Description of the system

Garden drip irrigation kits are produced by Chapin Watermatics in the USA. The Kenya Agricultural Research Institute (KARI) has been involved in promoting the use of this kit under the name “eighth-acre kit” because each unit is commonly set to irrigate a 500 m^2 area. Figure 4.10 shows the system layout and components.

Assembly instructions

1. Use a hose hole punch to make a precise hole for connecting the drip lines to the header hose. The hole location is marked along the header hose by marking the first at 37.5 cm and thereafter at intervals of 75 cm.
2. Lay out the header hose and insert a connecting tube in each hole. The other side of the connecting tube is attached to the barb fitting.
3. Connect a 1–ʃ” screen filter/pressure regulator assembly to one end of the header hose closest to the water source. The other end is closed using the end cap.
4. Connect the water source to the filter.
5. Cut 20 drip lines each 30 m long from the roll of drip tube.
6. Lay the drip lines perpendicularly to the header hose.
7. Connect the drip line to the head via the barb fitting on the connecting tube.
8. Connect the drip lock fittings to each drip line. The ends of the drip lines are closed with the aid of the end closures.

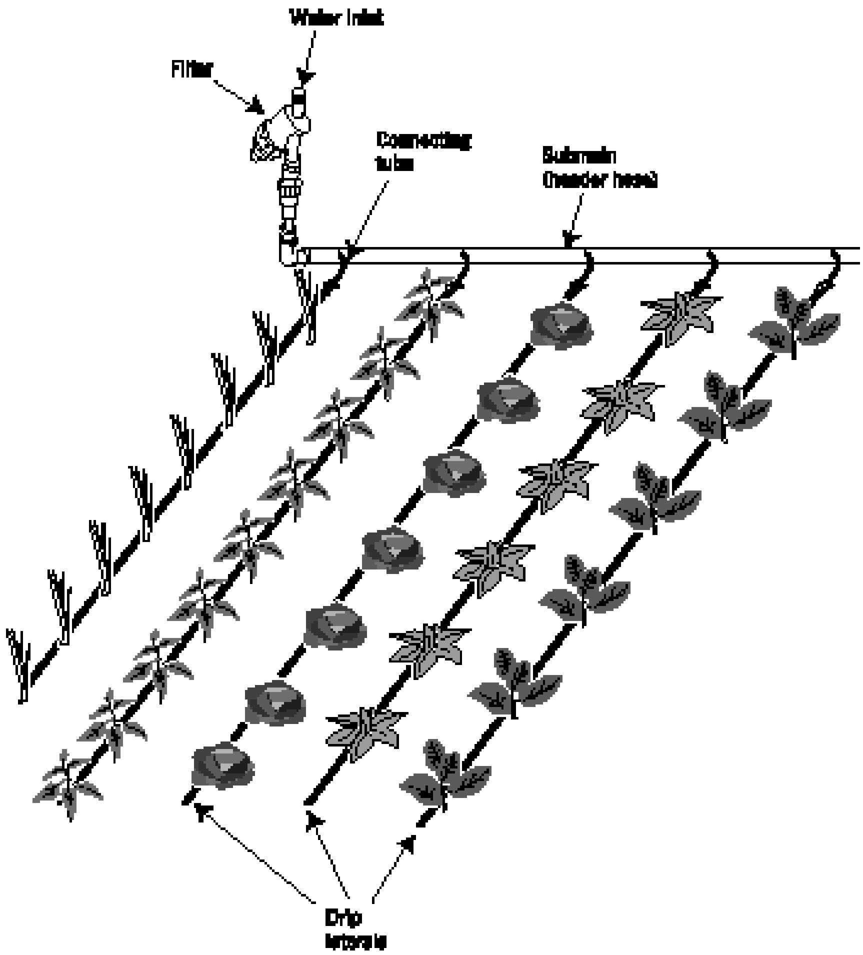


Figure 4.10 *Layout of Chapin system.*

System components
〈 1–ʃ” screen filter/pressure regulator assembly 〈 15 m header hose 〈 600 m drip tape 〈 2 header hose clamps 〈 20 connecting tubes 〈 20 barb x drip lock fittings 〈 20 end closures 〈 1 header hose punch 〈 1 end cap (1°”)

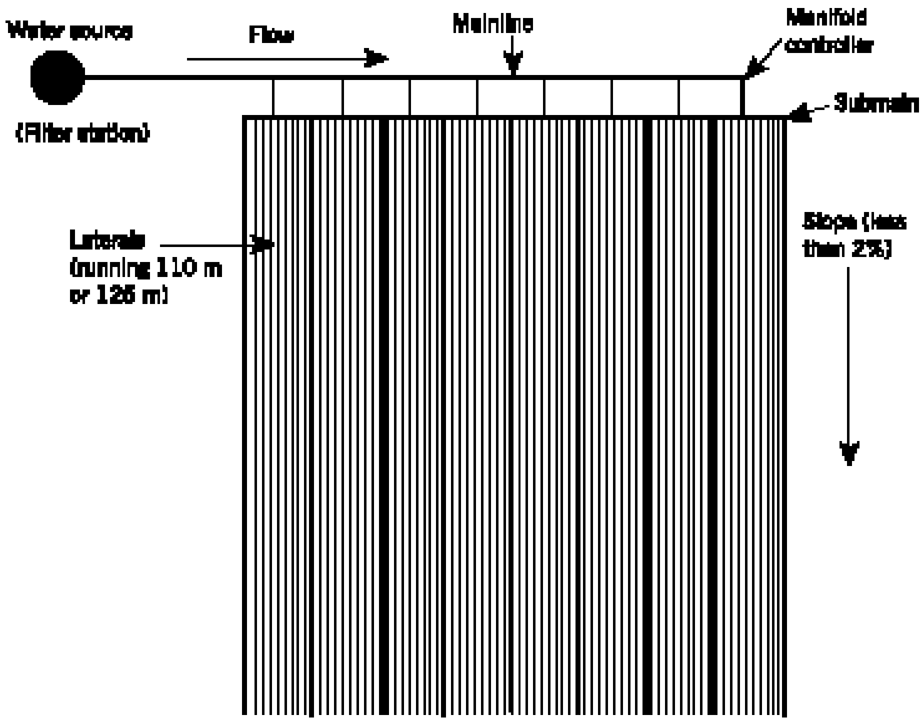
For further information contact Chapin Living Waters Foundation or the Small Scale Drip Irrigation Project, Kenya Agricultural Research Institute.

4.5.2 Integrated Irrigation Systems

Description of the system

The Zimbabwe-based Integrated Irrigation Systems (IIS) has developed a drip irrigation kit for a 10,000-m^2 area. The IIS kit is primarily aimed at small-scale commercial growers and is supplied in a complete kit form that enables the farmer to install and commission the scheme easily and conveniently on his own. The general field layout for this system is shown in Figure 4.11.

The irrigated area measuring 102 m wide and 110 m long is subdivided into eight sections that are irrigated independently of each other. Each section comprises a manifold controller that is complete with control valve, screen filter and pressure regulator. The manifold connects to a submain pipe connecting to 10 drip tubes. The number of manifolds that can be operated at any one time will depend on the available water.



4.11 *General layout of IIS drip kit.*

System components

〈 120- micron disc filter station with fertigation injector couplers 〈 Mainline and manifolds 〈 Manifold controllers with pressure regulators and vacuum release valves on each controller 〈 Infield off-takes, fittings and couplings 〈 Drip tape 〈 Accessories kit (for assembling) 〈 Lay-flat punch (for lay-flat kit only) 〈 Tools necessary for assembling and installation include hacksaw (PVC version) and scissors or sharp knife for cutting the drip tape laterals.

Assembly instructions

1. Prepare a fairly flat field with a gradient of less than 2% measuring 102 m wide and 110 m long.
2. Carefully unwind the drip tape from the reel to avoid stretching and twisting and do

not drag it over rough ground or surfaces that could cause damage to the edges of the tapes.

3. Lay the drip tape with the emitters facing upwards, according to instructions printed on the drip tape, to prevent any sediment that may have inadvertently entered the drip tube clogging the emitters.
4. Connect the other components according to supplied instructions.

   For further information contact Integrated Irrigation Systems.

4.5.3 KARI orchard drip irrigation system

Description of the system

At the National Agricultural Research Laboratories (NARL) in Nairobi, KARI has set up a simple orchard system that irrigates 500 banana and 60 passion fruit plants. The system facilitates watering of plants at a rate equivalent to their consumptive water use. The system uses polyethylene pipes for supply lines and for the drip laterals (see Figure 4.12). The polyethylene pipes are sized according to the required carrying capacity. On-line button drip emitters are inserted on the drip lateral to provide two drip emitters per plant. The use of on-line button drip emitters allows for fitting to take place in the orchard itself with varying spacing of plants. The advantage of the system lies in its simplicity.

Assembly instructions

1. Establish the total length of laterals and the number of plants per lateral required for the orchard. Count the number of laterals and measure the distance between them.
2. Locate the best position to connect to the water source. Measure the distance from the water source to the orchard header pipe.
3. Determine the available pressure and reliable supply rate.
4. Size the header lines according to the number of drip laterals served.
5. Select the most suitable dripper for the available water pressure.

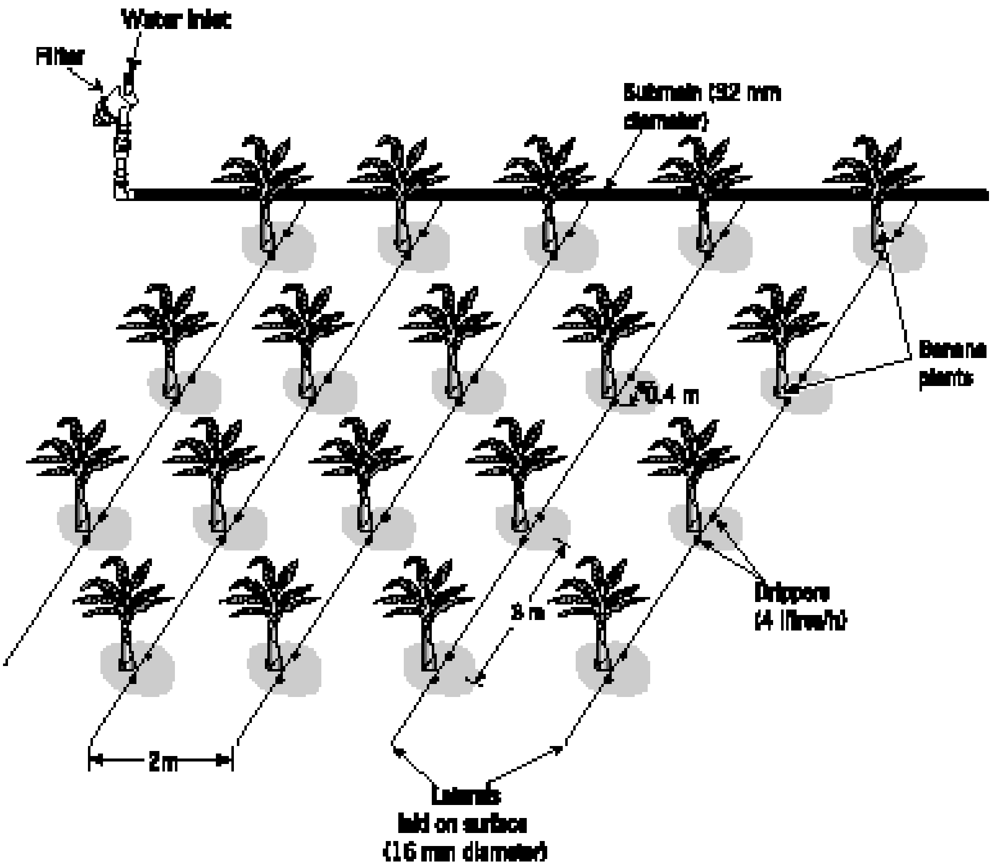


Figure 4.12 *KARI orchard drip system.*

System components

〈 Gate valve 〈 ʃ” screen filters 〈 Polyethylene pipes 〈 Button drip emitters 〈 Connecting tubing 〈 Hole puncher.

For further information contact the Small Scale Drip Irrigation Project, Kenya Agricultural Research Institute.

Research continues at NARL on small-scale orchard drip irrigation, and demonstrations and advice are available on request to NARL.

4.5.4 Water Technology Centre systems

Description of the system

During the 1970s, research on drip irrigation was initiated at the Water Technology Centre, College of Agricultural Engineering, Tamil Nadu Agricultural University in Coimbatore, India. As a result of continuous research, extension and feedback from the field, the scientists introduced some economies (e.g. planting two plant rows for each drip line), and durability (e.g. installing the drip tape below the soil surface) in the drip irrigation system elements. Hence, considerable cost reductions can be made in system components and installation, besides increasing the lifespan of the components. Economic drip irrigation designs, with detailed layout plans, have been proposed for medium- to long-duration crops like cotton, sugarcane, banana, turmeric, coconut and grapes which can save 20–30% of the system cost.

The drip irrigation design can have a surface or sub-surface water delivery system. When the water delivery system is laid on the surface, the lifespan of the system is reduced by physical and temperature damage. In the sub-surface water delivery system water is delivered to the drip lines using main, submain and laterals laid 80–90 cm below the soil surface. From the lateral, buried in the soil, a micro-tube with a 4-way outlet point is connected to bring the outlet up to the soil surface near the root zone (see Figure 4.13). Since the system components are buried in the soil, the lifespan of the main, submain and laterals can be as long as 13–18 years as compared to 8–10 years under surface installation. Also, cultural operations can be done with the help of tractor- or bullock-drawn implements without damaging the drip system.

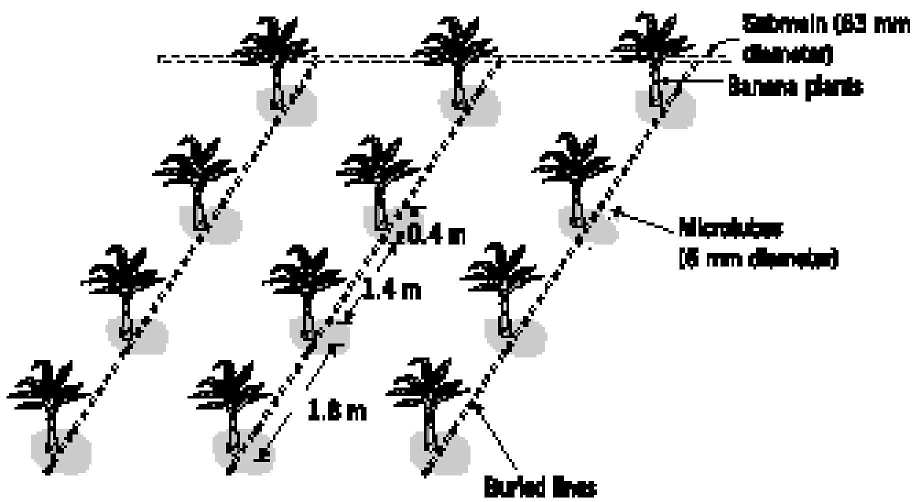


Figure 4.13 *Subsurface drip system for banana.*

In a surface water delivery system for coconut, for example, each plant is provided with 4 drip emitters at 90-degree angles, two drip emitters being fixed on the lateral and the remaining two through micro-tubes (see Figure 4.14).

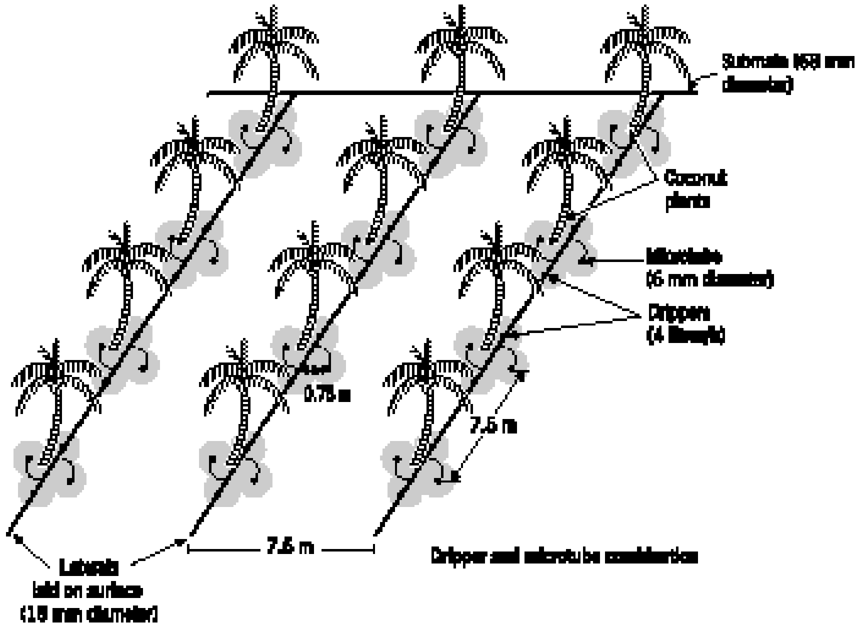


Figure 4.14 *Surface drip system for coconut.*

For irrigating cotton the normal pattern of drip irrigation laterals is laid 75 cm apart in furrows. To reduce the cost of the drip system further, a paired row system can be introduced with 60 cm within the pairs and 90 cm between the pairs (see Figure 4.15) thereby reducing the cost of the laterals by 25–30%. For further information contact Water Technology Centre.

4.6 Low-cost drip systems under development

4.6.1 Introduction

An alternative to off-the-shelf drip equipment is to install a very simple home-made low-pressure system. An example of such a system developed by Erik Nissen-Petersen is described here. The so-called ASALCON drip system had been used in the past for irrigating vegetables. ASALCON systems emphasize the use of locally available material, technology and labour. In 1999, three small drip irrigation systems were built of different materials, as follows.

Gourd system

Two gourds with the bottoms cut off were tied to two trees. Polythene tubing was connected to the neck of the gourds with a rubber band and laid out along lines of cabbage and tomato plants. Next to each plant a hole was punched in the tubing with a thorn. Then the tubing was covered with farm waste to conserve moisture and protect the tubing from sunshine. This system costs KSh 100 (US$ 1.50) for 20 m.

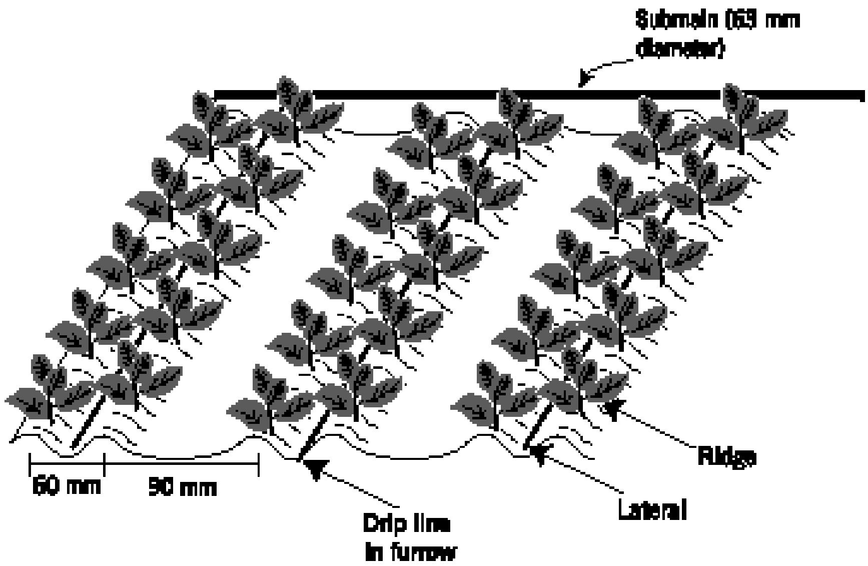


Figure 4.15 *A paired row drip system for cost reduction.*

Bucket system

In the bucket system a reducing socket was soldered on to the bottom of a galvanized iron bucket, which was then hung in a tree. Then a 19-mm PVC pipe was heated and pushed onto the nipple in the bucket. Polythene tubing was then tied onto the PVC pipe with a rubber band and laid out along a line of passion fruit plants. At each plant location a hole was punched in the pipe with a thorn. This system cost KSh 1,400 for 20 m.

Drum system

The drum system consisted of an oil drum onto which a ˚-inch nipple is soldered. The oil drum was first placed on top of another drum filled with soil, but later the drum was placed on a soil bund, thus saving the lower drum for other purposes. The second drum and soil bund served to raise the drum to the required height. Two lengths of PVC pipe were pushed onto two nipples attached with elbows and a T-piece connected to the nipple soldered in the drum. Polythene tubing was then tied to the PVC pipes with rubber bands and holes punched in the tubing opposite each passion plant. However, this tubing proved to be too weak and was later replaced with 19-mm PVC hose pipe. The final version of this system cost KSh 2,240 per 20 m.

For further information contact ASAL Consultants Ltd.

Glossary

Actual crop evapotranspiration The actual crop evapotranspiration, denoted as ET_{ca}, is the actual evapotranspiration from a crop grown under prevailing conditions. When growth conditions are optimal ET_{ca} equals ET_c.

Clogging Full or partial blocking of drip emitters by silt or other suspended solid matter. As a result of clogging the discharge rate of the emitter is reduced or completely zero.

Crop coefficient The crop coefficient, denoted as K_c, is the ratio between crop evapotranspiration and reference crop evapotranspiration.

Crop evapotranspiration The crop evapotranspiration, denoted as ET_c, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions.

Drip emitter A water outlet unit with a special mechanism where the pressure of the water is reduced from the operating pressure in the drip line to zero as the water leaves the emitter as a drip. There are many types of emitters available, differing both in their construction and principle of operation.

Drip irrigation kit A package comprising the core components required to install a drip irrigation system. Other components and materials that are readily available at the point of installation are usually not part of the kit unless special qualities of the components are desired.

Drip lateral/line The water delivery pipeline or polyethylene pipe that supplies water to the emitters from the main lines or submains.

Fertigation The application of liquid fertilizer through an irrigation system.

In-line emitter Drip emitters that are connected to each other by segments of polyethylene to form the required drip line. Usually available in various combinations of operating pressure, discharge rate and diameter.

Integral emitter Drip emitters welded to the inner tube as part of the tubing flow path. Usually available in pre-set emitter spacing (depending on the crop), wall thickness, operating pressure and discharge rate.

On-line emitter An individual drip emitter which is connected through the walls of the polyethylene pipe to form the drip line.

pH A measure of acidity or alkalinity of a liquid. A pH of 7.0 is neutral; a pH less than 7.0 is acidic; a pH greater than 7.0 is alkaline.

Plastic Plastic is a man-made organic polymer. Most common plastics are polyvinyl chloride (PVC) and polyethylene (PE). Plastic pipes are manufactured by the extrusion process, converting raw granular or powdered thermoplastic material to continuous lengths of finished product.

Pressure-compensated emitters Drip emitters that have a special mechanism that can maintain a uniform discharge rate in spite of great variations of water pressure.

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The Swedish International Development Cooperation Agency (Sida) has supported rural development programmes in Eastern Africa since the 1960s. It recognizes that conservation of soil, water and vegetation must form the basis for sustainable utilization of land and increased production of food, fuel and wood.

In January 1998, Sida inaugurated the Regional Land Management Unit (RELMA) based in Nairobi. RELMA is the successor of the Regional Soil Conservation Unit (RSCU), which had been facilitating soil conservation and agroforestry programmes in the region since 1982. RELMA's mandate is to contribute towards improved livelihoods and enhanced food security among small-scale land users in the region, and the geographical area covered remains the same as previously, namely, Eritrea, Ethiopia, Kenya, Tanzania, Uganda and Zambia. RELMA's objective is to increase technical know-how and institutional competence in the land-management field both in Sida-supported programmes and in those carried out under the auspices of other organizations.

RELMA organizes training courses, workshops and study tours, gives technical advice, facilitates exchange of expertice, and initiates pilot activities for the development of new knowledge, techniques and approaches to practical land management.

To publicize the experiences gained from its activities in the region, RELMA publishes and distributes various reports, training materials and a series of technical handbooks.

About this book:

Smallholder farmers in the semi-arid regions of eastern and southern Africa have to depend on erratic, unreliable and low rainfall for their livelihoods. Subsistence staple food crops are generally grown under rainfed conditions. Consequently there is a growing interest in complementing this risky rainfed food production with cultivation of high-value vegetable crops and fruits. But in most cases this means these small-scale vegetable gardens and orchards must be irrigated in order to assure an economic return.

Drip irrigation methods minimize the non-productive water losses associated with conventional irrigation, e.g. from evaporation and soil runoff, and thus can make more efficient use of the already minimal water supplies in these arid areas. But until recently drip irrigation technology had been associated with costly investments available only to large commercial farmers. Now there is growing interest in the technique and many efforts are being made around the world to develop low-cost, simple, drip irrigation systems suitable for smallholder farmers.

This handbook presents some of these drip irrigation options that can be promoted by extension officers in eastern and southern Africa. It describes the most interesting small-scale low-cost drip irrigation methods of which the author and the other contributors have practical experience. It also gives a brief overview of methods that have been used successfully in other parts of the world with details of how to obtain further information about them or order equipment.

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