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Initiative du Bassin du Nil

IRRIGATION BEST PRACTICES FOR SMALLHOLDER AGRICULTURE

Nile Basin Initiative – NELSAP
Regional Agricultural Trade and Productivity Project (RATP)

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IRRIGATION BEST PRACTICES FOR SMALLHOLDER AGRICULTURE

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About this Training Manual

The Nile Basin Initiative (NBI) is a partnership of the riparian states (Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda, Eritrea is participating actively in the NBI as an observer) that seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security through its shared vision of "sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources". NBI's *Strategic Action Program* is made up of the *Shared Vision Program (SVP) and Subsidiary Action Programs (SAPs).* The SAPs are mandated to initiate concrete investments and action on the ground in the *Eastern Nile (ENSAP) and Nile Equatorial Lakes sub-basins (NELSAP).*

NELSAP through its sub basin programs implements pre-investment programs in the areas of power, trade and development and natural resources management. As part of its pre-investment framework, the Regional Agricultural Trade and productivity Project (RATP), in concert with the NELSAP, intends to promote and disseminate best practices on water harvesting and small scale irrigation development as a contribution towards agricultural development in the NEL Countries. NELSAP has previously implemented completed a project called Efficient Water Use for Agriculture Project (EWUAP). One of the recommendations of EWUAP was the need to develop Training/Dissemination materials on "*adoption of low cost technologies for water storage, conveyance, distribution, treatment and use for agriculture that can be adapted by communities and households of the rural and peri-urban poor*". This Training Manual is the initiative of NELSAP, for that purpose.

This Training Manual summarizes the major components of irrigation planning, design, development and management and the requisite factors considered. It is meant to improve the skills of engineers, technicians, extension workers, managers and practitioners of irrigated agriculture, especially those working in smallholder irrigation in Africa. More specifically, the manual equips the reader with knowledge on how to (i) identify the appropriate irrigation system for a given area or circumstances, and (ii) plan and design of irrigation systems. It is meant to inform, educate, enhance knowledge and practice targeting smallholder irrigation in the NEL region. The information contained here may not be exhaustive and thus, readers are encouraged to seek further information from references cited in this publication and elsewhere.

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Glossary of Key Terms

Term	Definition/Brief description
Actual crop evapotranspiration	The actual crop evapotranspiration, denoted as ETca, is the sum total of actual evaporation and transpiration from a crop grown under prevailing conditions. Under optimal growth conditions, ETca equals potential ETc.
Agricultural water management (AWM)	The holistic management of water for agriculture (crops, trees, livestock) in the continuum from rain fed systems to irrigated agriculture. It includes irrigation and drainage, soil and water conservation, rainwater harvesting, agronomy, in-field water management, integrated watershed management and all relevant aspects of the management of water and land.
Basin Irrigation	Basins are flat areas of land, surrounded by low bunds. The bunds prevent the water from flowing to the adjacent fields. This method is suitable for crops that can withstand temporary water-logging.
Border irrigation	Borders are long, sloping strips of land separated by bunds. Irrigation water flows down the slope of the border, guided by the bunds on either side.
Centre-pivot	Automated sprinkler irrigation achieved by automatically rotating the sprinkler pipe or boom, supplying water to the sprinkler heads or nozzles, as a radius from the centre of the field to be irrigated.
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 blocked.
Coefficient of variation (CV)	A mathematical measure of the variability of runoff from year to year. It is the ratio of standard deviation of annual inflow to the mean annual inflow
Crop coefficient	The crop coefficient, denoted as Kc, is the ratio between crop evapotranspiration and reference crop evapotranspiration.
Crop evapotranspiration	The crop evapotranspiration, denoted as ETc, 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.
Drainage	The process of managing and/or removing excess surface water and controlling water logging from shallow water tables.
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 (trickle irrigation)	A planned irrigation system in which water is applied directly to the root zone of plants by means of applicators (orifices, emitters, porous tubing, perforated pipe) operated under low pressure with the applicators being placed either on or below the surface of the ground.

Term	Definition/Brief description
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.
Evaporation (E)	The annual net water loss from a free water surface (mm)
Evapotranspiration (ET)	The sum of water lost from an area through the combined effects of evaporation from the ground surface and transpiration from the vegetation.
Fertigation	The application of liquid fertilizer through an irrigation system.
Flood irrigation	The application of irrigation water where the entire surface of the soil is covered by ponded water.
Furrow irrigation	Furrows are small channels, which carry water down the graded land slope between crop rows. Water infiltrates into the soil as it moves along the slope. The crop is usually grown on the ridges between the furrows. Suitable for row crops and for crops that cannot withstand water-logging for long periods.
Gravity-fed irrigation	Irrigation in which water is available or made available at a higher level so as to enable supply to the land by gravity flow.
Groundwater	Water that exists beneath the earth's surface in underground streams and aquifers.
Irrigation	Any process, other than by natural precipitation, which supplies water to crops or any other cultivated plants.
Irrigation efficiency	The ratio of irrigation water consumed by the irrigated plants to the water delivered from the supply source. Irrigation efficiency can also be assessed in terms of economic benefit per unit of water used in irrigation *(see Water Productivity).*
Marginal-quality water	This term includes urban wastewater, agricultural drainage water, and saline/sodic surface water and groundwater
Overhead irrigation	A method of irrigation water application in which the water is ejected into the air to fall as spray on to the crops or on the ground surface.
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.
Recycled water	Water that has already been diverted and used at least once. Recycling takes place, for example, by reusing drainage water or urban waste water.
Rotation	A system by which irrigators receive an allotted quantity of water, not a continuous rate, but at stated intervals.
Runoff farming	Also known as runoff harvesting/ water spreading/ spate irrigation, is the collection of rainwater from a surface and its storage in the soil profile.
Salinity	Soils having high concentration of soluble salts. Salinity may be caused by the presence of salts in the soil or from irrigation water.
Salinisation	The increased accumulation of excessive salts in land and water at sufficient levels to impact on human and natural assets (plants, animals, aquatic ecosystems, water supplies or agriculture).

Term	Definition/Brief description
Spate irrigation	An irrigation practice that uses the floodwaters of ephemeral streams (wadi or lugga) and channels guided through short, steep canals to bunded basins where cropping takes place (also referred to as floodwater harvesting).
Sprinkler irrigation	A planned irrigation system in which water is applied using perforated pipes or nozzles operated under pressure so as to form a spray pattern.
Stream flow	Flow or discharge of water that moves along a river or channel (m3/s).
Sub-surface irrigation (Sub-irrigation)	Applying irrigation water below the ground surface either by raising the water table within or near the root zone or by using a buried perforated or porous pipe system that discharges directly into the root zone.
Supplemental irrigation	Providing additional water to stabilise or increase yields where a rainfall is insufficient for crop growth
Surface irrigation	Application of water by gravity flow to the surface of the field. Examples are: basin, border, furrow, corrugation, wild flooding, and spate irrigation.
Travelling gun	Sprinkler irrigation system consisting of a single large nozzle that rotates and is self-propelled.
Water application efficiency	The ratio of water applied as net increase in soil moisture in the crop root zone to the total amount of water applied at the field level.
Water conveyance efficiency	The ratio of water delivered in the fields at the outlet head to that diverted into the canal or pipe system from the source.
Water harvesting	Activities where water from rainfall and/or surface runoff is collected, diverted, stored and utilised.
Water logging	State of land whereby the water table is located at or near the surface resulting in poorly drained soils, adversely affecting crops production. Drainage can be used to solve the problem
Waste water	The water which is of no further immediate value to the purpose for which it was used or in the pursuit of which it was produced because of its quality, quantity or time of occurrence.
Waste water treatment	Process to render waste water fit to meet applicable environmental standards or other quality norms for recycling or reuse and irrigation.
Water control	The physical control of water by measures such as conservation practices on the land, channel improvements, and installation of structures for reducing water velocity and trapping sediments.
Water logging	State of land in which the water table is located at or near the surface resulting in poorly drained soils, adversely affecting crops production. Drainage can be used to solve the problem
Water productivity (WP)	An efficiency term quantified as the ratio of product output (goods and services) to water input. It is expressed in term of yields (physical WP), income (economic WP) or environmental services (environmental WP).
Water storage capacity	Maximum capacity of soil to hold water against the pull of gravity, also called field capacity.
Water table	Upper limit of the ground water
Water use efficiency	The ratio of water used in crop evapotranspiration (ET_o) to crop yield
Water withdrawal	The gross amount of water extracted from any source, either permanently or temporarily, for a given use, including irrigation. It can be either diverted towards distribution networks or directly used.

1. INTRODUCTION

1.1 Agriculture is faced with insufficient and unreliable rainfall

There are millions of farmers who cultivate areas that fit the description of drylands, and who could benefit by adopting irrigation. The drylands sometimes referred to as arid and semi- arid lands (ASALs), straddle vast areas of Africa already threatened by a multiplicity of natural and human-induced constraints. The main limitation is low and erratic rainfall, which can range from less than 100 mm in desert zones to about 800 mm in the Savannah, while the soils are generally highly weathered, of low fertility and prone to erosion. Furthermore, agriculture in the drylands relies on traditional agronomic, agro-pastoral and pastoral practices poorly matched to declining land space. These areas are inhabited by some of the poorest people, while expansion of agricultural activities (cultivation, livestock grazing) is occurring faster in these zones.

A major constraint facing the drylands includes droughts and prolonged dry spells, which are getting ever more frequent due to climate change. The average incidence of serious drought has increased from around seven serious droughts during the period 1980-1990 to 10 in the period 1991 to 2003, while in the decade 2001-2011, there has been a drought every two years. In addition, rainfall in the drylands is highly erratic, and normally falls as intensive storms with high spatial and temporal variability. The result is very high risk for rain fed crop production or quite often, total crop failure. The consequences of these rainfall deficits and uncertainties on agricultural production and productivity can be averted by adopting irrigation.

1.2 What is irrigation?

Irrigation is the controlled application of water for agricultural purposes, particularly crops, pasture trees and other plants, to supply water requirements not satisfied by rainfall. It is an intervention that seeks to artificially increase water made available to the crop root zone. There are many types of irrigation systems. In some systems, water is supplied to the entire field uniformly, while the more efficient methods supply water only to the plant root zone. Irrigation water can come from rivers, groundwater or wells, lakes, ponds, springs, water harvested from rainfall, reservoirs, or other sources such as treated wastewater or desalinated water.

1.3 Why irrigate?

The main objective of developing an irrigation system is to supply water to the soil/crop, so that moisture will be readily available at all times for crop growth, regardless of the rainfall availability. Irrigation is necessary for crop production in situations where rainfall is lacking e.g. in deserts, or too little e.g. in dry areas, or where rainfall is unreliable in amounts and distribution. The latter is the case in most agricultural areas where rain fed agriculture is practiced. Thus, crop irrigation is vital in order to provide the world's ever-growing populations with enough food.

Irrigation is also used to boost productivity of land, by increasing cropping intensity and thus yields. Irrigation makes it possible to plan crop sequencing better, enabling market targeting and improving the quality of produce. Irrigation enables the farmer to have control of water availability and use (unlike rain fed agriculture, where rainfall/water availability controls what the farmer may do).

Figure 1.1 (a) Crops suffer moisture stress due to prolonged dry spells *(photos by B. Mati)*

(b) Irrigation is needed in drylands for improved agricultural productivity

Whatever irrigation method is being chosen, the purpose of irrigation is to attain a better crop and a higher yield. Therefore proper design, construction and irrigation practice are of utmost importance. Irrigation is useful in areas with inadequate and/or unreliable rainfall and for bridging crop production during the dry seasons

1.4 Advantages of Irrigation

Irrigation has many advantages, some of the main ones include:

- **Increased agricultural productivity** – as irrigation makes it possible to grow crops in areas otherwise too dry for agriculture, open up idle land and improve productivity of rain fed agriculture
- **Increased yields** - When irrigated, yields of conventional crops, (crops grown on both dryland and irrigated land,) are commonly increased two to three-fold or more in the drier regions
- **Improved incomes**– Irrigation enables market targeting and production of niche crops thus improving farm incomes
- **Improved quality of produce** – Irrigation enables the farmer to apply water when required and in commensurate amounts to improved quality of produce
- **Crop diversification**– Irrigation makes possible the production of a broader range of crops, many of which are considered specialty crops, (crops that are generally not viable under dryland agriculture). These are typically higher value crops,
- **Labour productivity**- Irrigation creating employment and adding value to forage crop production.
- **Stability**– Irrigated crop yields are more stable and reliable, resulting in greater income stability, reduced crop failure rates, and greater assurance in meeting production targets and marketing contracts.
- **Environmental conservation** – Irrigation enables water to be made available to grow trees, grasses and generally to “green up” environments, thereby reducing environmental hazards such as wind erosion, desert creep, and denudation of grazing lands.
- **Climate change mitigation** -Irrigation avails water for crop production regardless of rainfall patterns and is a climate change preparedness, adaptation and mitigation intervention

1.5 Limitations of Irrigation

Irrigation development is also faced with various limitations. Some of the main ones include:

- **Costs** – Irrigation development can be expensive. It requires heavy investment in equipment, and use of engineers and other specialists
- **Water rights** - Irrigation takes water from its natural state for diversion elsewhere. This can cause competition, even conflicts over water between various users
- **Pollution** - Irrigation may lead to pollution of water resources due to increased use of fertilizers, pesticides and other chemicals
- **Drainage water management** – The management drainage/waste water poses problems especially in low-lying areas and floodplains.
- **Depletion of ground water** - In case of irrigation using ground water, there can be depletion of underground aquifers, sometimes this can cause ground subsidence
- **Salinity build up** - Under-irrigation or irrigation giving only just enough water for the plant (e.g. in drip line irrigation) gives poor soil salinity control which leads to increased soil salinity with consequent build up of toxic salts on soil surface in areas with high evaporation.
- **Raising water tables** - Deep percolation from over-irrigation may result in rising water tables which in some instances can lead to problems of water logging in other areas
- **Soil structure damage** - Irrigation with saline or high-sodium water may damage soil structure resulting in the formation of alkaline soil.
- **Socio-cultural implications** – Irrigation is quite often introduced to farmers whose cultural and agronomic background was subsistence rain fed agriculture, agro-pastoralism or pastoralism. This sometimes causes cultural barriers which can derail even the best designed irrigation scheme.

2. FACTORS CONSIDERED IN IRRIGATION PLANNING

Planning an irrigation system requires that a feasibility study be done, which involves some level of engineering, agronomic and socio-economic assessments. Many factors are considered, but the most basic can be grouped into the following factors; (i) physical attributes of the land, (ii) infrastructure development, (iii) crop selection and agronomy, (iv) cost-benefit analysis (v) socio- economic issues, (vi) health and environmental aspects (vii) organization and management, and (viii) Operation and maintenance. These are briefly described in this Chapter.

2.1 Physical attributes of the Land

2.1.1 Climate

Climatic data encompasses information on the quantities and seasonality of rainfall, temperature and evaporation, relative humidity, solar radiation and wind. These factors help determine how much extra water will be needed for irrigation throughout the year, as well as the most suitable crops, and how to sequence them. Generally, an analysis of climatic data with respect to crop production is needed before a cropping programme can be prepared. Accurate estimates of crop water requirements also rely heavily on the availability of accurate meteorological data. For instance, errors of only 20% in crop water requirement estimates can significantly affect the economics of a project, since irrigation development costs tend to be high.

Different crops have different climatic requirements. Other than water availability, crops also respond to solar radiation which supplies the heat energy necessary for photosynthesis. Temperature affects the rate of plant growth, while soil temperature regulates the availability of essential nutrients. Other climatic 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 effect on evaporation by influencing the number of hours of radiation. The more closely the climate matches a crop's basic growth requirements, which are a function of its genotype, the better the production. Thus, climatic data, particularly long-term records are needed for irrigation planning.

2.1.2 Soil type

The type of soil is very important in planning an irrigation system, as it has direct bearing on water application method as well as the irrigation schedule. The soil acts as a reservoir for water because it holds and stores water against the force of gravity, and the stored water can be used for irrigation. However, some soils are better suited to irrigated agriculture than others. A combination of soil factors is considered in planning irrigation systems, as follows:

a) **Soil texture**

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. However, irrigation favours clay soils as they hold moisture well, but nearly all soil types can be irrigated, with proper management.

b) **Soil profile depth**

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. The depth of the effective system (root zone) depends on both the crop and soil-profile characteristics.

c) Soil 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. These include; organic 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 fertility should be assessed so as to determine the nutrient contents, as well as levels of fertilizer required.

d) Soil pH

Irrigated soils should contain the right balance of chemical constituents. 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 indicates 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.

e) Salinity levels

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. Soils should be tested for salinity and sodicity as irrigation tends to increase salt build up in the soil profile. It is usually advisable to avoid irrigating saline/ sodic soils, unless under special conditions e.g. where regular flushing of salts are made available or with tolerant crops.

2.1.3 Land topography

Generally, a good combination of soil type and land topography is a basic prerequisite for identifying land suitability for irrigation development. Land surveys done at detailed scales are usually necessary for irrigation development planning. Topographic maps/digital elevation models together with soil survey maps are needed to provide the means of assessing the irrigability of the land and selection of appropriate irrigation method. Irrigation development best suits areas with relatively flat to gently undulating land topography, which has few surface imperfections, so that little or no land levelling is needed.

2.1.4 Water source and availability

A detailed Training Manual on sources of irrigation water and their development has been prepared as part of these series (See Training Manual 5) and thus only a brief overview is presented here. The source of water, amounts available, method of abstraction, energy requirements, whether piped or canal-based system, water quality and proximity issues are all very important in irrigation development as they determine the scale, cost and profitability of the project. Generally, long-term data of river flow and water quality are needed to assess the potential of the water resources. In the absence of hydrological data, rainfall records or flows of nearby streams are used for estimates. In the case of groundwater resources, hydro-geological studies are carried out and records from existing wells and test wells are used to establish long-term and short-term yields of the aquifer.

Meanwhile, once an appropriate water source is identified, the right to using that water should also be investigated. This is becoming ever more important with the establishment of water boards, water strategies and policies as well as water legislation in many countries in Africa. Hence, water rights should be obtained from the relevant authorities to permit the abstraction and use. Wherever a new scheme is planned, existing established demands for water upstream and downstream should be investigated and taken into consideration. Any proposed changes in water demand must be fully discussed with the national authority responsible for regulating abstraction. Water quality and flow rates are very important for the selection of crops to be grown and the irrigation method to be adopted. As such they should be included in the water resources surveys to be undertaken.

2.2 Infrastructure Development

Infrastructure development involves the construction works that prepare land for irrigation. These could include development of water sources such as dams, weirs, headworks, construction of water conveyance infrastructure e.g. canals, pipe layouts, as well as field levelling, laying field pipe networks, and drainage works. It also include selection of water application equipment e.g. sprinklers, drip lines and their accessories.

2.2.1 Engineering designs

Engineering designs are normally required in planning an irrigation scheme, involving qualified (preferably certified) engineers. Engineering infrastructure development should do detailed assessment of all components and avail functional infrastructure, for water supplies and distribution systems, water storage, control structures, measuring devices, on-farm irrigation works and drainage. For these and other engineering works, preliminary designs are made along with cost estimates. In addition, water allocation and availability should be calculated on a daily basis. The designs for infrastructure development are done for the development of new irrigation schemes, as well as for rehabilitation and/or extension of existing ones.

The design capacity of irrigation structures should consider the magnitude of flows, using peak storm/runoff rates whose return period is calculated through detailed analysis of available climate data as well as biophysical and hydrological characteristics of the catchment. Draining the excess water from irrigated lands is also import as its failure could lead to overall project failure. In this context, managers and engineers concerned with design, construction and operation of irrigation schemes should consider the hydrological processes governing the flows of water. In addition, it is important that the techniques of matching water supply rate with crop water requirements are embedded in irrigation design to permit efficient water application and use.

2.2.2 Planning and construction

The planning and construction of a smallholder irrigation scheme involves several stakeholders. Rural authorities, traditional leaders, farmers, relevant department or Ministry at central level, consultants and contractors are the major stakeholders. At times, sub-contractors are also involved with the construction of some parts of the project. This requires the services of professionals to coordinate and supervise the works of all involved in the planning and implementation of the project. The same professionals, through established procedures, should be responsible for the selection of the contractor and sub-contractors. Sometimes the selection of inexperienced contractors on the basis of a cheaper offer does not always cost less. Delays from one contractor can have far reaching effects on other contractors and on the project delivery as a whole.

2.3 Crop Selection and Agronomy

The type of crops to be grown in an irrigation scheme are selected based on a multiplicity of factors among them cultural preferences of the farmer, available knowledge, profitability of new enterprises and emerging opportunities.

2.3.1 Existing agricultural production systems

Many times, irrigation is introduced to farmers already engaged in agriculture, particularly rain fed systems. Good irrigation planning should try to upgrade production of existing crops even as new enterprises are adopted. Thus, the engineering approaches used should be considered as part of a broader system (irrigated crop production) for which the designed scheme will be constructed to serve. The existing agricultural practices are assessed to analyse the "with" and "without" project situation. Data are gathered from baseline socio-economic surveys. The data are aggregated to reflect the average production cost and gross margins and incorporated in the financial and economic analysis. The same surveys provide information on the availability of family labour in both rain fed and irrigation farming and assess the need for hired labour.

2.3.2 Proposed cropping system under irrigation

Irrigated agriculture enables a farmer to grow new crops which were not possible under rain fed agriculture. Crop selection should be made y consideration of available water, weather patterns, market targeting and other factors such as labour demand, rotations, disease and pest control. Sequencing irrigation with rain fed agriculture should be encouraged to make best use of water. The cultural requirements of each crop and expected yields should be elabourated and the crop water requirements estimated for alternative cropping programmes. Crop budgets for these crops should be prepared as part of the feasibility study, including the financial and economic analysis.

2.4 Cost-Benefit Analysis

Development of irrigation must include cost-benefits analysis at both the individual farmer level and at project scales. The financial analysis evaluates the project's capability to repay the investment and the operation costs of the project. In other words, the cost-benefit analysis assesses the economic viability of different alternatives and assists with the selection of one. The financial analysis evaluates different financial alternatives with respect to interest rates, repayment schedules and length of the loan period.

2.4.1 Direct costs and benefits

The cost-benefits relationship is important in the design of irrigation schemes. The decisions of farmers to engage in irrigation, like any other investment decisions on the farm, are guided by expectation of a net profit. This is achieved by either maximising profit or minimising costs. Two main types of costs need to be considered when planning irrigation projects or schemes. These are investment and operating costs. It is also important to estimate the cost of water and the full contributions made by various partners to the development of the scheme.

There are two ways of considering benefits, namely; direct and indirect components. Direct benefits are those occurring as a result of project activities, e.g. increased production due to irrigation. There are also indirect benefits due to infrastructure development such as roads, availability of water for livestock and domestic use, and ecosystem services, e.g. possibility to grow more trees.

2.4.2 Profitability

In most cases, irrigated crop production is a high-input, high output system. Smallholders therefore need to procure seeds, fertilizers and chemicals in order to optimize their production system. On the output side, market prices, transport costs and farm-gate prices must be predicted, as relates to expected increased volume of production. However, the poor cash flow from conventional rain fed farming is too low for such investments. Consequently, there is need for credit and/or subsidies for farmers to cope. It is therefore necessary that the feasibility study reviews potential options and makes recommendations under the prevailing socio-economic circumstances in the scheme. The choice of crops to be grown and the cropping patterns influence the field layout and irrigation method.

2.4.3 Market access

Market access, pricing and stability of prices can determine the success or otherwise of an irrigation scheme. This is because the choice of crops, as well as the cropping calendars, are influenced by market potentials. Therefore, an assessment of the existing markets, transport system/road infrastructure, including their potential for development, should be made. Processing and storage facilities should be included and planned as part of the overall marketing strategy.

2.5 Socio- Economic Issues

Irrigation development considers the target farmers cultural setting and their expectations, including any trade-offs that local communities may have to forego after development of irrigation. At times, smallholders' priorities differ from the project's priorities and plans, for instance, surrendering grazing land to irrigation development. There is therefore need to assess the acceptability and desirability of local communities to participate in the irrigation scheme. Other factors include land tenure and socio-cultural contexts.

2.5.1 Land tenure

Land tenure under smallholder agriculture varies across countries and communities in Africa. In some countries, smallholders have communal rights to land, while in others, smallholders own the land which may have title deeds. How one or the other type of land tenure affects the various aspects of an irrigation project should be elaborated during the feasibility study. Land rights and access to land should be clearly acceptable to target irrigators and other interest groups who have bearing on the project.

2.5.2 Required labour inputs

Irrigation can be a labour intensive activity. It requires laying pipelines, opening and closing gates, checking that the right quantities of water are added and other field activities. It tends to increase labour burden since crop production can be continuous throughout the year. Labour is also required during initial construction of irrigated fields as well as machinery and other equipment. The availability and cost of labour are major factors used to select type of irrigation. For instance, for surface irrigation methods, basin irrigation requires the less labour and skills compared to furrow or border systems, and is partly the reason the methods is popular among smallholder unskilled farmers.

2.5.3 Socio-cultural aspects

Development of irrigation considers the social and cultural norms among the target community. The nature of the population must be understood in order to match the rate of development with the absorptive capacity of the community. Another aspect is previous experience with irrigation. If irrigation was a traditional practice, then improving the traditional systems is preferable and should be encouraged. Elements such as the level of literacy, farming knowledge and skills, gender issues and attitudes to change are among the parameters to be considered.

Sometimes, irrigation development can bring about cultural shocks to a community. It may mean more work since compared to rain fed systems, farmers work for a few months in a year while irrigated crop production may require almost daily attention throughout the year. Thus, irrigated agriculture could mean less time for social aspects of society. The ability of a community to adjust to these and other changes are critical and should be discussed with the farmers.

2.5.4 Externalities

Irrigation projects sometimes bear external pressures, including certain costs and benefits commonly referred to as externalities. These are caused by issues which occur beyond the projects forecast. Externalities have repercussions in the choice of alternatives because, an irrigation scheme can have high direct benefits yet have higher and significant external costs to the society. In irrigation development, the intended benefits may increase crop production, but in doing so, reduce the water available to downstream users. This may cause decreased crop output as a result of reduced water flow to downstream farms. Furthermore, there may be external costs associated with control of erosion and floods hazards downstream or siltation of reservoirs. Thus, it is important for planners to consider both direct and indirect costs and benefits that will occur as a result of a new irrigation project.

2.6 Health and environmental impacts

Very often, the health and environmental aspects of irrigation development are not given the deserved attention in feasibility studies. Water-related diseases, such as malaria and bilharzia, affect the health of irrigators and thus the overall performance of the scheme. Measures to reduce such problems through engineering and other solutions should be incorporated in the feasibility study.

The development of irrigation sometimes entails removing natural vegetation to create agricultural lands. Water is also abstracted from catchment areas or ground water resources, impacting the overall water balance of an ecosystem. Water conveyance and application affects water tables, while new crops and pesticides used in irrigated agriculture bear impacts on water quality and pollution levels. Thus, the impact of irrigation development on the environment is equally important, as it affects the quality of the water resources and thus downstream water users as well as ecosystems within and beyond the irrigation scheme. An environmental impact assessment is therefore a prerequisite to irrigation development.

2.7 Organization and management

An analysis of the structures and competences of the agencies or persons responsible for the organization and management of the project is usually necessary. Constraints should be expected and should be factored into the planning, construction and operation of projects. This calls for the presence or establishment of competent agencies to manage the planning and implementation of the project.

2.7.1 Capacity building needs

Irrigation development, especially in sub-Saharan Africa, can be expensive. It is therefore necessary for investments to be utilised productively and as soon as possible. Thus, provisions should be made from the feasibility study stage, for the needed trained engineers, agronomists, technicians, administrators and social workers as well as the respective time considerations. Equally important is the assessment of the farmers' training needs, which will enable them to make well-informed decisions and to undertake the operation, maintenance and management of the in-field part of the system, and long-term sustainability of the project.

2.7.2 Extension services

Extension services are needed to facilitate the training of farmers on new crop enterprises and farming practices under irrigated agriculture. However, most extension agents are not familiar with the intricate requirements of irrigated crop production, agronomy, water management, handling and marketing systems. Sometimes, it is necessary to first train the extension staff. While the success of achieving the desirable results will greatly depend on the adaptability of farmers, this means developing and implementing appropriate extension packages, and encouraging farmer experimentation. This may require establishing on-farm trials, demonstration farms, farmer field schools and provision of advisory services with back up from specialists.

2.8 Operation and Maintenance

The operation and maintenance (O & M), which encompasses irrigation schedules, repairs, personnel, running costs and other requirements should be factored at the planning stage. O & M considers the maintenance of the full irrigation system e.g. water sources, pumps, canals, pipes, sprinklers, as well as support infrastructure e.g. roads, stores and handling. It also includes administrative and socio-economic adjustments that may be required to ensure sustainability of a project. For further details on O & M, see Training Manual 10 in these series.

3. DESIGN OF IRRIGATION SYSTEMS

3.1 Requirements of an efficient irrigation system

Several factors affect the efficiency of an irrigation system. The most commonly used is the water productivity of the system, which depicts the economic return per unit of water. This is affected by both the amounts of water applied as well as the timing of irrigation according to changing crop requirements, and optimal availability of macro and micro elements, according to plant needs. Other important considerations include initial capital investment, labour savings, reduction of losses, as well as operation and maintenance.

The physical requirements for an efficient irrigation system is that which best suits local conditions, by consideration of factors such as; (i) soil type and profile characteristics including soil fertility, (ii) crop types, their various stages of growth and rotations, (iii) topographic conditions, including if land leveling is needed, (iv) source and quantity of available water, including its delivery - whether by gravity or pumped, (v) underground water table conditions and opportunities for drainage, (vi) inherent levels of salinity build up and other likely limitations. A well planned irrigation system should not lose water nor allow deep percolation losses to the water table, and should avoid increasing soil salinity.

The proposed design and agricultural enterprise should ensure optimum productivity of available land, water supplies, labour and capital. Several factors are considered during project identification, design, and operation with relevant information gathered at each stage (Table 3.1).

Table 3.1: Information required in the design of an irrigation scheme

Activity	Data application	Data required
Project Identification	▪ Inventory of the resources ▪ Present hydrological budget ▪ Identification of irrigable area ▪ Choice of production system ▪ Method of water delivery	○ Average month and peak water supply requirements ○ Physical, hydraulic and chemical soil quality attributes.
Project Design	● Project size ● Layout of the distribution systems ● Cropping patterns ● Water supply scheduling. ● Capacity of the engineering	○ Irrigation interval and time ○ Size of the stream flow ○ Irrigation cycle
Project Operation	➢ A review of irrigation efficiency and water supply rate to the field ➢ Analysis of the production of different crops per unit water applied ➢ Monitor the field water balance	○ Daily water supply rate ○ Actual consumptive water use per crop ○ Production in kg per mm of the irrigation water.

Irrigation development should also be based on convincing evidence of beneficial outcomes and sustainability of the system. Feasibility studies are done to assess the developmental options for investment and the expected cost/benefit and other social aspects of the project. A feasibility study for irrigation development assesses the physical aspects of land, water and climate, and evaluates crop production potential and cropping programmes within the context of the physical aspects.

The same study reviews and analyses alternative engineering options in terms of benefits and costs, operation and maintenance, compatibility with the available land and water resources, their impact on the environment, the health of the users and the social life and welfare of the irrigators.

Finally, market potentials and access to markets are critically reviewed through such studies and the financial and economic aspects of the development are assessed. In summary, the feasibility study should provide options for the client with recommendations for the best option combining technical feasibility, financial and economical viability, social desirability and environmental sustainability.

3.1.1 Data requirements and preparation

The design of an irrigation scheme is an engineering undertaking, requiring use of reliable and accurate data as well as other information sources. Such data are collected from direct measurements or obtained from records. Information can also be gathered from observations and interviews with important stakeholders such as farmers, extension workers, local leaders and those engaged in the value chain. Generally, feasibility studies are conducted accompanied by field surveys.

3.1.2. Climatic data analysis

The most important climatic data used in design of irrigation include; rainfall, maximum and minimum temperatures, maximum and minimum relative humidity, wind and sunshine hours. Climate is an important factor in crop production. Different crops have different requirements in terms of temperature, humidity and light. Also, occurrence of frost at certain times may exclude a number of crops from the cropping programme. Analysis of climatic data with respect to crop production is needed before a cropping programme can be prepared. The reliability of estimated crop water requirements relies heavily on the availability of accurate meteorological data. Climatic data analyses are used to:

- Explain the relationships between hydrological processes and geomorphic characteristics of the landscape
- Show how the climatic variables influence the crop water needs
- Enable practical calculations of important variables
- Determine water flow measurements in the field.

3.1.3 Assessing soil parameters

It is necessary to identify, quantity and monitor the relevant soil quality indicators under different soil moisture regimes. The soil parameters to assess include; soil bulk density, soil pH, soil strength and aggregate stability, drainable porosity and pore size distribution, heavy metals such as boron and aluminum as well as the nutrient balances.

3.1.4 Determining irrigation water requirements

Irrigation water requirement is normally determined through calculation, based on climatic data as discussed above. The reference evapotranspiration together with crop coefficient assist to estimate the crop water requirement. How much and how often water has to be given depends on the irrigation water requirement of the crop.

Data analyses include:

1. Selection of the reference evapotranspiration (ET_0)
2. Determining the crop water requirement.
3. Calculate the irrigation interval and timing, and

4. Determine the water losses in the irrigation system (seepage from canals and other losses in the field).

3.2 Soil-Water-Plant Relationships

The design of irrigation schemes considers how much water will be needed on a daily, seasonal or annual basis. This in turn is affected by a complex relationship between the soil, water needed and plant characteristics including the stages of growth. If wastage and other losses of water are removed, a plant requires only the water taken up by the roots and passed to the leaves for growth and photosynthesis. This is known as the reference crop water requirement, or **reference evapotranspiration (ET_0).**

The value **ET_0 can be defined as** the sum of water spent through both evaporation and transpiration of a healthy crop, growing in a large field, where water, nutrients, pest and diseases are not limiting crop growth. The value of ET_0 is related to the temperature, radiation, air humidity and wind speed. 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.

Obtaining accurate climatic data can be time consuming, labourious and expensive, yet such data are needed at short notice for irrigation design.

3.2.1 Water Requirements of Plants

Crop water requirement is defined as the depth of water needed to meet the water loss through evapotranspiration of (ET_{crop}) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility, and achieving full production potential under the given growing environment. The actual crop water requirement is determined by multiplying ET_0 with a coefficient of a given crop. In practice water requirement of a crop includes water the water taken by the plant plus all the losses through surface runoff, deep percolation, evaporation and soil moisture (figure 3.1).

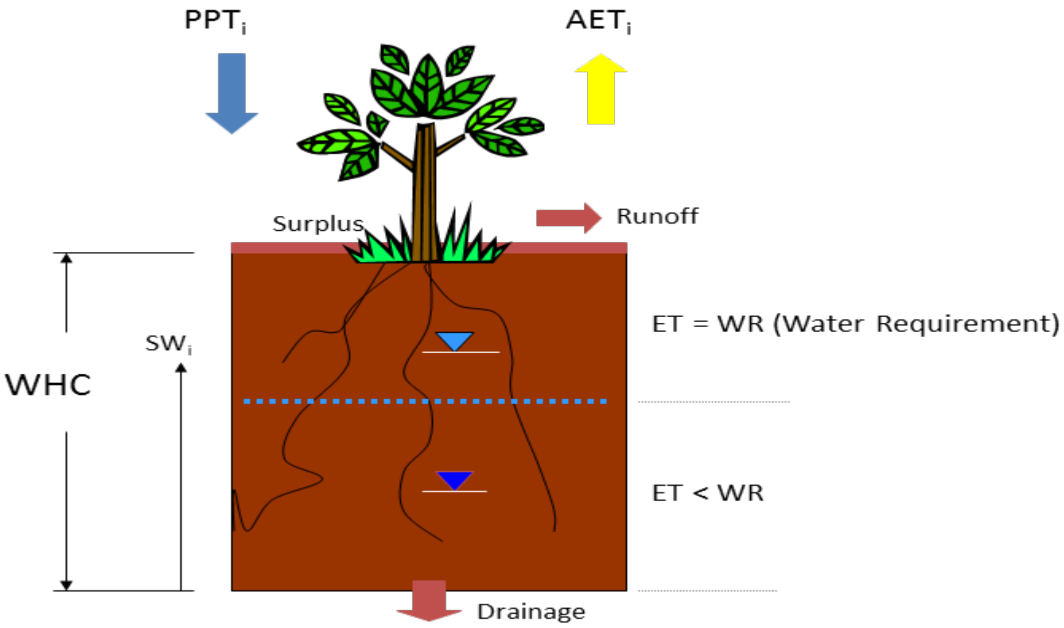


Figure 3.1 – Schematic presentation of soil water balance for a crop

It is important to note that the crop water needs change with growth stages and the designed rate of water application must meet the changing water demand in the right quantity and time. This is because 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. Plant nutrient uptake is regarded indirectly as one of these processes. Nutrients taken up by plant roots are dissolved in water (soil solution). 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.

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

(i) Transpiration, which is the water entering the plant roots and used to build plant tissue or passed through the leaves into the atmosphere, and

(ii) 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).

Transpiration is an unavoidable effect of CO_2 uptake by the stomata of the leaves. This also means that under constant hydro-climatic conditions, there is generally a linear relationship between crop growth and transpiration. More yield/biomass means more transpiration. The ratio between crop yield (grain or total biomass) and water use (expressed as ET_0) is defined as the water use efficiency (WUE).

3.2.2 Estimating reference crop evapotranspiration (ET_o)

There are several methods of determining reference crop evapotranspiration (ET_0). The methods can be experimental e.g. using an evaporation pan, or theoretical, using measured climatic data. If local data are not available, one of the general theoretical methods has to be used. 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 Penman-Monteith method, which is described in detail in FAO Irrigation and Drainage Paper 24. of determining reference crop evapotranspiration (ET_0). This method, however, is rather complicated and beyond the scope of this manual. The calculation of ET_0 can be done by hand with the help of a calculation sheet, or by means of a computer model e.g. AQUACROP. The program can also be used to calculate the water-supply requirement for an entire irrigation scheme. The methods presented here include the Pan evaporation, Blaney-Criddle and radiation methods.

Selection of the reference evapotranspiration (ET_0) is based on the climatic characteristics of the project area (Table 3.2) and the type of climatic data available 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 3.2: Daily evapotranspiration for different climatic zones

Evapotranspiration in mm/day at various daily temperatures (°C)			
Climatic zone	**Low (<15°C)**	**Medium (15- 25°C)**	**High (> 25°C)**
Desert/arid	4-6	7-8	9-1o
Semi-arid	4-5	6-7	8-9
Sub-humid	3-4	5-6	7.8
Humid	1-2	3-4	5-6

Source: Muya *et al.*, 2009

3.2.3 Pan Evaporation Method

Many different types of evaporation pans are being used. The best known pans are the Class A evaporation pan (circular pan), or the Sunken Colorado pan (square pan).
The E_{pan} is multiplied by a pan coefficient, K_{pan}, to obtain the ET_0.

$$ET_0 = K_{pan} \times E_{pan}$$

Where:

ET_0 = reference crop evapotranspiration
K_{pan} = Pan coefficient
E_{pan} = Pan evaporation

3.2.4 Blaney-Criddle Method

If no measured data on pan evaporation are available locally, a theoretical method (e.g. the Blaney-Criddle method) to calculate the reference crop evapotranspiration ET_0 can be used. The Blaney-Criddle method is simple, using measured data on temperature only. It should be noted, however, that this method is not very accurate; it provides a rough estimate or "order of magnitude" only. Especially under "extreme" climatic conditions the Blaney-Criddle method is inaccurate: in windy, dry, sunny areas, the ET_0 is underestimated (up to some 60 percent), while in calm, humid, clouded areas, the ET_0 is overestimated (up to some 40 percent).
The Blaney-Cridle method is expressed as follows:

$$\mathbf{ET_0 = C\{P(0.46T + 8)\}\ mm/day}$$

Where:

ET_0= Reference evapotranspiration in mm/day for the month
T = Mean daily temperature for the month considered.
P = Mean daily percentage of total annual daytime hours
C = Adjustment factor

The adjustment factor depends on the minimum relative humidity, sunshine hours and daytime wind estimates. The climatic data required for the calculation of the ET_o are obtained at the meteorological stations.

3.2.5 Radiation Method

The radiation method is used where available climatic data include measured air temperature, sunshine, cloudiness or radiation, but not measured wind and humidity, and it is expressed as follows:

$$ET_0 = C(W.Rs) \text{ mm/day}$$

Where:

ET_0 = Reference evapotranspiration
Rs = Solar radiation in equivalent of evaporation in mm/day.
W = Weighting factor which depend on the temperature and altitude
C =Adjustment factor which depends on mean humidity and day time conditions.

The effects of the crop characteristics on the crop water requirements are calculated, using crop coefficient provided by FAO (1998). These effects will determine the actual crop water requirement, determine the consumptive water use, depending on the prevailing weather conditions and soil moisture availability. For a given climate, crop growth and development stage, the maximum evapotranspiration (ET_m) in mm/day of the day considered as follows:

$$ET_m = \; k\, ET_0$$

Where ET_m is the maximum evapotranspiration and k_c is the crop coefficient.

The areas where measured data on temperature, humidity, wind and sunshine duration or radiation are available, use of Penman method is recommended. This method is expressed in the following equation:

$$ET_0 = C[W.Rn+(1-W).f(u).(ea-ed)]$$

Where:

ET_0 = Reference crop evapotranspiration
C= Adjustment factor to compensate for the effect of day and night weather conditions.
W = Temperature-related weighting factors.
Rn = Net radiation evaporation in equivalent mm/day
f(u) =Wind-related factor
(ea-ed) = Difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in members

Evaporation rate can be measured directly using evaporation pan and the results can be used to estimate ET_0.

3.2.6 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.

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.

The crop evapotranspiration is estimated by the following formula:

$$\mathbf{ET_C = K_C \times ET_0}$$

where:
ET_C = crop evapotranspiration in mm/day
ET_0 = reference evapotranspiration in mm/day
K_C = crop coefficient.

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 (ETca), and therefore crop production, will result from influences such as inadequate soil fertility, moisture deficit, soil salinity, water logging, and incidence of pests and diseases.

3.2.7 Determining stream size for irrigation

The design quantity of the flow in an irrigation system is determined by calculating the stream size. This is based on amount of water needed in each field, which is a function of the flow in the design canal or pipe capacity and distribution system. The data required for this design include (i) irrigation efficiency, (ii) the available water holding capacity of the soil in mm/m, (iii) the fraction of the available water permitting unobstructed evapotranspiration, (iv) rooting depth, and (v) area to be irrigated.

The stream flow into each field is given by the following equation:

$$\mathbf{q=10\{(pxSa)xDxA\}/\{(ET_C x\ t)\}}$$

Where:
Q = Stream size in m^3/s
p = the fraction of the available water permitting unobstructed ET
Sa = Available soil moisture holding capacity mm/m
D = Rooting depth in m

A = Area of each field
ET_C = Crop Evapotranspiration
t = Time

Irrigation Interval

Irrigation Interval is the length of time allowed between successive irrigations during peak consumptive use of the crops. It can be calculated from the available moisture for the soil-crop system and the rate of consumptive use of the crop.

3.2.8 Determining irrigation water requirement

The determination of the irrigation water needed by a crop is more than just crop evapotranspiration. In practice, it will not be possible to apply exactly this calculated amount of water and some percolation and other losses will occur. During irrigation, water will also be lost in farm channels and basin feeders.

The irrigation water requirement is the water need for the crop plus an added amount to cover the various losses on the farm and in the field. In scheme water management, the farm water requirement is the amount that has to be delivered to the farms in the scheme. It is usually expressed in mm/day or mm/month. Some guide values for water requirements of various crops under surface irrigation, and the respective irrigation intervals are presented in Table 3.3.

Table 3.3 Guide values for water requirements of various crops under surface irrigation

Crop	Average water requirement (mm)	Interval (days)
Maize	400	6-7
Groundnut	450	7-8
Sorghum	400	14-15
Bajra	400	6-7
Ragi	400	6-7
Sunflower	450	7-8
Soybean	670	6-7
Greengram	250	10-12
Blackgram	250	10-12
Gingelly	250	15-20
Sugarcane	2000	7-8
Banana	1800	6-7

Source: Muya et al, 2009

3.2.9 Effect of growth stage on crop water needs

A fully grown maize crop will need more water than a maize crop which has just been planted. As discussed before, the crop water need or crop evapotranspiration consists of transpiration by the plant and evaporation from the soil and plant surface. When the plants are very small the evaporation will be more important than the transpiration. When the plants are fully grown the transpiration becomes more important than the evaporation.

The evapotranspiration or crop water need during the initial stages can be estimated at 50 percent of the crop water requirement when the crop is fully developed.

During the crop development stage, the crop water need gradually increases from 50 percent of the maximum crop water need to the maximum crop water need. The maximum crop water need is reached at the beginning of the grain filling stages during crop development. With respect to the late season stage, which is the period during which the crop ripens and is harvested, a distinction can be made between two groups of crops:

Fresh harvested crops: such as lettuce, cabbage, etc. With these crops the crop water need remains the same during the late season stage as it was during the mid-season stage. The crops are harvested fresh and thus need water up to the last moment.

Dry harvested crops: such as cotton, maize (for grain production), sunflower, etc. During the late season stage these crops are allowed to dry out and sometimes even die. Thus, their water needs during the late season stage are minimal. If the crop is indeed allowed to die, the water needs are only some 25 percent of the crop water need during the mid-season or peak period. Generally, no irrigation is given to these crops during the late season stage.

3.3 Irrigation efficiencies

There is increasing demand on water resources, which emanates from growing human population and the need for more irrigated crops. This means that there is increasing competition for the use of water for agricultural, industrial, domestic and ecosystem purposes. This calls for more efficient use of finite water resources in order to minimise conflict between users and sectors.

Planners are concerned optimizing the use of water while selecting irrigation systems, based on their efficiencies. In the process of applying irrigation water to crops, water losses occur. These losses have to be taken into account when calculating the gross irrigation requirements of an irrigation project. This can be done through the use of an efficiency factor, which has to be estimated during planning.

The application efficiency, or field efficiency, shows which fraction of the flow entering at the farm intake will become available to the crop. The application efficiency for basin irrigation can be as high as 80 % for experienced farmers.

Different types of irrigation systems have different levels of efficiency. The higher the irrigation efficiency, the larger the area that can be irrigated from a given water source. This results in reduced leaching of nutrients, less damage to the soil and better environmental management. The water so saved can be used for other productive purposes. More details on irrigation efficiencies are presented in Training Manual 8 of these series.

3.4 Identifying appropriate Irrigation Method

The suitability of the various irrigation methods, i.e. whether surface irrigation, sprinkler or drip irrigation, requires an analysis of the technological and socio-economic considerations, as well as assessing the advantages and disadvantages of the various methods. It is important to know which method suits the local conditions best.

However, in many cases, it is difficult to identify a single best solution as all methods have certain advantages and disadvantages. Testing of the various methods - under the prevailing local conditions, provides the best basis for a sound choice of irrigation method. Several important criteria in the selection of a suitable irrigation method are used such as the natural conditions, crop type, affordable technology, labour inputs, and income benefits.

3.4.1 Natural physical conditions

The natural conditions of the land such as such as soil type, slope, climate, water quality and availability, have major impact on the choice of an irrigation method. Table 3.4 shows some guideline showing which irrigation methods are suited to respective natural conditions.

Table 3.4: Natural factors considered in selecting irrigation method

Soil type:	Sandy soils have a low water storage capacity and a high infiltration rate. They therefore need frequent but small irrigation applications, in particular when the sandy soil is also shallow. Under these circumstances, sprinkler or drip irrigation are more suitable than surface irrigation. On loam or clay soils all three irrigation methods can be used, but surface irrigation is more commonly found. Clay soils with low infiltration rates are ideally suited to surface irrigation.
	When a variety of different soil types is found within one irrigation scheme, sprinkler or drip irrigation are recommended as they will ensure a more even water distribution.
Slope:	Sprinkler or drip irrigation are preferred above surface irrigation on steeper or unevenly sloping lands as they require little or no land levelling. An exception is rice grown on terraces on sloping lands.
Climate:	Strong wind can disturb the spraying of water from sprinklers. Under very windy conditions, drip or surface irrigation methods are preferred. In areas of supplementary irrigation, sprinkler or drip irrigation may be more suitable than surface irrigation because of their flexibility and adaptability to varying irrigation demands on the farm.
Water availability:	Water application efficiency is generally higher with sprinkler and drip irrigation than surface irrigation and so these methods are preferred when water is in short supply. However, it must be remembered that efficiency is just as much a function of the irrigator as the method used.
Water quality:	Surface irrigation is preferred if the irrigation water contains much sediment. The sediments may clog the drip or sprinkler irrigation systems.
	If the irrigation water contains dissolved salts, drip irrigation is particularly suitable, as less water is applied to the soil than with surface methods.
	Sprinkler systems are more efficient that surface irrigation methods in leaching out salts.

3.4.2 Crop selection

The crop type is usually matched to irrigation method. For instance, surface irrigation can be used for nearly all crops types albeit it uses more water. Surface irrigation methods are commonly used for staple food crops e.g. rice, maize and legumes. Sprinkler and drip irrigation, due to their high capital investment per hectare, are mostly used for high value cash crops, such as vegetables, coffee, fruit trees and flowers. Drip irrigation is suited to irrigation of individual plants or trees or row crops such as vegetables, sugarcane or fruit trees. Other localised forms of irrigation, e.g. pitcher pots are used for small gardens.

3.4.3 Essential requirements of suitable irrigation method

The essential requirements for adoption of any irrigation method include the following:

(i) Application is within desirable limits. - Stream flow is adequate so that the quality of irrigation is such that the depth of wetting and hence the stand of crop are approximately uniform. The irrigator achieves high productivity so that during a day's work he can irrigate a large area.

(ii) Afford a uniform water distribution in root zone of a crop with as small as 6 cm applications for light irrigation,

(iii) Allow uniform application of water depth and under some conditions extra water for salt leaching where such a problem exists,

(iv) Allow use of large concentrated water flows for reduction of conveyance losses, field channel network and labour cost,

(v) Suitable for use with economical conveyance structure,

(vi) Facilitate mechanised farming,

(vii) Occupy minimum land, especially land taken over by field ditches and bunds,

(viii) Inexpensive and economically justifiable,

(ix) High efficiency of water application i.e., the ratio of water stored in the root zone to that delivered to the field should be maximum,

(x) Minimum wastage of water either through surface runoff or through deep percolation below the root zone of a crop. A suitable irrigation method should ensure maximum yield at optimum water utilization, i.e., conservation of water resource.

3.4.4 Choice of water application method

The design, equipment and techniques used to replenish the soil water deficit by applying irrigation water are referred to as irrigation methods. Various methods exists and can be designed to suit different crops, soil type, topography, water availability and its quality, climatic conditions, individual holdings and costs. The commonly are clustered into four groups as follows:

(i) Surface irrigation methods (check basin, border strips and furrow irrigation),

(ii) Overhead irrigation/Sprinkler irrigation,

(iii) Drip irrigation (includes other special localised irrigation techniques)

(iv) Sub-irrigation

(v) Spate irrigation.

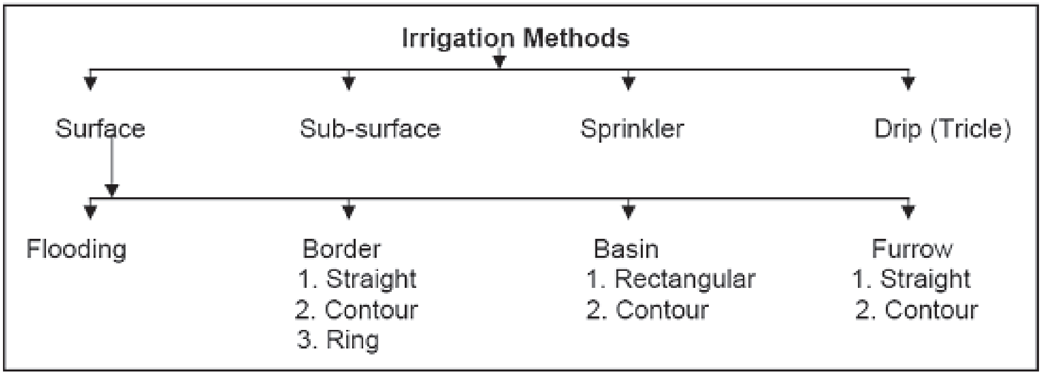


Figure 3.2 Water application methods in Irrigation

In selecting an appropriate system, it is important to note that surface irrigation systems apply water to the land by an overland water flow regime. Within this group are the furrow, border strip and basin irrigation systems. The border irrigation method is wider than furrow and longer than the basin and its selection criteria is similar to furrow and basin. In sprinkler irrigation systems, water is conveyed and distributed through pressurized pipe networks before being sprayed onto the land to mimic natural rainfall. There are several sprinkler irrigation systems, which can broadly be divided into set systems and continuous move systems. In localised irrigation systems, a pipe distribution network is used to distribute and deliver filtered water (and fertilizer) to a predetermined point. Micro-irrigation systems such as drip supply water directly to root zone of the crop and have the highest efficiencies. Sub-surface irrigation systems rely on the raising or lowering of the water table in order to affect groundwater flow to the root zone. As such, sub-irrigation utilises drainage flow systems. Spate irrigation is a special type of irrigation using flood waters. The basic requirements for each of these methods are described in Table 3.5.

Table 3.5: Criteria for selecting irrigation methods for different conditions

Irrigation methods	Suitable crops	Suitable soils	Slope	Water availability	Advantages	Disadvantages
Watering Bucket	Horticulture	Most soil types	Relatively flat	Applicable where water supply is unlimited	Inexpensive, requires little land grading/ leveling	Labour intensive
Basin	Row field crops and horticultural crops	Fine textured soils	Relatively flat	Requires large quantities of water and size depends on water availability	Good control of large flows. Can be used to leach excess salts	May require land grading and leveling, hence costly
Furrow	Row field crops and horticulture	Most soil types	Very gently sloping with slopes less than 2%	Requires large quantity of water	Permits irrigation of large fields	Difficult to achieve uniform water application
Sprinkler	Most crops except rice	Light textured and highly permeable soils	A wide range of slopes	Applies in areas with limited water supply	Highly efficient and can be used in area with limited water supply	High installation cost and requires skill in management and operation
Drip	Trees and low density crops	A wide range of soil types	A wide range of slopes	Applied in areas with limited water supply	Efficient water use	High initial cost

Source: Withers and Vipond, 1974

4. SURFACE IRRIGATION METHODS

4.1 Overview of Surface Irrigation Methods

Surface irrigation methods are based on the principle of moving water by gravity over the surface of the land in order to wet it, either partially or completely. They can be subdivided into furrow, border-strip and basin irrigation. In an irrigation scheme, the layout from the water source up to field level, such as canals and drains, can be similar for each system. Surface irrigation is the most commonly used method of irrigation especially by smallholder farmers.

Figure 4.1 Surface irrigation of onion crop *(photo by B. Mati)*

4.1.1 Conditions that favour surface irrigation

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

Land topography

Surface irrigation may be difficult to use on steep and irregular slopes as considerable land levelling may be required to achieve the required land gradients. It is best suited to relatively flatter terrain, with a slope of 0.1% or less. But some land levelling is normally needed. If the slope is more than 1%, terraces can be constructed. However, the amount of land levelling can be considerable.

Crop type

Nearly all crops can be grown under surface irrigation. However, the method suits better field crops and especially grain crops. Surface irrigation is better suited to row crop that can withstand some temporary water-logging.

Soil types

Nearly all soil types can be used for surface irrigation, except coarse sand with an infiltration rate of more than 30 mm/hour. If the infiltration rate is higher than 30 mm/hour, sprinkler or drip irrigation should be used. However, clay soils are better suited to surface irrigation as the hold moisture longer and have less seepage losses during water delivery by canals. Table 4.1 shows selection criteria for various surface irrigation methods based on soil properties. Surface irrigation not appropriate for porous soils e.g. those with infiltration rate exceeding 70 mm/hr, due to deep percolation losses at the upstream end.

Table 4.1 Selection criteria for surface irrigation methods based on soil type

Soil type	Crop rooting depth	Net irrigation depth per application (mm)	Surface irrigation method
Sand	Shallow	20-30	Short furrows
	Medium	30-40	Medium furrows, short borders
	Deep	40-50	Long furrows, medium borders, small basins
Loam	Shallow	30-40	Medium furrows, short borders
	Medium	40-50	Long furrows, medium borders, small basins
	Deep	50-60	Long borders, medium basins
Clay	Shallow	40-50	Long furrows, medium borders, small basins
	Medium	50-60	Long borders, medium basins
	Deep	60-70	Large basins

Source: Jansen, 1983

Land levelling

Most surface irrigation developments require some land levelling to create just the right gradient for even flows and distribution. This adds extra costs to irrigation development. Surface irrigation can have low irrigation efficiencies usually associated with poor land levelling, wrong stream size and change in soil type along the irrigated area both vertically and horizontally.

4.1.2 Water delivery and control structures

The farm intake is the point where water from the feeder canal enters a farm. Each farm should have only one farm intake. This will reduce the leakage losses from the feeder canal through the farm intakes. The farm intake should therefore be located on the highest point along the feeder canal in the farm.

Water is delivered to the filed by either pipeline or canal. If a canal is used, it should be lined or incase of earthen canal, it should be cleared of weeds. The feeder canal to farms should ideally be a group feeder or lateral canal. In small highland schemes, water is usually abstracted at the farm intakes directly from the main canal or branch canal. In open canals, water flow is diverted and controlled with different kind of devices. The most common one are gates and siphons (figure 4.2). Gates are used in canal turnouts. The gates can be of various types, such as box distribution structures made of concrete, or simple earthen breaches made on the embankment. A good design should incorporate water control, including measuring devices, so that individual irrigators can have the autonomy to manage the water within their fields without being affected or affecting other water users.

Figure 4.2 (a) Canal diversion box with metal gate *(photos by B. Mati)* **(b) Siphon diversion of water from field canal**

4.1.3 Arrangement of water distribution system

The arrangement of the water distribution system in surface irrigation normally follows the pattern shown in figure 4.3. Water is diverted from main source to field canals or arrangement of piping in such a way as to enable drainage. The whole system should be synchronised and there should be no obstructions to flow.

In a typical arrangement, water reaches the field through the farm channel, which connects the farm intake to the feeder canals/ sub-mains. In highland schemes, the field channel often runs down the slope, usually at the boundary of two plots. If due care is not taken, this can cause erosion problems, as this part of the farm is usually not terraced. The velocity of flow tends to be high, and can be reduced by construction of stone masonry drop structures creating a canal profile similar to terraces. In farms with less steep slopes, a cover of short grass in the channel (grassed waterway) prevents erosion in earthen canals. In lowland schemes, farm channels run along the contour while the feeder canals are laid out to run down the predominant slope. The danger in this case could be very slow flows leading to deep percolation losses. All the canals should be properly maintained.

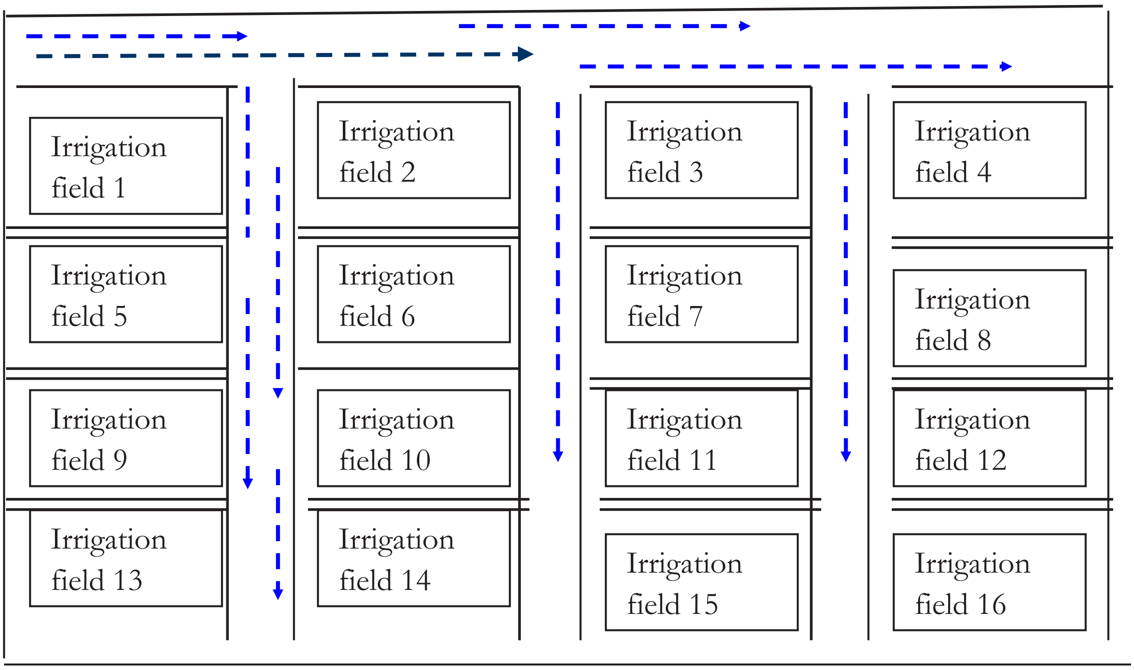


Figure 4.3: Illustration of water distribution system through irrigated fields

4.1.4 Advantages of surface irrigation

Some of the major advantages of surface irrigation systems over other systems are that they are easy to operate and maintain with skilled labour, they are not affected by windy conditions and, with the exception of furrow irrigation, they are good for the leaching of the salts from the root zone. Surface irrigation also works with shallow soils. Generally, surface irrigation is associated with low energy costs. Surface irrigation is comparatively cheap to develop, and requires minimal investment on the part of the farmer.

4.1.5 Limitations of surface irrigation

Surface irrigation systems have several disadvantages. They include:

- Surface irrigation utilises large streams of water and is inefficient in water use
- Not suited to land which is steep or rigged terrain.
- Land levelling and grading are usually needed, adding to cost of land preparation
- Field ditches can interfere with farm layout and movement of machinery
- Excessive loss of water by run of and deep percolation
- The spatial and temporal variability of soil characteristics, such as infiltration rate and texture, make water management practices difficult to define and implement.
- Can require high labour demand, as compared to sprinkler and localised irrigation systems, in situations where labour is not abundant.
- Can lead to water logging and soil salinity if there are no provisions for adequate drainage.

4.2 Basin irrigation

A basin is a level cultivated piece of land surrounded by earthen bunds and totally flooded during irrigation (figure 4.4). Basin irrigation is the most common type of surface irrigation in Africa and is particularly used in rice cultivation, where the fields are submerged. Basin irrigation requires substantial quantities of water which can be either pumped or diverted from a river or a reservoir. It also works with borehole water. It is also used for the leaching of salts by deep percolation in the reclamation of saline soils.

Figure 4.4: Basin irrigation system with paddy rice crop (photo by B. Mati)

4.2.1 Check basin irrigation

Check basins are the rectangular or square fields, with sizes, varying from about10 to 100 square meters or even more (figure 4.5). The basins are levelled in both directions. Slopes up to 3% can be irrigated by using this method with a good control on irrigation water and high water-application efficiency. On steeper slopes, this method can be used after proper terracing.

Basin layout not only refers to the shape and size of basins but also to the shape and size of the bunds. It also refers to the shape of the basin, whether square, rectangular or irregular and is a function of land slope and available land space. This also determines the height of the bunds, their shape and width.

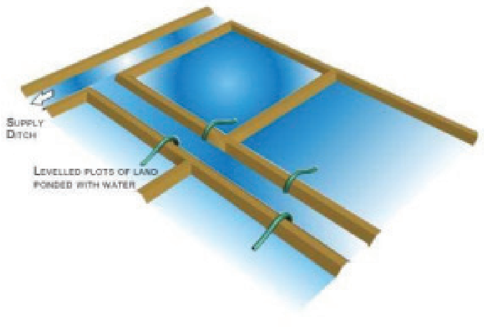


Figure 4.5 (a) Layout of a check basin irrigation system

(b) Check basin irrigation of paddy rice *(photo by B. Mati)*

4.2.2 Micro-basins

Micro-basins are smaller basins used for irrigation of field crops such as maize, rice and other or vegetables (figure 4.6). They are made small to improve water management especially under manual cultivation systems. Because only small amounts of water enter the basin, the chances of over-wetting or failure of enclosing bunds is reduced. Micro-basins are suitable in areas where topography is uneven or on hillsides which are terraced.

Figure 4.6 Micro-basin irrigation with maize crop *(photo by B. Mati)*

4.2.3 Contour-basin irrigation

Contour basin irrigation is constructed where the land is too steep for check basin, preferable on a terrace (figure 4.7). The check banks of the basin are erected across the slope following the contour of the land. These banks are constructed by borrowing the soil from the outside edges of the bank area resulting in a toe-furrow which serves as supply as well as drainage channel for the basin. Water is allowed to fill the basin from the supply channel and upon completion of irrigation, drainage runoff is allowed into the next downstream basin. The water enters and ponds the first basin till it is completely inundated. The supply is then cut-off from the first basin and diverted towards the next basin. This process is repeated until all the basins in the irrigation block are irrigated. Contour basin irrigation is best adopted for cultivation of soils with low infiltration rates and where water may need to be ponded for long periods of time.

Figure 4.7 Contour basin irrigation for paddy rice *(photo by O. Rafalimanana)*

4.2.4 Ring-basins

A ring basin is a small earth basin with a nearly flat bottom surrounded by low bunds. The method is commonly used for widely spaced orchard crop to irrigate individual trees or groups of trees (figure 4.8). The important consideration in the case of the ring and basin method is to wet the soil only around the tree and not the entire land, thus economizing on the water.

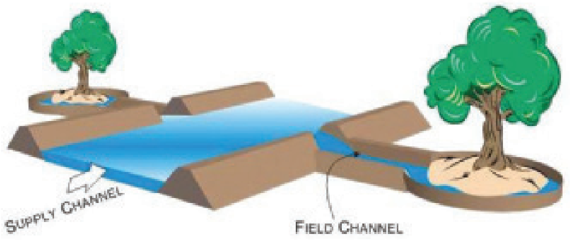


Figure 4.8 (a) Sketch of ring basins with tree crop	**(b) Ring basin with citrus fruit tree** *(photo by B. Mati)*

4.2.5 Conditions that favour basin irrigation

Suitable crops

Basin irrigation is suitable for many field crops and is the preferred method of irrigating paddy rice. Other crops which are suited to basin irrigation include: field crops such as maize, wheat, and beans; pastures, grasses, trees, e.g. citrus, banana, including various vegetables. Basin irrigation is generally suited to crops which cannot stand in wet or waterlogged conditions for periods up to 24 hours. Basin irrigation is not suitable for crops which require loose, well-drained soils especially root and tuber crops such as potatoes, cassava, beet and carrots.

Topographic conditions

Basin irrigation is practiced where land is relatively flat to very gently sloping with soils with relatively low water permeability. The flatter the land surface, the easier it is to construct basins. On flat land only minor leveling may be required to obtain level basins. It is also possible to construct basins on sloping land, even when the slope is quite steep. Level basins can be constructed like the steps of a staircase and these are called terraces.

Suitable soils

Basin irrigation may be used on a wide variety of soil textures, though fine-textured soils are preferred. Paddy rice is best grown on clayey soils which are almost impermeable as percolation losses are low. Rice can also be grown on sandy soils but percolation losses are high unless a high water table can be maintained. Such conditions sometimes occur in valley bottoms. Although most other crops are grown on clays, loamy soils are preferred for basin irrigation to avoid so that water logging. Coarse sands are not recommended for basin irrigation as, due to the high infiltration rate, percolation losses which can be high.

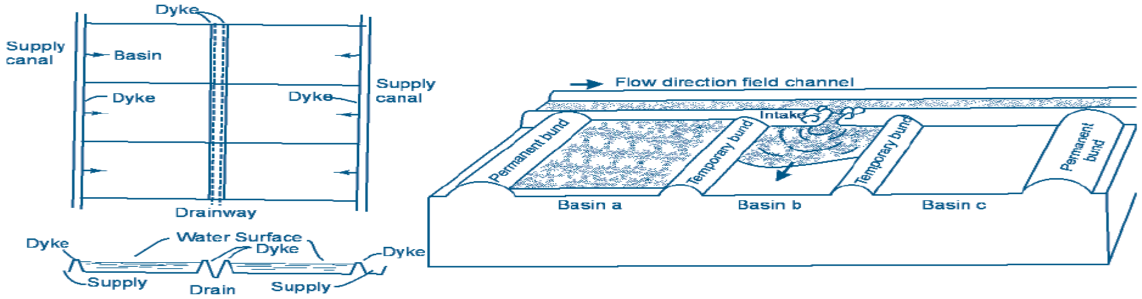
Stream size

Basin irrigation utilises large stream sizes as the entire irrigated area is flooded. Water is applied from a field canal through siphons, spiles or by breaching the dyke to create an inlet. The water used in basin irrigation should be free of salinity or sodicity. Water application can take several hours or days depending on crop grown and other soil conditions.

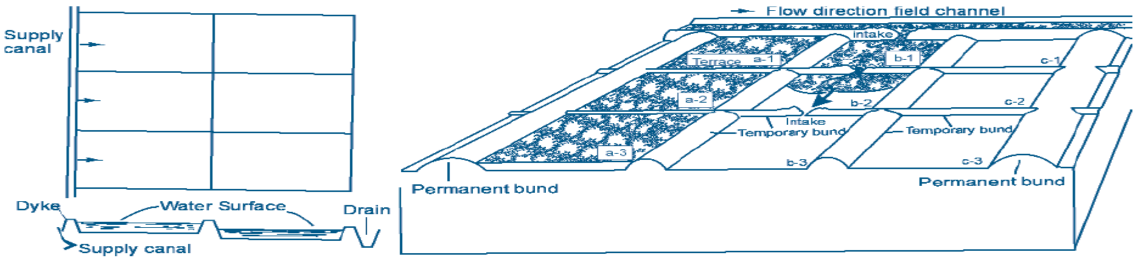
4.2.6 Design features

The design of basin irrigation system considers several factors such as land topography, soil type, crop to be grown, water availability and levels of available technology, e.g. whether mechanization is possible. These in turn determine the basin size, shape and size of enclosing bunds as well as the water application arrangements. The general layout (figure 4.9) comprises an inlet canal, the check basin, dykes or retaining bunds and a drainage channel.

Layout of basin irrigation (Source: FAO, 1985)



Direct method of water supply to the basins with a drainway midway between supply canals. "Basin a" is irrigated, then "Basin b", and so on.



Cascade method of water supply to the basins with a tier arrangement. Ideal on terraced land, where water is supplied to the highest terrace, and then allowed to flow to a lower terrance and so on.

Figure 4.9 Layout of basin irrigation system (Source: FAO, 1985)

Basin size

The size of basin is a function of topsoil depth, slope gradient, method of basin construction and the crops to be grown. The size of basin is critical in the design of this irrigation method and, it depends on the following factors: soil type, stream size, irrigation depth, field size and shape, land slope, and farming practices. There should be detailed description of different parts of the irrigated land so as to establish a range of slopes and soil types. Not only the selection of the appropriate size of the basin is important, but also application of the required design criteria and methods of operation. Table 4.2 indicates the general criteria for selecting a basin size.

Table 4.2 Criteria for basin size determination

Criteria	**Large basin size**	**Small basin size**
Soil type	Sandy	Clay
Stream size	Small	Large
Irrigation depth	Small	Large
Land slope	Steep	Gentle or flat
Filed preparation	Hand/animal traction	Mechanised

Generally, in order to use water more efficiently, there is an optimum relationship between the flow entering the basin, the soil type, and the size of the basin. Table 4.3 shows the recommended maximum size for basins. In smallholder irrigation, basins are usually smaller than the sizes indicated in table 4.3.

Table 4.3. Maximum basin sizes (area in m^2) for various soil types.

Flow (lt/sec)	**Sandy**	**Sandy loam**	**Clay loam**	**Clay**
1	6	20	40	60
2	12	40	80	120
5	30	100	200	300
10	60	200	400	600
15	100	300	600	1000

Source: Traditional Irrigation Project, Tanzania

Basin width

The width of a basin is determined by the dominant slope of the area being irrigated detailed surveys, soil description and analysis. The main limitation on the width of a basin is the land slope. If the land slope is steep, the basin should be narrow, otherwise too much earth movement will be needed to obtain level basins. Table 4.4 provides some guidance on the maximum width of basins or terraces, depending on the land slope.

Basins can be narrow if they are constructed by hand labour, but are made wider if machines are used so that the machines can easily be moved around. For mechanised agriculture, it is important to make sure that basin widths are some multiple of the width of the machines for efficient mechanization.

Table 4.4 Guide values for the maximum basin width

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

Shape and dimensions of bunds

Basin irrigation utilises earthen bunds or small earth embankments which contain irrigation water within basins. They are sometimes called ridges, dykes or levees. The height of bunds is determined by the irrigation depth and the freeboard. The freeboard is the height above the irrigation depth to be sure that water will not overtop the bund. The width of bunds should be such that leakage will not occur, and that they are stable.

Permanent bunds

Permanent bunds usually have a base width of 130-160 cm and a height of 60-90 cm when constructed (figure 4.10). The settled height will be 40-50 cm. This settling (compaction of the soil) will take several months. Permanent bunds are mostly used in rice cultivation, where the same crop is planted on the same fields year after year. The bunds are used as paths in the rice fields as well. Temporary bunds may be used to subdivide the various fields further.

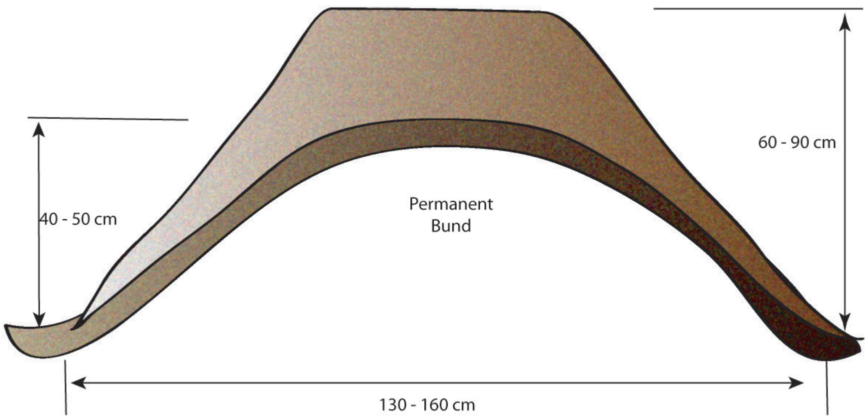


Figure 4.10 Shape and dimensions of permanent bunds

Temporary bunds

Temporary bunds are normally 60-120 cm wide at the base and have a height of 1.5-30 cm above the original ground surface (Figure 4.11), including a freeboard of 10 cm (for an irrigation depth of 5-20 cm). Temporary bunds surround fields on which annual crops are grown; these bunds are rebuilt each season.

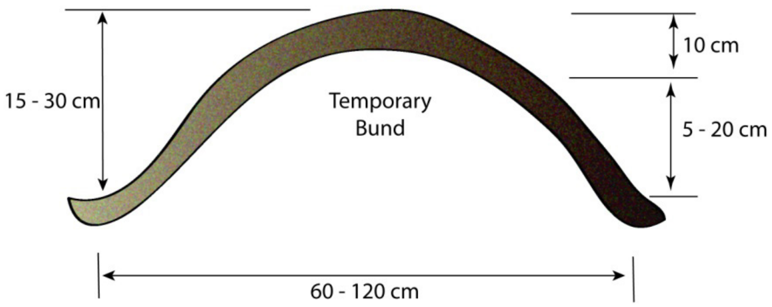


Figure 4.11 Shape and dimensions of temporary bunds

4.2.7 Water application

Water application in basin irrigation should be done using a large stream size that advances quickly in order for water to spread rapidly over the basin (figure 4.12). The advance time should not exceed a quarter of the contact time, so as to reduce difference in contact time on the different sections of the basin. As the area near the water inlet is always longer in contact with the water, some percolation losses occur, assuming the entire root zone depth is filled at the bottom of the field. There are two methods to supply irrigation water to basins; (i) Direct method and (ii) the cascade method.

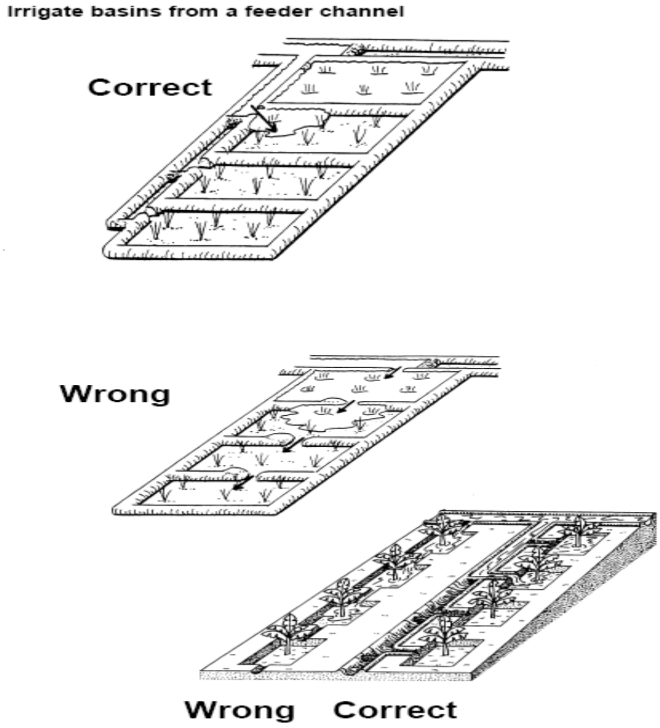


Figure 4.12 Orientation of feeder canals for basin irrigation

Direct method

Irrigation water is led directly from the field channel into the basin through siphons, spiles or bund-breaks. This can be done for most crop types and is suitable for most soils.

Cascade method

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

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

Wetting patterns

For good crop growth it is very important that the right quantity of water is supplied to the root zone and that the root zone is wetted uniformly. If crops receive too little water, they will suffer from drought stress, and yield may be reduced. If they receive too much water, then water is lost through deep percolation and, especially on clay soils, permanent pools may form, causing the plants to drown. How the irrigation water can be evenly distributed in the root zone.

Ideal wetting pattern

To obtain a uniformly wetted root zone, the surface of the basin must be level and the irrigation water must be applied quickly. Figure 4.12 shows an ideal wetting pattern: the basin is level and the right quantity of water has been supplied with the correct scream size. In most cases, it is not possible to have the wetting pattern and root zone coincide completely (Figure 4.13). The part of the basin near the field channel is always in contact with the irrigation water longer than the opposite side of the basin. Therefore percolation losses will occur near the field channel, if sufficient water is supplied to the opposite side of the basin.

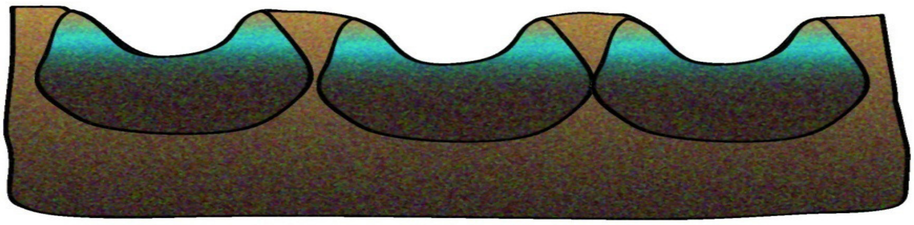


Figure 4.13. Ideal wetting pattern in basin irrigation

Causes of poor wetting patterns

Poor wetting patterns can be caused by:

- Poor management, e.g. supplying incorrect stream size, applying too little or too much water.
- Unfavourable natural condition, e.g. a compacted subsoil layer, or different soil types within one basin. Infiltration through the compacted sub-soil layer may be very slow and so water tends to accumulate above this layer forming a perched water table.

- Poor layout e.g. a poorly graded surface.

Under-irrigation

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

Over-irrigation

Basin irrigation sometimes uses too much water causing over-irrigation. This results in high percolation losses. Sometimes, plant nutrients are washed away and on clay soils, the plants may even suffer water logging. The obvious solution is to apply less water.

4.2.8 Basin construction

The construction works for a basin irrigation system usually starts with the basin feeder canals (assuming the rest of the water delivery infrastructure has been done). The basin feeders are constructed as a small canal by forming the banks. These are preferably made straight, running down the slope, and should be parallel to each other. It should be noted that "canals are constructed, drains are dug". This will allow the water level in the basin feeder to be above the ground level. The banks should be about 30 cm high, 30 cm wide at the top and well compacted. Soil for the construction of the banks will be taken from the adjacent fields. The banks of the basin feeder form one side of the basins.

The basins can now be set out according to the designed dimensions. The bunds are constructed on the boundaries of the basins. The bunds should be some 20 cm high and about 20 cm wide at the top. As with the feeder banks, the bunds have to be well compacted to prevent leakage from one basin to another.

The construction of feeder banks and basin bunds will have left some low spots in the basin. After construction of the bunds, the basin needs to be leveled. This can be done "by eye" or with the use of a water hose level (for larger basins). A simple trick is to fill the basin with water and check for high and low spots and do the leveling. This "pre-irrigation" will also make tillage and planting easier. After leveling, ridges can be formed in the basins in case ridged basins are required.

On small plots with uniform slope, it is possible to construct the basins directly. This starts with pegging out contour lines at a vertical interval of 10 cm. The distance between the contour lines is divided by three. This is the width of the basins. As a result of this method, the basins may be curved and not rectangular. The determination of the length of the basin will be guided by the maximum basin size (see Table 4.3) and the location of the basin feeders. The basin feeders should be down the slope and parallel to each other.

4.2.9 Limitations of basin irrigation

Basin irrigation, if not well designed, can suffer poor water distribution patterns, under-irrigation over-irrigation. Another limitation is that basin irrigation has too many ridges which not only occupy the land but also hinder other agronomic operations as well as use of machinery.

4.2.10 Maintenance of Basins

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

4.3 Border irrigation

Border irrigation (or border strip irrigation) involves irrigating strips of land having a small slope but which are levelled to allow uniform water distribution. The method is also suited well to all irrigable soils and to closely spaced rowed crop and even to pasture crop. Slopes up to seven per cent can be irrigated when the pasture crop are grown.

4.3.1 Straight borders

Straight borders are rectangular levees in which the field is divided into long narrow strips, with small paralleled ridges on the sides (figure 4.14). The entire area is levelled perfectly and irrigation water flows down the graded field in a slow wetting front. The width and length of strips depends on the slope, the rate of water-intake of the soil and the stream size.

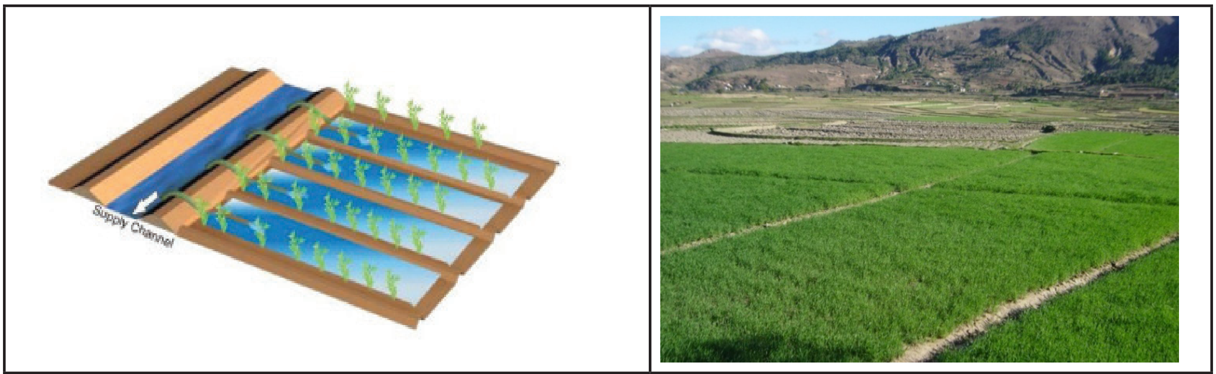


Figure 4.14 (a) Sketch of straight borders

(b) Straight borders for irrigation of wheat *(photo by B. Mati)*

4.3.2 Contour borders

On steeper slopes, the borders are laid along the elevation contours of the topography when the land slope is excessive. Thos method of border is called *contour border method* of irrigation (figure 4.15).

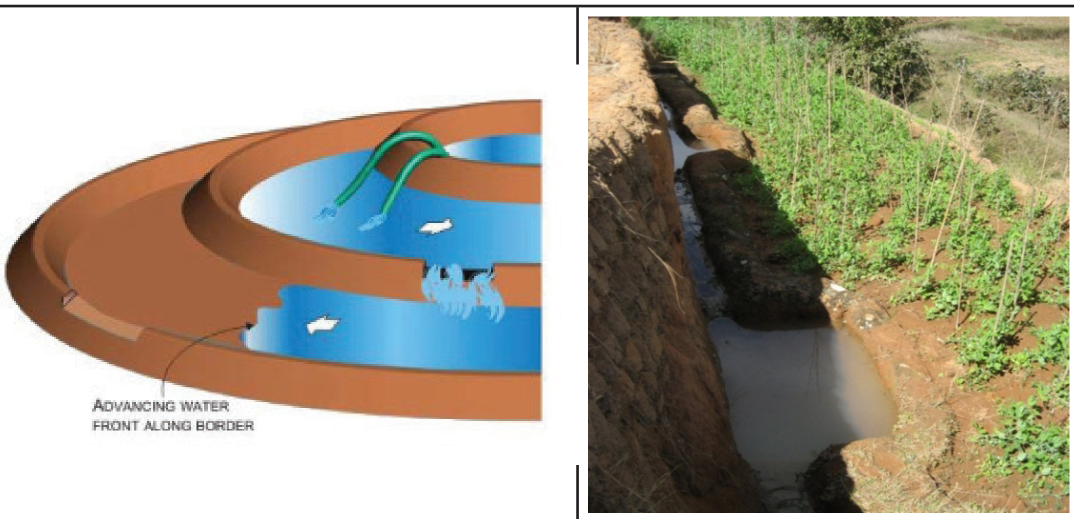


Figure 4.15 (a) Sketch of contour borders

(b) Contour border irrigation with peas
(photo by O. Rafalimanana)

4.3.3 Design features

The design of border dimensions depends on soil type, stream size, irrigation depth, land slope; field size and shape and cultivation practices. Border strips are made by creating parallel dykes or border ridges (levées). They can vary in size ranging from 3-30 m in width and 50-300 m in length or more, depending upon the slope irrigation are best suited to very gently sloping land (figures 4.16 and 4.17). Borders can be used on sloping land up to 2% on sandy soil and 5% on clay soil. A minimum slope of 0.05% is recommended to ensure adequate drainage. For laying out border strips, the land needs to be graded uniformly to achieve a high water-application efficiency.

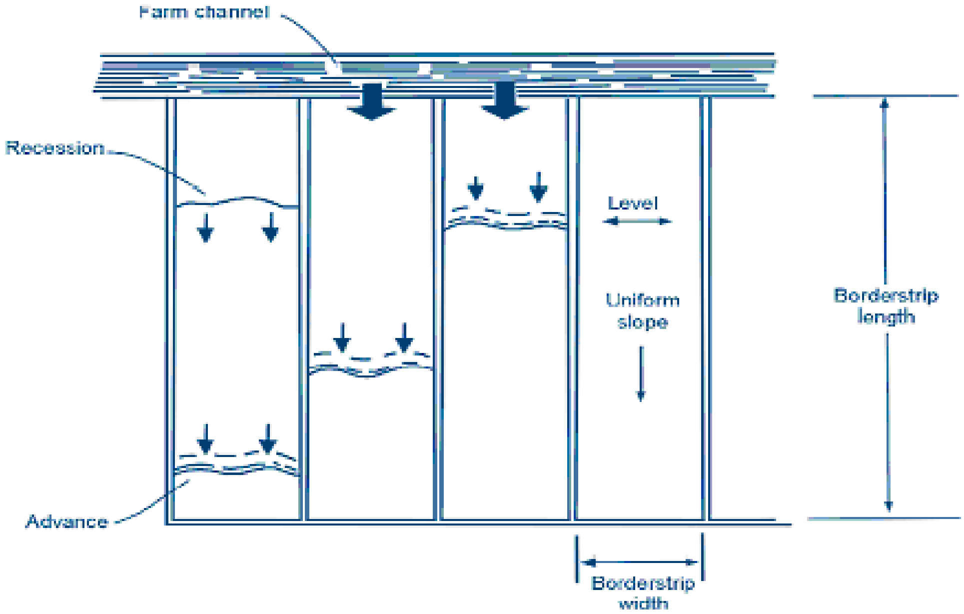


Figure 4.16: Border strip irrigation layout (Source: Kay, 1986)

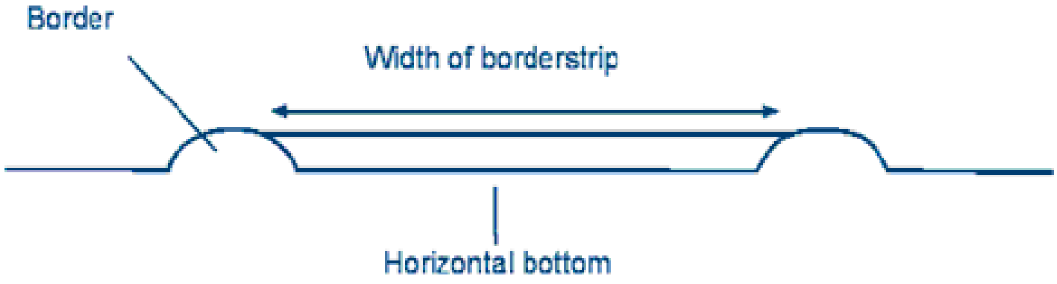


Figure 4.17: Cross-sectional view of border strip irrigation

Border width

For the practical management purpose and for the attainment of reasonable irrigation efficiency, the border strip widths and lengths should not exceed critical size to permit uniform water distribution. Guide values of border strip length, width and flow rates are presented in table 4.5.

Table4.5: Critical widths and lengths of border strips by soil infiltration rates

Soil type	Border strip slope (%)	Unit flow per metre width (l/s)	Border strip width (m)	Border strip length (m)
Sand Infiltration rate greater than 25 mm/h	0.2-0.4	10-15	12-30	60-90
	0.4-0.6	8-10	9-12	80-90
	0.6-1.0	5-8	6-9	75
Loam Infiltration rate 10 to 25 mm/h	0.2-0.4	5-7	12-30	90-250
	0.4-0.6	4-6	9-12	90-180
	0.6-1.0	2-4	6	90
Clay Infiltration rate less than 10 mm/h	0.2-0.4	3-4	12-30	180-300
	0.4-0.6	2-3	6-12	90-300
	0.6-1.0	1-2	6	90

Source: Withers and Vipond, 1974

Water management

Normally water is let onto the border-strip from the canal through intakes, which can be constructed with gates on the wall of the canal or, when unlined canals are used, by temporarily making an opening in the canal wall. The latter is not recommended since it weakens the walls of the canal, leading to easy breakage. Other means used for the same purpose is the insertion of short PVC pipes into the canal through the wall. The short pipes are usually equipped with an end cup, which is removed when irrigation is practiced.

Stream size

The stream size applied in border irrigation must be just right, neither too big to cause erosion and not too small to cause over-wetting at the upstream end. This balance is determined by assessing a combination of factors such as slopes of the border run, soil infiltration properties, crop root zone depth and border size (table 4.6).

Table 4.6: Guide values for border stream size for various soil and slope characteristics

Soil type	Slope (%)	Depth applied (mm)	Flow (l/s)	Border strip width (m)	Border strip length (m)
Coarse	0.25	50	240	15	150
		100	210	15	250
		150	180	15	400
	1.00	50	80	12	100
		100	70	12	150
		150	70	12	250
	2.00	50	35	10	60
		100	30	10	100
		150	30	10	200
Medium	0.25	50	210	15	250
		100	180	15	400
		150	100	15	400
	1.00	50	70	12	150
		100	70	12	300
		150	70	12	400
	2.00	50	30	10	100
		100	30	10	200
		150	30	10	300
Fine	0.25	50	120	15	400
		100	70	15	400
		150	40	15	400
	1.00	50	70	12	400
		100	35	12	400
		150	20	12	400
	2.00	50	30	10	400
		100	30	10	400
		150	20	10	400

Source: Withers and Vipond, 1974

Larger flows are required for irrigating border strips than those in the case of other layouts. On steep slopes, this method can be used by proper terracing or trenching along the contours. Land levelling is usually necessary and has to be accurate to remove surface imperfections. Border irrigation is particularly suitable for close growing crops such as wheat, but it can also be used for row crops such as maize as well as for trees.

4.3.4 Limitations of border irrigation

Like other surface irrigation methods, border irrigation utilises large stream flows and has lower irrigation efficiency. The method wet the entire field and thus is wasteful of water. There is some danger of erosion damage as the water is made to flow down some slope. Also, the risks of either under-watering or over-watering on each end of the border, and consequently, poor uniformity in water distribution in the soil profile.

4.4 Furrow irrigation

A furrow irrigation system consists of parallel channels (furrows) separated by slightly raised beds or ridges running at a slight gradient to allow slow flow of water and wetting of the soil (figure 4.18). The shape, spacing and length of furrows depend mainly on the crops to be grown and the types of soils. Furrow irrigation is an improvement over basin and border irrigation methods, as it reduces the area ponded or contacted by water, and hence water used in surface irrigation. Crops, such as sugarcane, cotton, tobacco, potato, some vegetables and other widely spaced row crops, are irrigated by using the furrow method.

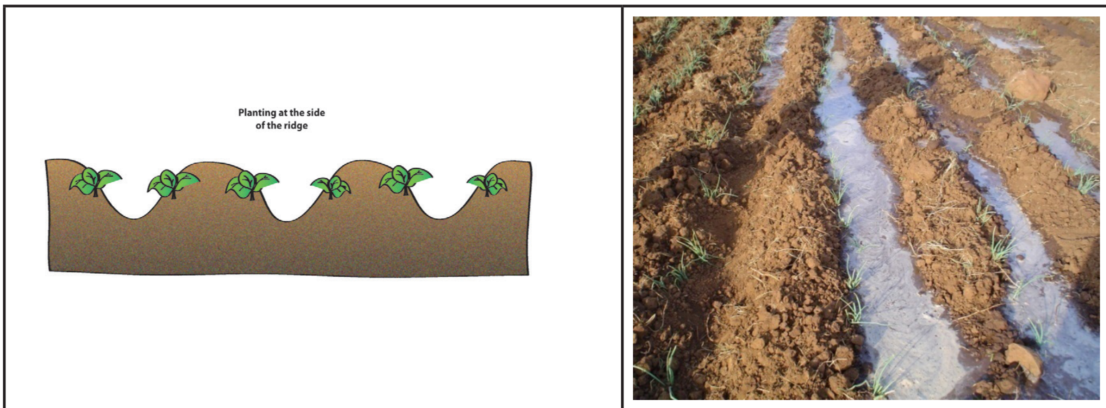


Figure 4.18 (a) Sketch of furrow irrigation system

(b) Furrow irrigation with onion crop *(photo courtesy of G. Alemu)*

4.4.1 Straight furrows

Straight furrows are made on relatively flat ground and they run in straight lines down a small grade (figure 4.19). Water is applied to the field into furrow between ridges and the top of the ridge is not directly wetted. Straight furrows are recommended for slopes up to three per cent.

Figure 4.19 (a) Sketch of straight furrows

(b) Straight furrows *(photo by Omar el Seed)*

4.4.2 Contour furrow

Contour furrows are made on sloping lands where the slope exceeds three per cent and is up to about fifteen per cent. The furrows are laid out in graded contours (Figure 4.20). Water distribution is well controlled to achieve uniform application and the consequent high efficiency.

Figure 4.20 Contour furrow irrigation with tomato *(photo by B. Mati)*

4.4.3 Conditions that suit furrow irrigation

Crop types

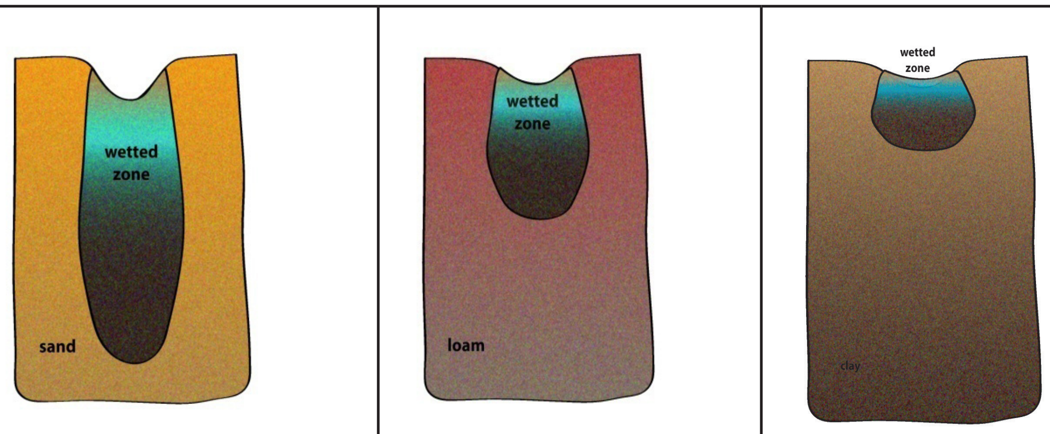
Furrow irrigation is suitable for a wide range of soil types, crops and land slopes, as indicated below. It is particularly suitable for (i) row crops such as maize, sunflower, sugarcane, soybean, (ii) crops that would be damaged by inundation, such as tomatoes, vegetables, potatoes, beans, (iii) fruit trees such as citrus, grape and (iv) broadcast crops (corrugation method) such as wheat. However, crops that would be damaged if water covered their stem or crown should not be irrigated by furrows. Furrow irrigation is also suited to the growing of tree crops. One furrow alongside the tree row may be sufficient. However, with this type of irrigation there is a risk of localised salinisation in the ridges.

Suitable slopes

Furrow irrigation favour uniform, flat or gentle slopes. Furrow irrigation can be used on flat land (short, near horizontal furrows), and on mildly sloping land with a slope of maximum 0.5%. On steeper sloping land, contour furrows can be used up to a maximum land slope of 3%. A minimum slope of 0.05% is recommended to assist drainage. In areas where there is a risk of erosion due to intensive rainfall, the maximum slope should be limited to 0.3%. For land slopes steeper than 0.5%, furrows can be set at an angle to the main slope or even along the contour to keep furrow slopes within the recommended limits. Furrows can be set in this way when the main land slope does not exceed 3%. Beyond this there is a major risk of soil erosion following a breach in the furrow system. On steep land, terraces can also be constructed and furrows cultivated along the terraces.

Suitable soils

Furrow irrigation is suited to most soil types. However, as with all surface irrigation methods, it works best with heavy clay soils. Coarse sands are not recommended as percolation losses can be high. Soils that crust easily are especially suited to furrow irrigation because the water does not flow over the ridge, and so the soil in which the plants grow remains friable. Coarse soils require closely-spaced furrows in order to achieve lateral water flow in the root zone. Figure 4.21 shows the general wetting patterns of sandy, loamy and clay soils. There is more lateral water flow in clay than in sand.



(a) Wetting pattern-sandy soil

(b) Wetting pattern-loamy soil

(c) Wetting pattern-clay soil

Figure 4.21 Typical wetting patterns under furrow irrigation for different soil types

4.4.4 Design features of furrow irrigation

Generally, the shape, length and spacing are determined by the natural circumstances, i.e. slope, soil type and available stream size. However, other factors may influence the design of a furrow system, such as the irrigation depth, farming practice and the field length. For instance, furrow widths can vary from 250-400 mm, depths from 150-300 mm and spacing can vary from 0.75-1.0 m, depending on soil type, crops and stream size to be applied to the furrow. For sandy soil, furrows are made deeper, while for clay soil, they are made shallow and wide, as shown in figures 4.22 and 4.2.3.

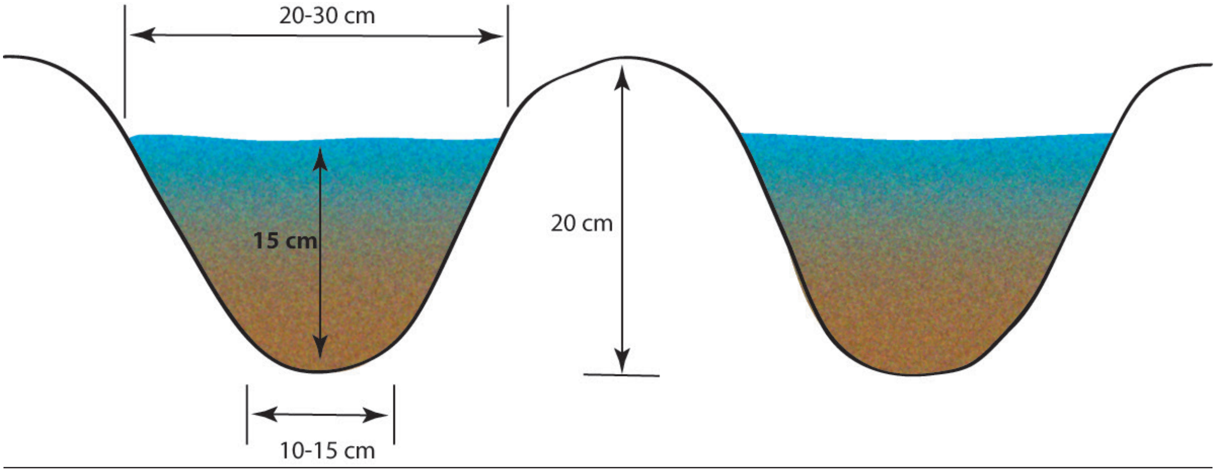


Figure 4.22: Sketch of furrow irrigation and cross-section on a sandy soil

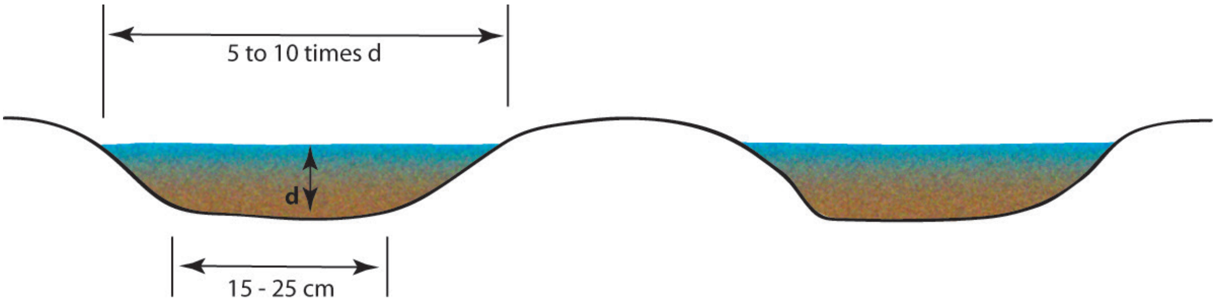


Figure 4.23: Sketch of furrow irrigation and cross-section on a clay soil

Furrow length

The design furrow length is a function of the land slope, the soil type, the stream size, the irrigation depth, the cultivation practice and the field length. But it is usually more practical to make the furrow length equal to the length of the field, instead of the ideal length. Generally, typical furrow lengths vary from about 60 m on coarse textured soils to 500 m on fine textured soils, depending on the land slope, stream size and irrigation depth. In sandy soils water infiltrates rapidly. Furrows should be short (less than 100 m), so that water will reach the downstream end without excessive percolation losses. In clay soils, the infiltration rate is much lower than in sandy soils. Furrows can be much longer on clayey than on sandy soils. The dimensions of furrows can be determined using the guidelines of the factors shown in Table 4.7. However, care is needed to ensure that the standard spacing provides adequate lateral wetting on all soil types.

Table 4.7 Furrow length as related to soil type, slope, stream size and irrigation depth

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

Source: FAO 1985

Stream size

Furrow irrigation utilises stream sizes that allow adequate and uniform ponding of water along the length. Generally, stream sizes may range 0.5 up to 3.0 litres/sec depending on soil type crop and furrow length. When stream sizes are too large, water moves rapidly down the furrows and can either cause erosion or poor wetting distribution. Stream sizes that are too small may cause over-wetting at the inlet and poor wetting at the tail end.

Irrigation depth

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

Cultivation practice

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

4.4.5 Irrigating Furrows

During irrigation, water is supplied to each furrow from the field canal, using siphons or spiles. Sometimes, instead of the field canal with siphons or spiles, a gated pipe is used Depending on the available flow in the farm channel, several furrows can be irrigated at the same time.

Wetting patterns

In order to obtain a uniformly wetted root zone, furrows should be properly spaced, have a uniform slope and the irrigation water should be applied rapidly. As the root zone in the ridge must be wetted from the furrows, the downward movement of water in the soil is less important than the lateral (or sideways) water movement. Both lateral and downward movement of water depends on soil type. An ideal wetting pattern is where lateral infiltration enables wetting fronts to converge, while deep percolation losses are minimised (figure 4.24).

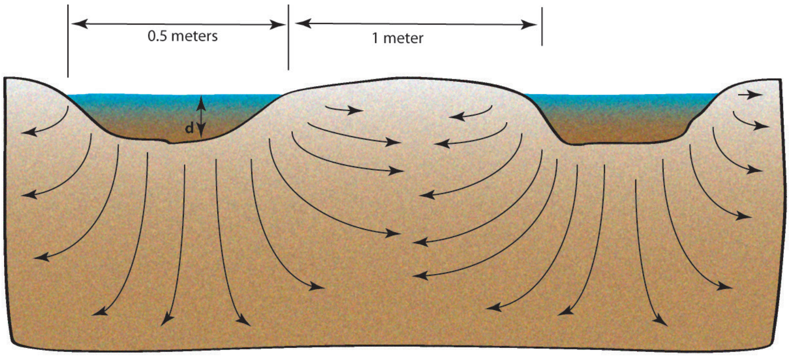


Figure 4.24 Ideal wetting pattern under furrow irrigation

Alternate furrow irrigation

When there is a water shortage, it is possible to limit the amount of irrigation water applied by using alternate furrow irrigation (figure 4.25). This involves irrigating alternate furrows rather than every furrow. For instance, instead of irrigating every furrow after 10 days, furrows are irrigated after 5 days and the alternate furrows irrigated within the next 5 days. Thus the crop receives some water every 5 days instead of a large amount every 10 days. Small amounts applied frequently in this way are usually better for the crop than large amounts applied after longer intervals of time.

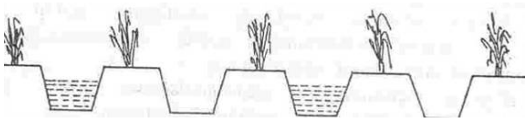


Figure 4.25 (a) Sketch showing alternate furrow irrigation

(b) Alternate furrow irrigation of vegetable crop *(photo by B. Mati)*

4.4.6 Corrugations

Are small furrows known sometimes prepared in the within border-strip method to increase efficiency and the uniformity of flooding from the ditch method. Corrugations can be made by using an implement called 'corrugator'. This implement is suited to close-growing crops grown on a medium type of soil with the rather uneven topography. Corrugations are mostly used to grow fodders.

4.4.7 Surge irrigation technique

Surge irrigation is a technique whereby water flow is applied to furrows (or less commonly, borders) intermittently during a single irrigation set. It is meant to save water by reducing the stream flow. It is used for crops like maize, sunflower and sorghum.

4.4.8 Hillside Irrigation

Hillside irrigation is a term commonly used to mean irrigating uplands and other steep areas. This can be achieved through both gravity fed water supplies as well as pumped systems. Due to ruggedness of the terrain piped water delivery is preferred, but canal systems are also possible.

Hillside irrigation is easily achieved with sprinkler irrigation, as well as with drip. It is also practices with surface methods such as basin (figure 4.24) and furrow. An important feature of hill-side irrigation is the construction of level terraces to enable conservation of the water and even distribution.

Figure4.24 (a) Hillside irrigation with bench terraces *(photos by O. Rafalimanana)*

(b) Hillside irrigation with canal water supply

Hillside irrigation requires tremendous amounts of labour to construction of the terrace walls, and building up the earth fill for each field unit. The terraces also require regular maintenance and repair so as to ensure the soundness of the terrace walls. Skilled water control, however, is the most important factor in maintaining good soil as well and high productivity of the field units.

4.5 Advantages of furrow irrigation

- High water efficiency
- Can be used in any row crop
- Relatively easy in stall
- Not expensive to maintain
- Adapted to most soils.

4.6 Disadvantages of furrow irrigation

- Requirement of skilled labour is more
- A hazard to operation of machinery
- Drainage must be provided.

4.6 Maintenance of furrow irrigation

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

5. SPRINKLER IRRIGATION

5.1 What is sprinkler irrigation?

Sprinkler irrigation is a method of applying irrigation water under pressure to the surface of any crops or the soil in the form of a thin spray from above. Sprinkler irrigation tries to mimic natural rainfall. It is generally an overhead irrigation technique that operates under high pressure, and utilises piped water. However, the water is spread uniformly over the land surface just when needed and at a rate less than the infiltration rate of the soil so as to avoid surface runoff from irrigation. This is achieved by distributing water through a system of pipes usually by pumping which is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground. A typical sprinkler system consists of a pump to lift and convey water under pressure, pipes or tubing for conveyance of water the sprinkler heads or nozzles, the risers which connect the sprinkler heads with the pipeline. Figure 5.1 shows a typical sprinkler irrigation system in operation.

Figure 5.1 Sprinkler irrigation system *(photo courtesy of Madev Balloo)*

5.2 Conditions that favour sprinkler irrigation

Suitable crops

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

Preferred slopes

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

Suitable soils

Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils. The average application rate from the sprinklers (in mm/hour) is usually chosen to be less than the basic infiltration rate of the soil so that surface ponding and runoff can be avoided. Sprinklers are not suitable for soils which easily form a crust. If sprinkler irrigation is the only method available, then light fine sprays should be used, while large sprinklers producing huge water droplets are to be avoided.

The water holding capacity of soils is different for different soils. Thus, type of soil determines the type of sprinkler, irrigation schedule, size and type of equipments. The general nature of the soil and its characteristics should be given in the scheme. Design of Sprinkler system also depends upon the infiltration rate of soil (Table 5.1). The higher the infiltration rate, the larger is the flow rate that can be utilised. Data on soil characteristics is thus vital.

Table -5.1: Infiltration rate of some soils

SNo.	Soil Type	Infiltration Rate (cm/hr)
1.	Coarse sand	2.0 to 2.5
2.	Fine sand	1.2 to 2.0
3.	fine sandy loam	1.2
4.	Silty Loam	1
5.	Clay loam	0.8
6.	Clay	0.5

Suitable irrigation water

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

5.3 Design features of a sprinkler system

Components of the system

The design of sprinkler irrigation systems considers that the water has to be conveyed under pressure through pipes to the area to be irrigated. It also considers the layout of the piping, laterals and sprinklers in relation to operating pressures, the crop type, soil characteristics, topography, water sources and costs of operation. The design and planning of sprinkler irrigation system should aim at maximising the returns and minimising both the initial capital outlay and the operating costs per unit volume of water used. The system comprises a set of equipment which include the following components (figure 5.2).

- Water source – e.g. river, lake, pond, open well, bore well, canal
- Pump unit (may be absent in case gravity flow provides adequate pressure)
- Mainline and sometimes sub-mains
- Laterals
- Sprinklers and
- Other accessories, e.g. fittings like reducers, elbows, regulators and gauges, valves, filters, end plug tees, boosters, fertilizer applicator and operational control equipment.

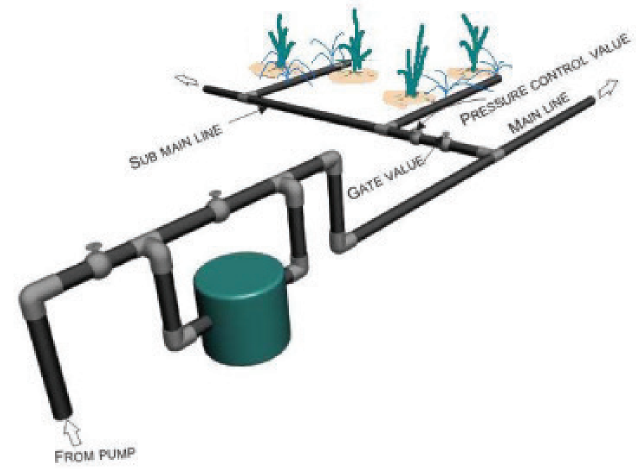


Figure 5.2(a) Typical layout of a sprinkler irrigation system *(adapted from CE IIT, Kharagpur)*	**(b) A view of sprinkler irrigation** *(Photo courtesy of E. Tamiru)*

Pumping unit

A pump is required to carry water from the source through the main line and laterals up to the sprinkler or nozzle from where it is sprayed and applied to the crops. Pumps are also used to boost the pressure necessary to run the sprinklers (Figure 5.3). In areas where the land topography allows to develop enough pressure at nozzle or sprinkler head under gravity a separate pump may not be necessary.

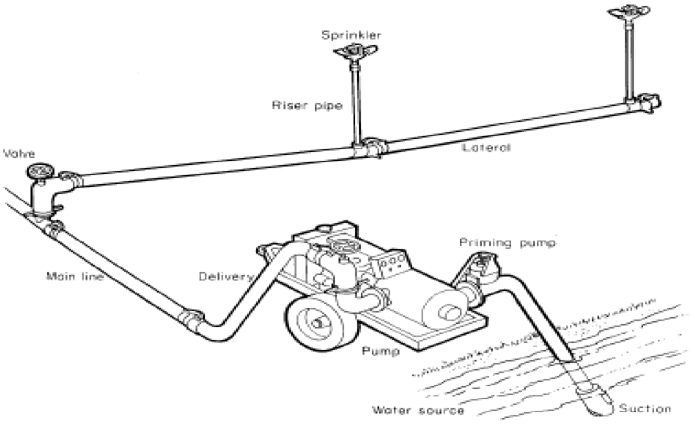


Figure 5.3 Components of a sprinkler irrigation method

In most cases it is necessary to pump water and carry it under pressure through the system. The pump is normally a centrifugal pump or a submersible pump fitted with usual accessories. If the water is pumped from a well or a tube well, and the capacity and horse power of the existing pump is sufficient to provide the desired pressure at the nozzle or sprinkler head, a separate pump may not be necessary for the system. But, in case the existing pump is not sufficient to provide the required pressure for the sprinkler system, a separate booster pump has to be provided depending upon the field situation after taking into account frictional losses in the main, laterals and risers and nozzles.

Mainline and sub-mains

The mainline and sub-mainlines - are pipes which deliver water from the pump or source to the laterals. Main line may be permanent or portable. Permanent main line is advantageous where field boundaries are fixed and where crops require full season irrigation. Portable main lines are more economical when a sprinkler system is used for different fields or let out on hire to other farmers. Main line pipes are often buried so that they do not come in way of other agricultural operations. The main pipe materials used include asbestos cement, plastic or aluminum alloy.

Laterals

The laterals deliver water from the mainlines or sub-mainlines to the sprinklers. Lateral pipes are normally available in 5 m, 6 m, 12 m lengths. Each length has quick couplings. All couplings are provided rubber gaskets in female portion, which tightens the coupling and makes it, leak proof. Lateral pipes should be of good quality and must conform to the respective prescribed standards. Number of laterals on a main pipe line varies depending upon the crop geometry, water requirement of crop, area required to be wetted so that the total frictional head losses are not very high as that would require a very high capacity pump. Laterals can be permanent but more often they are portable and made of aluminium alloy or plastic so that they can be moved easily.

Sprinkler riser

The risers convey the irrigation water from the laterals through a valve to the sprinkler where it is sprinkled over the crops. The riser pipe connects the rotating sprinkler head to the lateral. Usually the pipe diameter varies from 12 mm to 75 mm with standard pipe threads. Riser with height 10 cm for small sprinklers and 1 m on large sprinklers give best results. In orchard and other crops the riser length could be 4-5 m for tree sprinkling. Sprinkler should stand slightly away from the crop so that the foliage does not interrupt its jets. High risers should be avoided unless necessary except for crops like sugarcane, banana, maize where height of the plant is high.

Sprinkler head/ nozzles

Sprinkler heads/nozzles are the most important component of the sprinkler system (figure 5.4). Their operating characteristics under optimum water pressure and climatic conditions, mainly wind velocity, will determine their suitability and the efficiency of the system. Most agricultural sprinklers are the slow rotation type. They may range from small single nozzle sprinklers to multiple nozzle sprinklers that operate at high pressure. The combination of pressure and rotation results in the jet of water being thrown to a considerable distance.

(a) Rotary sprinkler head

(b) Boom sprinkler head

(c) Micro-sprinkler head

Figure 5.4 Different designs of locally made sprinkler heads *(photos by B. Mati)*

Other sprinkler accessories

Other accessories used in the sprinkler system are:

1. Reducers: Where more than one pipe size is used on the sprinkler line, a reducer is necessary for coupling pipes of different diameters. However, it is recommended that same diameter pipes are used everywhere.

2. Elbows: These are used at joints for changing the direction of water flow. It is also used for reducing the pipe size. Valve opening elbows are used which fit over the take off valves on the mainline and allow a lateral to be connected.

3. End plug Tees: These are placed at the end of a line so that the water feeds into them and the run of each tee points directly across the line. Therefore, two branches could be attached 180 degrees from each other.

4. Regulators and Gauges: These include pressure regulators installed below the sprinkler to keep a constant pressure applied to the sprinkler regardless of whether the pipeline is laid up slope or down slope. Flow regulators are installed to control the flow and pressure of water flowing in the sprinkler. Pressure gauges are used to know the pressure at the pump set or at the sprinkler. It is desirable to install gauges on each lateral.

5. Valves: Valves are used to control the flow of water. Screw type valves are common. Drain valves are needed at valley portion of the land. Other valves are conventional pressure relief valves, check valves, outlet valves, air relief valves etc.

6. Filters: Sprinkler nozzles are prone to blockage if water carries silt or is saline. In order to stop entry of dirt, sand weed or other suspended material in water flowing through the system, it is necessary to install filters placed on suction side of the pump and at vulnerable places.

7. Fertilizer Applicator: This device is used for fertilizer application through the system instead of direct application. Only soluble fertilizers can be applied this way. Phosphorous fertilizers are not readily soluble and hence not applied through the system. When the fertilizers are applied through the system it is desirable to operate the system for long time to wet the soil and plant foliage and then inject the fertilizer in the system.

Water application rates

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

Sprinkler drop sizes

As water sprays from a sprinkler it breaks up into small drops between 0.5 and 4.0 mm in size. The small drops fall close to the sprinkler whereas the larger ones fall close to the edge of the wetted circle. Large drops can damage delicate crops and soils and so in such conditions it is best to use the smaller sprinklers. Drop size is also controlled by pressure and nozzle size. When the pressure is low, drops tend to be much larger as the water jet does not break up easily. Therefore, to avoid crop and soil damage, the use of small diameter nozzles operating at or above the normal recommended operating pressure is usually recommended.

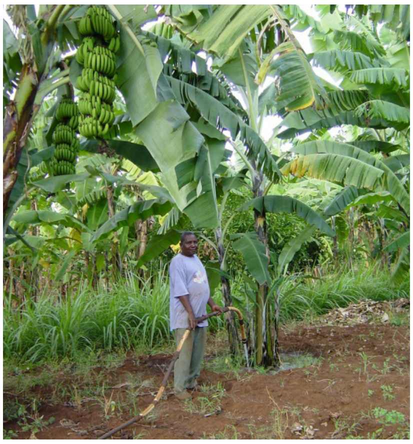
5.4 Sprinkler spray types

Water application under sprinkler irrigation produces various types of spray based on the type of equipment used. The type of spray created by a sprinkler is a function of operating pressure, height of the riser and nozzle size. Large sprays result from high pressures and large nozzles. The methods of creating different spray types diverse, ranging from manual systems, to conventional rotating head sprinkler, micro-sprinklers and centre pivot systems, as described here below.

5.4.1 Hosing

Hosing is a manual method of sprinkler irrigation which is quite common among smallholder farmers (figure 5.5). It involves using a flexible pipe to manually irrigate with water under pressure directly onto the plants. The spray is created by attaching a slotted head or by simply squeezing the pipe outlet. Hosing is slow and inefficient as it relies on manual labour. Also, the spray created sometimes has a higher flow rate than the infiltration rate of the soil, causing surface runoff before the root zone is adequately wetted. Hosing should be only be used as an emergency measure while more reliable methods of sprinkler irrigation is being organised.

Figure 5.5 (a) Hose pipe with slotted head for irrigating vegetable crop (photos by B. Mati)



(a) Manual hosing of banana crop

5.4.2 Rotating head sprinkler system

The rotating head sprinkler system has small sized nozzles are placed on riser pipes fixed at uniform intervals along the length of the lateral pipe (Figure 5.6). The lateral pipes are usually laid on the ground surface. The nozzle of the sprinkler rotates due to a small mechanical arrangement which utilises the thrust of the issuing water.

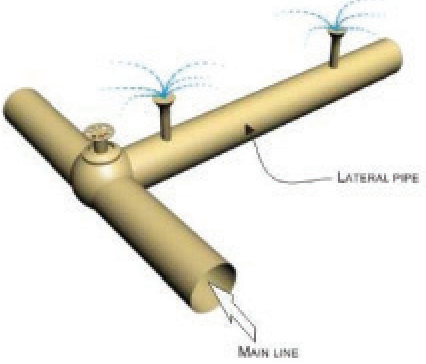


Figure 5.6(a) Sketch of a rotating head sprinkler

(b) Rotating head sprinkler *(photo by B. Mati)*

5.4.3 Perforated pipe system

This consists of holes perforated in the lateral irrigation pipes in specially designed pattern to distribute water fairly uniformly (Figure 5.7). The sprays emanating from the perforations are directed in both sided of the pipe and can cover a relatively large area. Since the spray is in a fixed direction, there is the danger of over-wetting one spot and under-wetting other areas. To avoid this, the spray released should be fine so as to allow enough time for water infiltration into the soil.

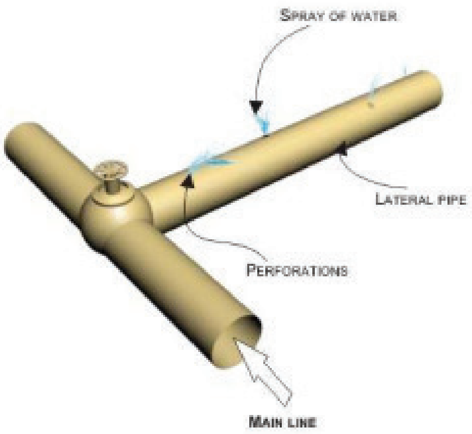


Figure 5.7 Sketch of Perforated pipe sprinkler system

(b) Perforated pipe sprinkler *(photo by B. Mati)*

5.4.4 Micro-sprinklers

The micro-sprinkler irrigation system is a variation of conventional sprinkler system, whereby water is applied to localised areas using mini sprinklers or spray jets. Thus, smaller quantities of water are applied and the diameter of wetting is smaller Micro-sprinklers utilise lower operating pressures and are capable of higher uniformity coefficient. These systems are suited to irrigation of widely spaced tree crops as they can irrigate just the tree root zone and avoid wetting unnecessary spaces between the trees. They are also suited to irrigation of closely spaced horticultural crops and widely spaced row crops (Figure 5.8).

Figure 5.8 (a) Micro-sprinkler irrigation of cabbage *(photos by B. Mati)*

(b) Micro-sprinkler irrigation of beans

5.4.5 Centre pivot irrigation

Centre pivot irrigation is a form of sprinkler irrigation which irrigates large areas. Although associated with large scale farming, centre pivot can also be used for irrigation of smallholder farms as part of group irrigation. Several small farms can share one Centre pivot and the method can be efficient as it permits centralized water control.

Centre pivot consists of several segments of pipe (usually galvanized steel or aluminum) joined together and supported by trusses, mounted on wheeled towers with sprinklers positioned along its length. The system moves in a circular pattern and is fed with water from the pivot point at the centre of the arc. These systems are found and used in all parts of the world and allow irrigation of all types of terrain. Newer systems have drop sprinkler heads as shown in Figure 5.9.

Most centre pivot systems now have drops hanging from a u-shaped pipe attached at the top of the pipe with sprinkler heads that are positioned a few feet (at most) above the crop, thus limiting evaporative losses. Drops can also be used with drag hoses or bubblers that deposit the water directly on the ground between crops. Crops are often planted in a circle to conform to the centre pivot. However, some centre pivot systems are designed to move in a linear direction providing a rectangular pattern.

	
Figure 5.9 (a) Centre pivot irrigation system *(photo by B. Mati)*	(b) **Details of centre pivot nozzle** *(photo courtesy of E. Tamiru)*

5.5 Classification of sprinkler irrigation sets

Sprinkler irrigation systems are also classified on the basis of the portability of the equipment as follows:

1. Semi-portable sprinkler irrigation system, suitable for an individual small farm
2. Semi-permanent sprinkler irrigation system for a smallholder schemes, used in a grouping of several small fields
3. Drag-hose sprinkler irrigation system for a smallholder schemes (for several small fields)
4. Hose-drag travelling irrigator for individual farm
5. Hose-pull travelling irrigator for individual farm
6. Solid-set system which is permanent, mostly used in large farms.

The stationary type is more expensive than the portable one. In the portable and the semi-portable systems, again there are manual (hand-moved) systems or power-moved systems. These are self propelled sprinkler systems which move laterally or radially around central-pivot feeding-line. These portable systems can be designed to cover any area ranging from 3 to 4 hectares to 50 60 hectares or more. There are boom type sprinkler systems which employ one boom sprinkler head on each lateral. These systems irrigate an area of 75 to 100 meters radius, depending on the nozzle size and the pressure. The boom-type sprinklers are commonly used for tall crops and orchards. Another system which does not need a large labour force is the drag-hose sprinkler system. Main and laterals are buried PVC pipes: one lateral covers three positions.

5.6 Sprinkler layout systems

Sprinkler irrigation systems are laid out in various designs. The most common layout involves arranging the rises along the laterals on both sides of a mainline as shown in Figure xxx. This allows for coordinated movement of lateral lines. Sprinkler spacing should allow for overlap of wetting patterns to enable good wetting pattern.

The most common type of sprinkler system layout is shown in figure 5.10. It consists of a system of lightweight aluminum or plastic pipes which are moved by hand. The rotary sprinklers are usually spaced 9-24 m apart along the lateral which is normally 5-12.5 cm in diameter. This is so it can be carried easily. The lateral pipe is located in the field until the irrigation is complete. The pump is then switched off and the lateral is disconnected from the mainline and moved to the next location. It is re-assembled and connected to the mainline and the irrigation begins again. The lateral can be moved one to four times a day. It is gradually moved around the field until the whole field is irrigated. This is the simplest of all systems. Some use more than one lateral to irrigate larger areas.

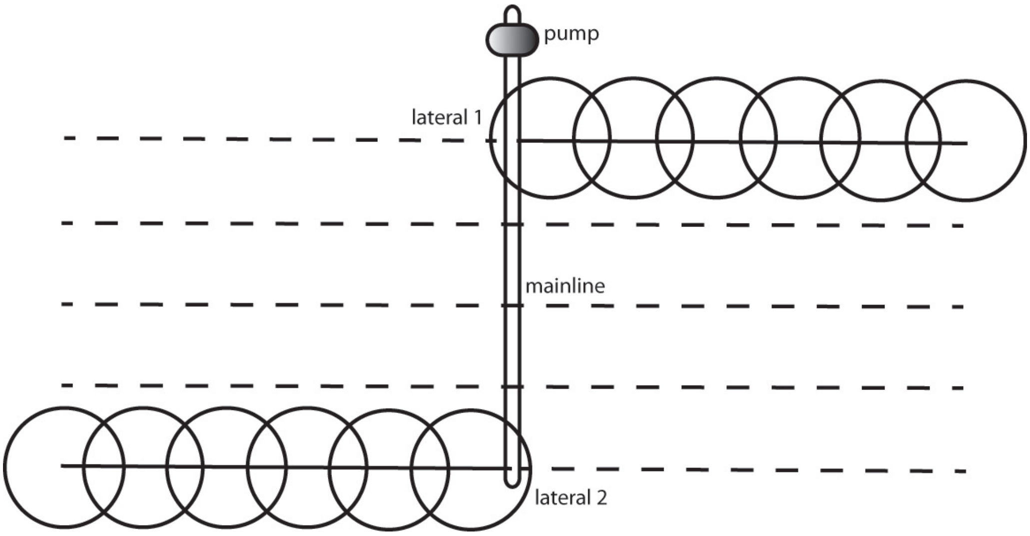


Figure 5.10 Manually shifted sprinkler system using two laterals

5.7 Operating sprinkler systems

A sprinkler irrigation system is meant to apply water as uniformly as possible to fill just the field capacity of the crop root zone. Sprinklers work well at the right operating pressures as recommended by the manufacturer. If the pressure is above or below this then the distribution pattern gets affected. The most common problem is when the pressure is too low. This happens when pumps and pipes wear. Friction increases and so pressure at the sprinkler reduces. The result is that the water jet does not break up and all the water tends to fall in one area towards the outside of the wetted circle. If the pressure is too high then the distribution will also be poor. A fine spray develops which falls close to the sprinkler.

Wetting patterns

The pattern formed by a single rotary sprinkler is normally circular, unless distorted by the wind. However, the wetting within the soil profile is not truly uniform (Figure 5.11), as there is usually more wetting closer to the sprinkler riser. For good uniformity several sprinklers must be operated close together so that their patterns overlap. For good uniformity the overlap should be at least 65% of the wetted diameter. This determines the maximum spacing between sprinklers.

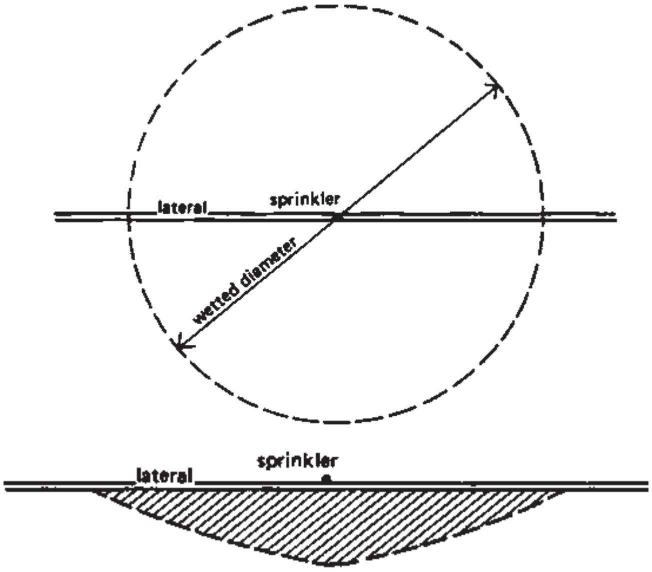


Figure 5.11 Wetting pattern for a single sprinkler (Top and side view)

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

5.8 Advantages of sprinkler irrigation

Sprinkler irrigation can be used on undulating lands, with poor water availability, sandy or shallow soils, or where uniform application of water is desired. No land levelling is required as with the surface irrigation methods. Sprinkler irrigation is advantageous, as water can be applied at any controlled rate and uniform distribution and high efficiency can be ensured. It has high efficiencies, but this varies with climatic conditions, averaging around being 60% in warm climate; 70% in moderate climate and 80% in humid or cool climate. Sprinkler irrigation can be adopted in the case of all crops and is very popular in the case of cash and some orchard crops.

Sprinkler systems are specially suited to shallow sandy soils of uneven topography, where levelling is not practicable, and in areas where labour and water are scarce. Sprinkler irrigation systems are better than surface irrigation in leaching out salts from the soil, and they are not affected by uneven land distribution. The sprinkler system is also used for cooling the crops during high temperatures and for frost control during freezing temperatures. The pesticides, herbicides and fertilizers have also been applied successfully by adopting the sprinkler irrigation system.

5.9 Limitations of sprinkler irrigation

Sprinklers are, however, not suitable for soils which easily form a crust. The water that is pumped through the pump pipe sprinkler system must be free of suspended sediments, as otherwise there would be chances of blockage of the sprinkler nozzles. Another disadvantage of sprinkler systems is that they are affected by windy conditions which disturb the even distribution of water from the sprinklers. Another common problem with sprinkler irrigation is the large labour force needed to move the pipes and sprinklers around the field. In some places such labour may not be available and may also be costly. To overcome this problem many mobile systems have been developed such as the hose reel raingun and the centre pivot. Also, large sprinklers are not recommended for irrigation of delicate crops such as lettuce because the large water drops produced by the sprinklers may damage the crop. Sprinkler irrigation requires skill and is fairly expensive to install and operate.

5.10 Operation and maintenance of sprinkler systems

The operations of a sprinkler systems should be such that the prime mover and the pump are in alignment. Thus, the drive shaft as well as the pump shaft should lie at nearly the same height to prevent too great an angle on the universal shaft. Service and installation procedures in respect of the pump and power units should be strictly observed. While laying the main and lateral pipes, always begin laying at the pump. This necessarily gives the correct connection of all quick coupling pipes. While joining couplings, it is ensured that both the couplings and the rubber seal rings are clean.

In starting the sprinkler system, the motor or engine is started with the valves closed. The pump must attain the pressure stated on type-plate or otherwise there is a fault in the suction line. After the pump reaches the regulation pressure, the delivery valve is opened slowly. Similarly, the delivery valve is closed after stopping the power unit. The pipes and sprinkler-lines are shifted as required after stopping.

A sprinkler system, like any other farm equipment, needs maintenance to keep it operating at peak efficiency. Parts of the system subject to the most wear are the rotating sprinkler heads, the pumping set, the couplers and the pipeline. General principles regarding the maintenance of the pipes and fittings and sprinkler heads are given below :

Pipes and fittings

The pipes and fittings require virtually no maintenance but attention must be given to the following procedures:

(a) Occasionally clean any dirt or sand out of the groove in the coupler in which the rubber sealing ring fits. Any accumulation of dirt or sand will affect the performance of the rubber sealing ring.
(b) Keep all nuts and bolts tight.
(c) Do not lay pipes on new damp concrete or on piles of fertilizer. Do not lay fertilizer sacks on the pipe.

Sprinkler heads

The sprinkler heads should be given the following attention:

(a) When moving the sprinkler lines, make sure that the sprinklers are not damaged or pushed into the soil.
(b) Do not apply oil, grease or any lubricant to the sprinklers. They are water lubricated and using oil, grease or any other lubricant may stop them from working.
(c) Sprinklers usually have a sealed bearing and at the bottom of the bearing there are washers. Usually it is the washers that wear and not the more expensive metal parts. Check the washers for wear once a season or every six months - this is especially important where water is sandy. Replace the washers if worn.

(d) After several season's operation the swing arm spring may need tightening. This is done by pulling out the spring end at the top and re-bending it. This will increase the spring tension.

In general, check all equipment at the end of the season and make any repairs and adjustments and order the spare parts immediately so that the equipment is in perfect condition to start in the next season.

6. DRIP IRRIGATION

6.1 What is drip irrigation?

Drip irrigation, also known as trickle irrigation, is an irrigation system in which water is delivered at or near the root of the plant, drop by drop. It is the slow application of water to the soil through mechanical devices called emitters, located at selected points along the delivery line (Figure 6.1). The system consists of a network of pipes along with water filtration provisions and suitable emitting devices, which could maintain high frequency application of water in and around the root zone of plants. The system is based on the fundamental concept of irrigating only the root zone of the crop, which would maintain excellent soil-water-plant relationship. The root zone is always kept at field capacity (FC) due to which the microbial activities are enhanced to the maximum extent with best aeration properties.

Figure 6.1 Drip irrigation of green beans, a high value crop *(photo by B. Mati)*

Drip irrigation systems consist of water storage, water filtration, water conveyance and distribution, and water application sub-systems. Water is conveyed under pressure through a pipe system to the fields where it drips slowly onto the soil through emitters (drippers), which are located close to the plants. For low pressure, drip is appropriate overhead irrigation method.

6.2 Conditions that favour drip irrigation

Crop types

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

Suitable slopes

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

Preferred soils

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

Water quality

For drip irrigation, it is essential to use clean water which is free of sediments. Generally, water used in drip irrigation is usually filtered. Blockage may occur if the water contains sediments, algae, fertilizer deposits and dissolved chemicals which precipitate such as calcium and iron. Drip irrigation is particularly suitable for use with saline water.

Water management

An optimum soil-moisture regime is maintained 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 interval) 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. It is important to ensure that the crop does not experience moisture stress during this period.

6.3 Design components of a drip irrigation system

There are different kinds of drip irrigation systems. However, the basic components of a typical drip irrigation system consists of the following components:

(i) Water source—to provide the amount of water required at the necessary pressure to distribute and push water out of the drip emitters;

(ii) Main and sub-main lines—to carry and distribute water to the drip laterals;

(iii) Drip laterals—to carry the water and distribute it to the drip emitters;

(iv) Filter—to remove particles from the irrigation water that may clog the drip emitters;

(v) Emitters—to control the flow of water from the laterals into the soil;

(vi) Accessories and control valves.

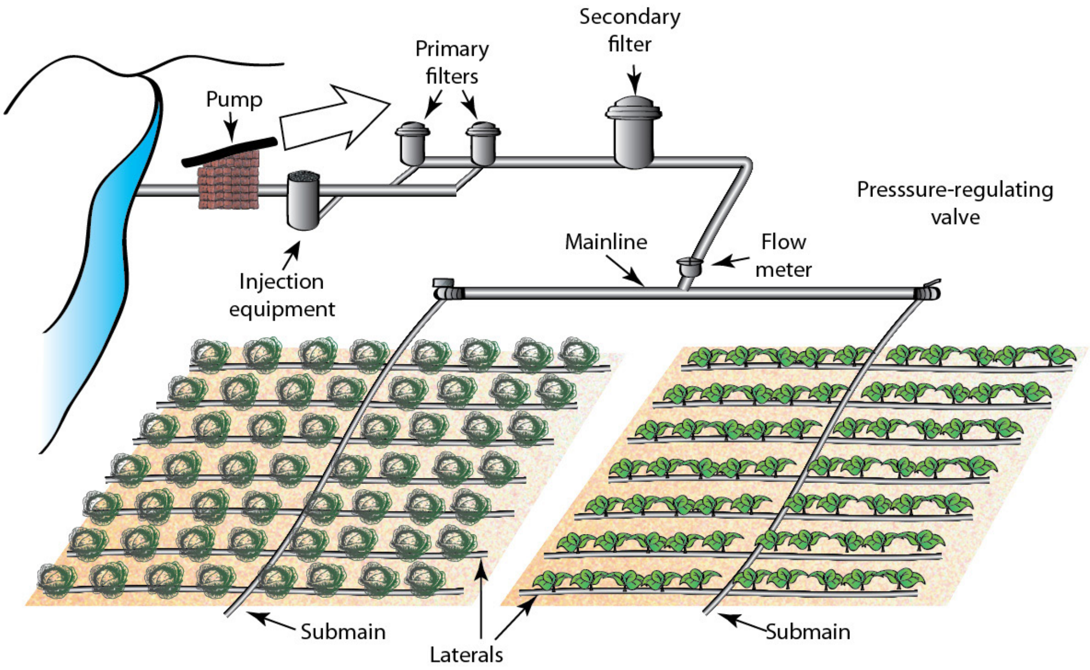


Figure 6.2: Components of a drip irrigation system

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.

Main and sub-main lines

Main and sub-main lines supply water from the control head into the drip laterals. They are usually made of from PVC or polyethylene hose, although steel pipes are also used. They are usually made and should be buried below ground because they easily degrade when exposed to direct solar radiation. Lateral pipes are usually 13 - 32 mm diameter but the size depends on the required water flow in the laterals served. Large main lines are connected to smaller sub-mains, which are in turn connected to the drip laterals.

Drip lateral lines

Drip lines are made from polyethylene tubes with diameters of 8 –5 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.

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.

Drip emitters

Emitters or drippers are devices used to control the discharge of water from the lateral to the plants. They are usually spaced at the same spacing as the crop, with one or more emitters used for a single plant such as a tree. For row crops more closely spaced emitters may be used to wet a strip of soil. A good emitter should provide a specified constant discharge which does not vary much with pressure changes, and does not block easily. 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%.

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 (figure 6.3-a). 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.

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 (figure 6.3-b). Drip lines are available in various diameters, wall thickness and emitter spacing. Integral drip lines are mainly used in field crops and orchard irrigation.

Figure 6.3 (a)In-line drip emitter on lateral line *(Source: FAO)*

(b) **Integral drip emitter with string**

(photo by B. Mati)

Perforated pipe drippers

Plastic piping can be perforated with a very small diameter hole to act as a drip emitter. However, unlike a perforated pipe sprinkler, the water from the dripper is not allowed to fall in a jet/spray. There are ways to achieve the right size of droplets; (i) the punched hole on the plastic tube is tied using a small polythene paper (see figure 6.4-a), thereby reducing water out-flow into a drop. (ii) An alternative method is to punch two holes directly across the pipe, and then pass a small thread through both holes (figure 6.4-b). The thread is knotted on both ends so as to retain it in place. The thread can also be used to unclog the emitter in case it gets blocked. The advantage of using perforated pipe drippers includes lower capital cost since emitters are not bought. Also, the method permits the farmer to punch drippers that correspond to the crop spacing. The main limitation is that the method is manual and has high maintenance requirements.

Figure 6.4 (a) Perforated pipe drip emitter with plastic covering *(photo by B. Mati)*

(b) Perforated pipe drip emitter with threaded string

Perforated polythene tubing

This is a cheaper version of the perforated pipe dripper, whereby a polythene tube is used instead. Small holes are punched to create drippers on a thin polythene tubes connected to a water supply. Since the polythene is a weaker material, the tubing is suspended slightly above ground (figure 6.5) to avoid damage during cultivation, and also to reduce clogging of the drippers. The tubing may be used for only one crop season after which it is un-usable. It is used on crops with a short growing season e.g. vegetables.

Figure 6.5 Perforated polythene tube dripper with tomato crop *(photo by B. Mati)*

Other accessories

These include various components as shown in Figure 6.6, such as control valves, which regulate the water flow, flow meters used to measure the water flowing on to the fields, the injectors used to apply fertilizer and other materials to the water in the drip lines, pressure regulators as well as the flushing manifold, which is used to clean up the drip system.

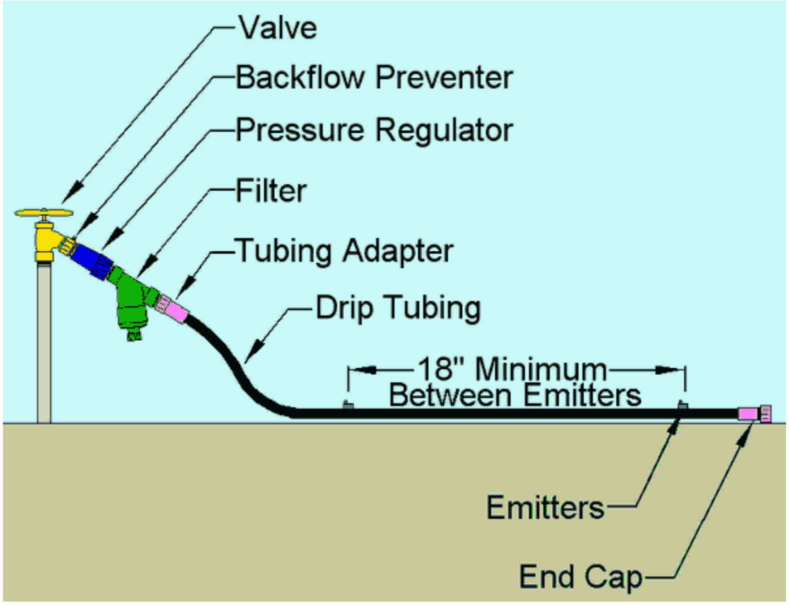


Figure 6.6 Illustration of fittings on a drip irrigation lateral

6.4 Operating drip systems

A drip system is usually permanent or semi-permanent. When left in place during more than one season, the system is considered permanent. Thus it can easily be automated. This is very useful when labour is scarce or expensive to hire. However, automation requires specialist skills. For drip irrigation, the land to be irrigated is prepared preferably tillage followed by formation of planting beds. For best results, drip systems are used to irrigate level beds.

The drip laterals are usually laid as straight as possible. The water container stand or source of water is prepared to ensure correct pressure in the laterals (figure 6.7). The container water outlet pipe (mainline), water filtration and flow regulator fittings are fixed. The water distribution system components are connected to the individual drip lines, making sure that the open ends are closed to avoid foreign material entering the pipe. The drip lines are unrolled and laid along the full length of each row of plants to be irrigated. The system is usually flushed first to remove any foreign matter that may have entered the pipeline. Then the ends of the drip lines are closed. The crop is planted where each plant will benefit most from the water supplied by the emitters. It is recommended to irrigate the field before planting seeds/ seedlings on the wetted circles.

Figure 6.7 (a) Fixing emitters onto a drip lateral *(photo by G. Alemu)*

(b) **Drip irrigation showing wetted zone** *(photo by B. Mati)*

In drip irrigation, water can be applied frequently (every day if required) as this provides favourable conditions for crop growth. However, if crops are not watered adequately, they may develop shallow roots and if the system breaks down, the crop may easily suffer.

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

6.5 Advantages of drip irrigation

- Drip irrigation is the most efficient method of irrigating. While sprinkler systems are around 75-85% efficient, drip systems typically are 90% or higher. If managed properly, since evaporation and runoff are minimised.

- More uniform and higher crop yields because drip irrigation takes place on a frequent basis, enabling the water manager to maintain the soil moisture at an optimum level. Improved crop quality and lower 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.

- Direct evaporation from the soil surface and water uptake by weeds is reduced by not wetting the entire soil surface between rows or trees.

- Reduced cost for fertilizer and other chemicals, since these are applied precisely at the root zone

- Reduced labour costs especially since agronomic practices such as weeding are reduced. Also, 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.

- Operational costs can be reduced by simultaneous application of water, fertilizer, herbicide, insecticide or other additives through the drip system.

- Low energy requirement compared to conventional pressurized system because of the lower operational water pressure required for drip systems.

- Reduced salinity hazard since drip irrigation does not substantially raise the water table.

6.6 Limitations of drip irrigation

- The main disadvantages are that it is the most expensive and least aesthetically pleasing method because of all the plastic lines which have to be installed close to each other on the ground.
- Cost - Conventional drip irrigation systems typically have introduced some adaptations in the systems that are making them accessible to small-scale farmers
- 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.
- One of the main problems with drip irrigation is blockage of the emitters. All emitters have very small waterways ranging from 0.2-2.0 mm in diameter and these can become blocked if the water is not clean.
- 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.
- 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.
- 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 area.

6.7 Maintenance of drip irrigation systems

Drip irrigation equipment should be inspected regularly to identify leaks, blockages or other malfunctions. The emitters should be checked to identify clogged ones and unblocked or replaced. Clogged drip emitters cause non-uniform application of water and result in non-uniform growth of the plants.

Only clean water should be used in order to minimise 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. The filtration system should be cleaned at least twice a month. Field operations should be done carefully to avoid damaging the drip lines. When no longer in use the components of the system can be removed and stored in a safe place.

6.8 Drip irrigation kits for small gardens

Drip irrigation is manufactured to suit diverse scales from small plots to large mechanised fields. Hence there are different designs to suite various conditions and costs. Some of the common methods used in smallholder agriculture include the following:

6.8.1 Bucket drip kit

The bucket drip kit comprises a 20 litre bucket fitted with a filter and a pair of drip laterals. The bucket acts as a reservoir and is placed about 1 m above the ground to provide the required water pressure. Tubes connect through the bottom of the bucket to the irrigation tape. Water drips from the tape into the soil. A 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 (figure 6.8). These bucket kit systems can irrigate 10–20 m, depending on the length of the drip tube and plant spacing.

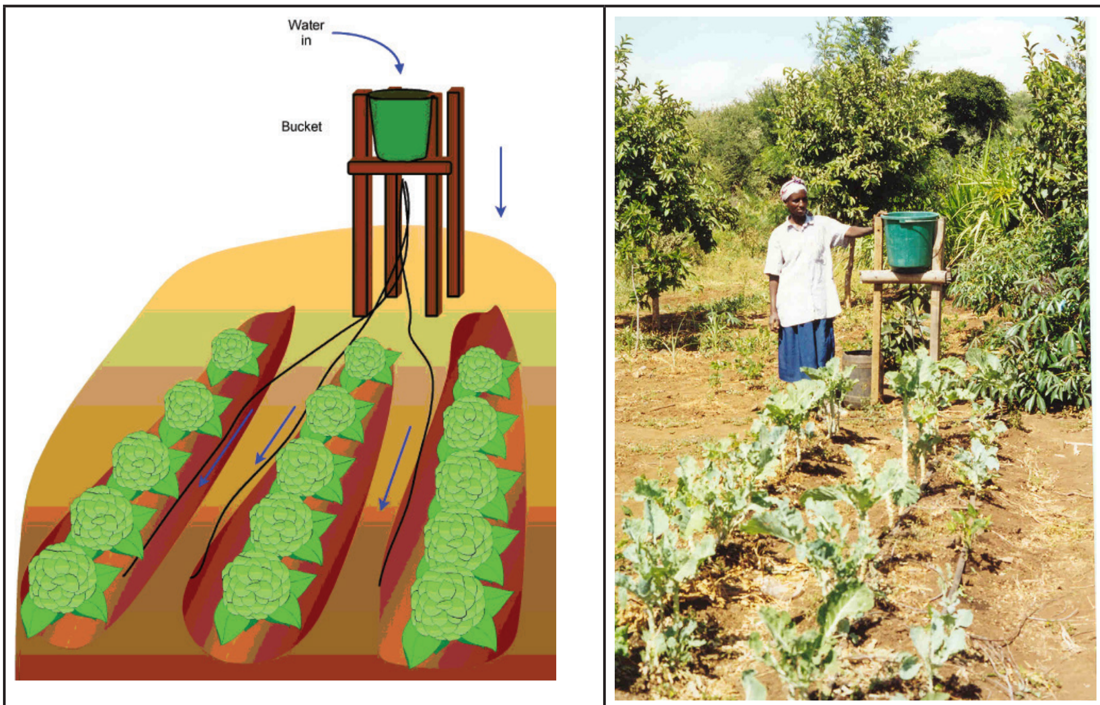


Figure 6.8 (a) Sketch of a bucket drip kit (b) **Bucket drip kit with vegetable crop** *(photo by B. Mati)*

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, or pepper and similar plants requiring a spacing of 30 cm along the plant rows. The bucket should be filled once in the morning and once in the afternoon to supply. It provides enough moisture for a small vegetable garden.

6.8.2 Water boys bucket kit

This is a simple bucket drip kit which comprises of one 30-litre bucket 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 (figure 6.9). Since a filter is not included in the kit, the water boys bucket kit system requires water that has already been filtered for irrigation. Alternatively, a home-made filter can be made using a double by tying a clean cloth at the outlet from the bucket. The bucket once filled with water can irrigate a small kitchen garden of just two rows of vegetables. It is popular due to its low cost.

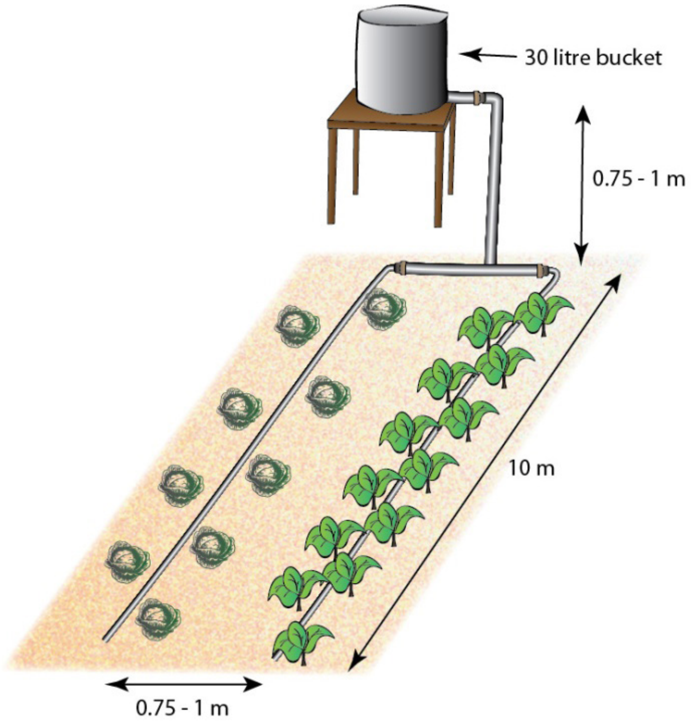


Figure 6.9 Layout of Water boys bucket system.

6.8.3 Drum drip kit systems

A drum drip kit comprises a 200-liter water storage drum, barrel, tank, or similar container placed at an average height of 1 meter to allow the water to flow by gravity. The standard drum kit system comprises a drum, control valve, a manifold and drip lines (figure 6.10). It has five or more rows of lateral drip lines 10 to 20 meters long, depending on crop spacing and shape of the plot. 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.

The drum requires a minimum planted area of 100 m^2. Drum systems operate under a low pressure head of water (0.5–5 m). The irrigated area can be expanded up to 1000 m^2 by using a larger drum placed at an average height of 1 to 1.5 m. 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.

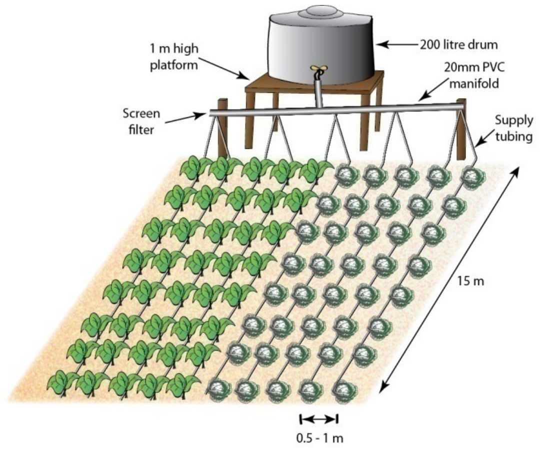


Figure 6.10 Sketch of a drum drip kit

(b) **Drum drip kit with vegetables**
(photo by M. Balloo)

6.8.4 Waggon wheel system

The waggon wheel is a localised method of drip irrigation, which is used to grow vegetables and grapes in arid zones. The waggon wheel irrigation system (Figure 6.11) uses a circular arrangement of several drip lines all connected directly to a central reservoir drum of about 200 litres, hence its name. The length of each drip line is about 6 m but this can vary. Waggon wheels can also be used for kitchen gardens and in urban agriculture. Several types of crops can be grown each with different spacing.

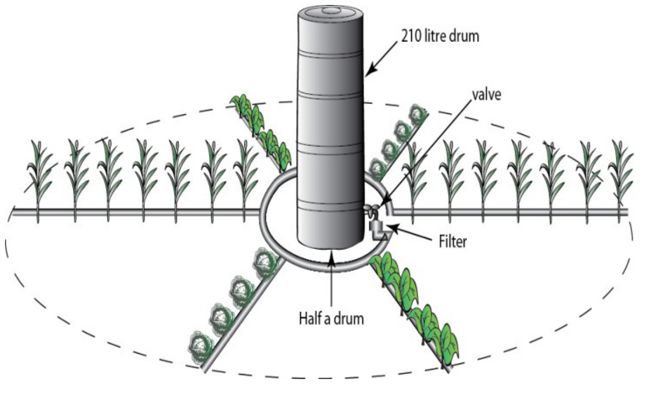


Figure 6.11(a) Sketch of waggon wheel drip irrigation system

(b) **Waggon wheel drip irrigation system** *(photo by B. Mati)*

6.9 Other Localised Irrigation Systems

Localised irrigation is a system where water is distributed under low pressure through a piped network, in a pre-determined pattern, and applied as a small discharge to each plant or adjacent to it. Localised irrigation system is a capital-intensive system with built in management that requires very little but skilled labour. The main advantage of localised irrigation is its potential to reduce water requirements and achieve a very high efficiency, while at the same time increasing crop yield and quality. The system has been successfully used on tree and vegetable crops, and high yields attributed to it.

Localised irrigation provides the means for very frequent irrigation, daily if needs be. Hence it is particularly suitable for light shallow soils, irrespective of slope, and for shallow-rooted crops. It has also proved suitable for most row crops. The main disadvantages of localised irrigation systems are their high capital cost, a susceptibility to clogging and a tendency to build up localised salinity, especially in low rainfall areas. As such, this category of system requires careful management for its maintenance. Drip irrigation, spray or micro-sprinkler irrigation belong to this category of localised irrigation methods. Other localised irrigation systems include

- Bubbler irrigation
- Bucket irrigation
- Pitcher pot irrigation (or gourd irrigation)
- Buried perforated pipe systems

6.9.1 Bubbler irrigation

Bubbler irrigation utilises a small stream which is applied to flood small basins or the soil adjacent to individual trees. It works like a miniature sprinkler systems that provides water to the entire root system (Figure 6.12). For young trees point-source drippers can be used provided they are expandable with more drippers to account for higher water requirements as the trees grow. It is used on relatively mature trees.

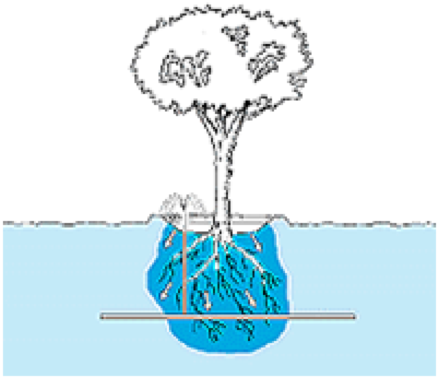


Figure 6.12(a) Schematic view of bubbler irrigation system

(b) **Bubbler irrigation system**
(source: http://www.heis.gov.pk/irrigation.htm)

6.9.2 Bucket irrigation

Bucket irrigation involves using a simple bucket to manually irrigate crops (figure 6.13). Although slow and inefficient, it is still a popular method among small scale farmers in Africa. It is affordable and easy to apply in areas where labour is abundant and gardens are small. Different sizes of the buckets can be used to apply different quantities of water which will penetrate to different application depths for a specified soil types. Table 15 shows rough guidelines on appropriate water application using bucket irrigation. It also requires knowing the different soil types in an irrigated area so that correct irrigation water can be applied to suit specific conditions and crops.

Table 6.1: Water application depths for bucket irrigation using 15 and 20 litre cans

Bucket size	Quantity of water(litres)	Irrigated Area (m^2)	
15 litre-Bucket		3	6
	15	5	26
	30	10	5
	45	15	7.5
	60	20	10
20 litre-Bucket	20	7	3
	40	13	7
	60	20	10
	80	27	13

Figure 6.13 Manual bucket irrigation of vegetables *(photo by B. Mati)*

6.9.3 Pitcher pot irrigation

Pitcher Irrigation or 'Pot Irrigation' is a traditional, low-volume irrigation technology that uses baked clay pots buried adjacent the roots of the crop to be irrigated (Mati, 2007). Such pots are made by women in the traditional way, but the clay is mixed with saw-dust to create porosity when the pot is fired during curing. A hole is usually dug adjacent the tree crop to be irrigated and the pot placed within. The 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 pot is filled with water and covered with a clay slab or polythene paper, to reduce evaporation losses. Water seeps slowly through the porous sides of the pot (Figure 6.14). The minute hairs of nearby plants pull the water out from the pots. The method encourages deeper rooting and reduced evaporation. The method is commonly used for fruit-tree crop production.

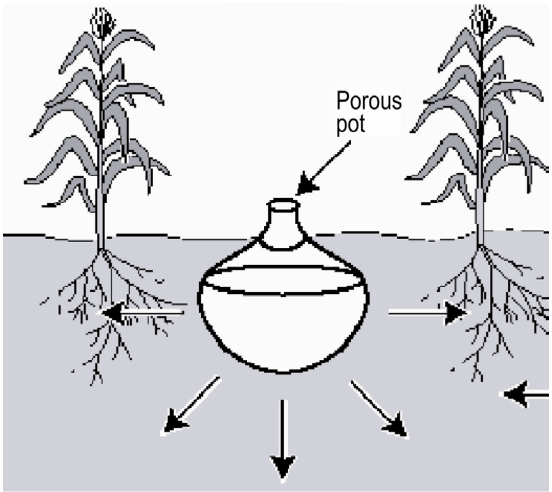


Figure 6.14 (a) Illustration of pitcher pot irrigation	(b) **Pitcher pot with citrus tree** *(photo by B. Mati)*

6.9.4 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.

6.9.5 Porous clay pipes

Porous clay pipes can be buried under the soil and used for localised irrigation. The 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.

6.9.6 Perforated plastic sleeves

Plastic sheeting has been used to make a sleeve-like casing. The plastic casing is essentially impervious, it must be perforated. The pipe ends in an emitter, a block made from a 1:10 cement/sand mixture. 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%. The advantage of this is the low cost. However, the method has several distinct disadvantages that restrict the range of its applicability. Moreover, the sand itself tends to retain a significant fraction of the moisture and thus to restrict outflow.

6.9.7 Wick irrigation

The wick irrigation method consists of using small nylon or cotton threads in conjunction with buried clay pot irrigation. A hole or holes are punched in the buried clay pot and a porous wick made of cotton is inserted in the hole. One end of the wick is placed into the soil, while the other is placed into a water container. The irrigation water is sucked into the soil through capillary action and provides a slow steady source of water to encourage root development and plant growth. This method is good for potted vegetables in urban areas, as well as to grow flowers and other potted plants. The method may be used to grow vegetables on paved surfaces.

Figure 6.15 (a) Illustrating how wick irrigation works *(photo by M. Aman)*

(b) **Wick irrigation of potted vegetables** *(photo by B. Mati)*

6.9.8 Bottle irrigation

Bottle irrigation is a kind of modified drip irrigation, in which a bottle is filled with clean water and sealed with a top. Then a small hole is punched onto the bottle top and the bottle inserted into the soil at the tree root zone, ensuring that it lies at an angle. The water enters the soil as small droplets, lasting several days, after which the bottle is refilled. One litre of water can last for about 2 weeks before refilling. This way, water loss by evaporation is reduced to a minimum. Sometimes, farmers bury the bottle under the soil to regulate the water temperature. Bottle irrigation is used for tree establishment in semi-arid areas, which have water scarcity. It is also used for vegetable irrigation in small gardens (figure 6.16).

Figure 6.16 Bottles and tins used for drip irrigation of vegetables *(photo by B. Mati).*

7. SUB-SURFACE IRRIGATION

7.1 What is sub-surface irrigation?

Sub-surface irrigation, sometimes also called *sub-irrigation* or *seepage irrigation,* is a method of irrigation in which water is applied beneath the ground by creating and maintaining an artificial water table at some depth, usually 30 to 75 cm, below the ground surface. This involves the use of underground conduit systems enabling water to infiltrate into the subsoil in order to maintain an optimum groundwater level for crop production. The method is used to maintain a fixed water table below the root zone of a crop (Figure 7.1). The water is sucked by the plant roots as the moisture then moves upwards by capillary action towards the soil surface.

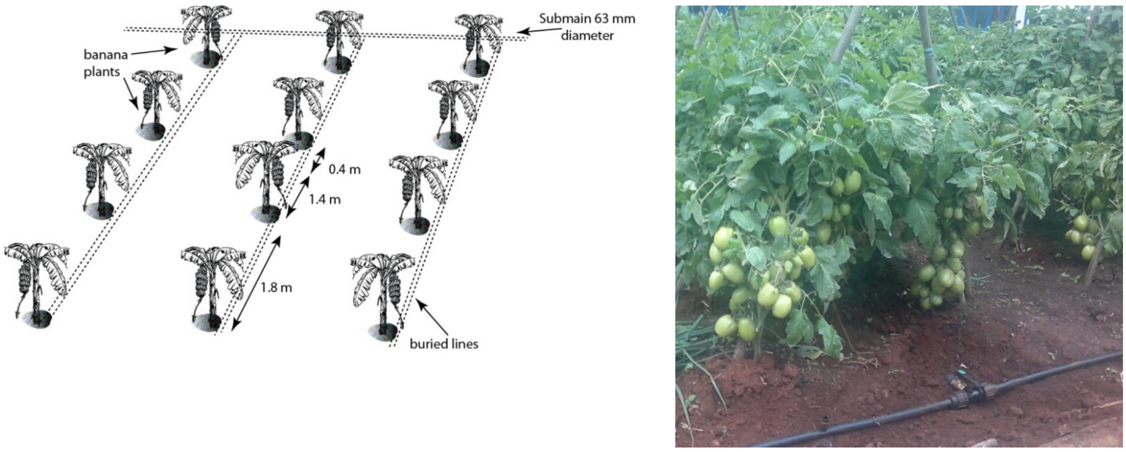


Figure 7.1: (a) Illustration of sub-surface irrigation with buried pipe

(b) **Sub-surface irrigation of tomato using buried pipe** *(photo by B. Mati)*

A system of pumping stations, canals, weirs and gates allows it to increase or decrease the water level in a network of ditches and thereby control the water table. Open ditches are preferred because they are relatively inexpensive and suitable for all types of soils. Tiles and mole drains are suitable only for organic soils. The efficiency of water use depends on soil characteristics, topography and operation and maintenance management. In good system, the efficiency can be up to 70-75 per cent. It is similar in principle and action to subsurface drip irrigation.

Sub-irrigation is also used in commercial greenhouse production, usually for potted plants. Water is delivered from below, absorbed upwards, and the excess collected for recycling. Typically, a solution of water and nutrients floods a container or flows through a trough for a short period of time, 10-20 minutes, and is then pumped back into a holding tank for reuse. Sub-irrigation in greenhouses requires fairly sophisticated, expensive equipment and management.

7.2 Conditions that suit sub-irrigation

The essential requirements for a successful sub-surface irrigation include:

(i) Availability of adequate supply of good quality water throughout growth period of the crop,

(ii) Fields must be nearly level and smooth. Ground slope is moderate. Land is approximately parallel to water table,

(iii) Availability of a layer of permeable soil such as sandy loam or loam immediately below the surface soil to permit free and rapid movement of water laterally and vertically,

(iv) Availability of a relatively impervious layer at 2 to 3 m in the substratum to prevent deep percolation of water or a permanently high natural water table on which an artificial water table can be built,

(v) A well planned distribution system of main ditches, field laterals, etc., which raises the water table to a uniform depth below the ground surface over the entire area,

(vi) Availability of adequate outlet for drainage of the area so irrigated particularly in humid areas,

(vii) Subsoil water table is within 2 to 3 m below the ground surface,

(viii) Topographic conditions should be uniform on the surface and beneath, and

(ix) Soil should have high capillarity e.g. clay soils to be able to lift moisture from the water table to the root zone. Also the soil should permit lateral and downward movement of water.

7.3 Types of sub-irrigation systems

In sub-surface irrigation, water is introduced into soil profile through open ditches, mole drains, tile drains or perforated buried pipe. But generally, three systems can be distinguished; (i) buried perforated pipe irrigation, (ii) ditch water infiltration systems and (iii) vertical irrigation.

7.3.1 Buried pipe irrigation

Buried pipes made of PVC or baked clay pipes can be used for for sub-surface irrigation of crops. The pipes are buried at such a depth that there is no risk of interference with any kind of farming operations The buried piping can be porous, but if non-porous materials are used, tiny perforations in the pipe are made to allow the water to seep into the ground. A separate pipe is used to convey the water from the supply or source to the buried pipe. Normally, a layer of coarse sand is packed around the pipe to improve outflow and to prevent the pores or perforations from clogging.

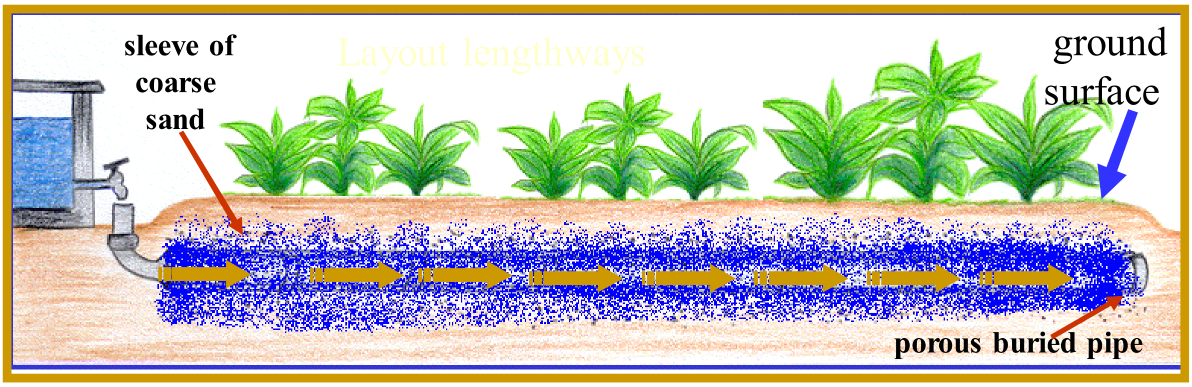


Figure 7.2 Sketch of porous buried pipe irrigation

Buried pipe irigation can be made low cost and improvies use effeciency. The buried pipe supplies water directly to a plant's root zone. It reduces losses by evaporation and can be more efficient than drip irrigation. The main limitation is clogging of the opennings in the pipe which are not easily detected until the plant starts to wither. Similarly a burst pipe may not be immediately recognized especially of the ecess water gets lost through deep percolaton. Also, there are control and maintenance problems.

7.3.2 Ditch irrigation systems

Subsurface-ditch irrigation system involves digging furrow which are very deep of depth equivalent to the crop root zone, and these are used for irrigation where there is a high water table in the soil profile. The applicability of this system is very limited as specific conditions are needed. These include a level ground surface and where an impervious soil layer exists below the crop root zone. It is not suitable on soils with deep groundwater and natural drainage, or in arid or semi-arid climates where salinity is a problem.

7.3.3 Vertical irrigation

Under vertical irrigation, the water is supplied by pouring it into a vertical pipe to that is sunk down to the crop rootzone. The water is filled in vertical pipes which direct the water to the root zone. The method is used for growing trees and shrubs in dry areas Water distribution in the root zone depends on soil texture and profiel charachteristics. Vertical irrigation works better on clay soils or where the profile is underlain by a hard pan or high water table. Vertical irrigation can be quite efficient in water use since it drastically reduces evaporation and unnecessary wetting. However, the method is labour intensive.

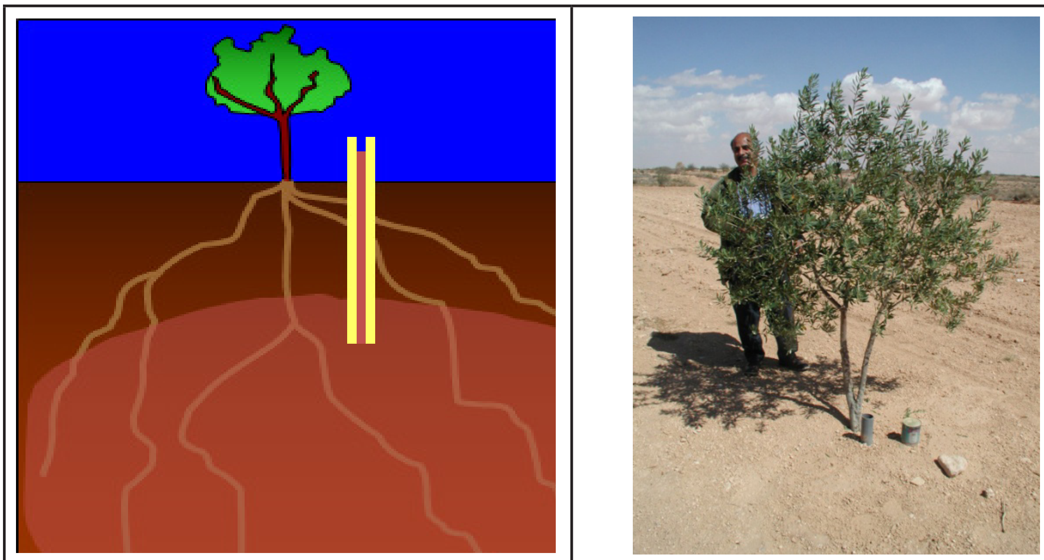


Figure 7.3 (a) Sketch of vertical pipe irrigation

(b) **Vertical irrigation of fruit tree** *(photo by D. Prinz)*

7.4 Advantages of sub-irrigation

Sub-surface irrigation requires little field preparation and labour. The method allows reduction of water losses by evaporation. The method also allows for water and nutrient conservation, and labour-saving through lowered system maintenance and automation.

7.5 Limitations of sub-irrigation

The use of sub-irrigation is limited because it requires certain soil condition that is the soil is permeable in root zone, underlain by an impervious horizon or high water table. The irrigation water used for sub-irrigation must be of good quality to prevent excessive soil salinity. The flow rate in supply ditches is should be slow to prevent water-logging of the field.

8. SPATE IRRIGATION

8.1 What is spate irrigation?

Spate irrigation is a unique method of irrigation which utilises flood water, harvested from ephemeral watercourses during and immediately after a rainfall event (figure 8.1). It is concerned with diversion of large quantities of flood flow from highlands into levelled basins in the lowland (called locally "wadi or lugga"). More specifically, FAO in 1987 defined spate irrigation as "an ancient irrigation practice that involves the diversion of flashy spate floods running off from mountainous catchments where flood flows, usually flowing for only a few hours with appreciable discharges and with recession flows lasting for only one to a few days, are channelled through short steep canals to bunded basins, which are flooded to a certain depth".

Figure 8.1 (a) Diversion canal prepared for spate irrigation during the dry season **b) Spate flow diversion of runoff from same ephemeral stream after rains in the hills**

<u>Distinguishing features</u>

There are three important features that distinguish spate irrigation from other forms of flood irrigation/water harvesting:

(i) In spate irrigation, flood water is physically diverted from stream channels via canals to bunded fields that may be located at some distance from the water course, and

(ii) Spate irrigation is carried out on a large scale, by groups of farmers rather than individuals, who need to work closely together to divert and distribute flood waters and maintain their intakes and canals.

(iii) Spate irrigation is also distinct from semi-perennial irrigation, as it depends on short-duration floods, whereas semi-perennial irrigation makes use of flows lasting weeks, even months.

8.2 Types of spate irrigation systems

There are several types of spate irrigation and several terms are used to describe similar practices. Spate irrigation has some similarities with flood inundation and flood recession systems found along alluvial plains, where crops are grown from the residual moisture following floods (see Training Manual 1). The term *water harvesting* is also used to describe the practice in which the flow discharged from a small catchment area after a storm is directed through channels to a nearby field enclosed by bunds, and soil moisture is increased by subsequent infiltration. In all cases, the crops take up the supply of water in the soil during the dry periods that follow rainfall and they can survive longer periods without yield losses in places with deeper and heavier soils.

Spate irrigation classifications can be based on size, infrastructure, management or hydrological regime and source of water. Other classifications are possible, based on the range of crops that are grown or on the way water is distributed. Substantial local wisdom has developed in setting up and constructing intakes, organizing water distribution and managing the flood waters and their heavy sediment loads.

Spate irrigation can be applied either on-stream or off-stream. With *on-stream systems,* spate irrigation involves floodwater harvesting within streambeds, where channel flow is collected and spread through the valley where the crops are planted. *Off-stream systems* is when floodwater -or spates are diverted from seasonal rivers into adjacent embanked fields for direct application. Spate irrigation is practised in dry areas and is a traditional method of irrigation in the Horn of Africa and the Middle East.

8.3 Conditions that favour spate irrigation

Spate irrigation schemes contain unique features and considerations must be made to ensure the following features are attainable.

- Ingenious diversion systems, built to capture short floods but also designed to keep out the larger and most destructive water flows;
- Sediment management, as the flood water has high sediment loads that would otherwise fill reservoirs and clog intake structures and distribution canals; these sediments are used to build up soil and level the land but can also result in excessive rising of land and loss of command;
- Soil moisture conservation, is a core component of spate irrigation, especially as floods often come ahead of the sowing season;
- Social organization is necessary to manage the sometimes complex system, ensure timely maintenance of the structures and channels and oversee the fair distribution of the flood.

Meanwhile, there are other conditions such as crop type, soil profile characteristics, land topography, and amounts of flood waters available. Preferred conditions should be as follows:

Crops

Spate irrigation is best practiced with drought resistant crops, such as sorghum, millets and pulses and trees e.g. mango. Sometimes, the crops are grown using one or a few flood events, by utilizing the residual moisture stored in the deep alluvial soils formed from the sediments deposited in previous irrigations. Although spate irrigation has been primarily developed for cropping, it rarely serves only agriculture. In many instances, it also sustains rangelands and local forestry, and helps recharge groundwater, thus providing drinking water for humans and livestock.

Soils

The cropped area under spate irrigation should have deep alluvial soils which can hold moisture for long periods of time. The soils should also have relatively moderate infiltration rates that vary with soil texture, density and soil management practices. Generally, spate soils are largely built up from the heavy sedimentation loads of spate water and thus their textures vary within the spate systems as a result of the sediment transport and depositing pattern.

8.4 Design of spate irrigation systems

The design of a spate irrigation system involves:

- Determination of volumes of expected runoff
- Site investigation and characterization
- Design of water delivery and diversion structures, division boxes, canal networks, field intakes, drainage outlets, spillways, and field embankments or bunds.

Estimating peak flows

The flood flows should be properly evaluated in order to determine how much area to irrigate and therefore, enable the design of the different structures required. The proportion of the mean annual runoff that can be diverted to the fields is an important parameter in determining the potential command area, although in spate schemes the areas that are irrigated can vary widely from year to year. It is conventionally expressed as a runoff depth from the catchment, in mm, but can easily be converted to a volume by multiplying it by the catchment area. The proportion of the runoff volume that can be diverted for irrigation depends on the diversion arrangements and the patterns of spate flows that are experienced. This is difficult to estimate without extensive long-term site-specific flow data. One of the simplest methods to estimate peak runoff from a given rainfall even is the Rational equation given as:

$$\mathbf{Q = KIA/360}$$

Where:
Q = Peak flood flow (m^3/s)
K = A runoff coefficient for the catchment
I = Rainfall intensity (mm/hr)
A = Catchment Area (m^2)

Ideally, long-term data are needed to provide the data for spate irrigation design. However, most valleys in dry areas are ungaged, local observations and indigenous knowledge are used to estimate the expected amounts of flows and sediments in the watercourse. The relationship between the flows in a stream in particular seasons and the areas that are irrigated can thus be quite complex and require a large investment in field investigations and farmer interviews if it is to be fully understood.

Intake structures

Intakes in spate irrigation systems are used to divert large and varying volumes of flood flows, delivering water to canals at a sufficiently high level to ensure command over the irrigated fields. The canals should be capable of conveying large volumes of water to fields quickly in the short periods when flood flows occur (figure 8.2). The timing, duration and maximum discharge of spate flows are unpredictable and thus canal capacities have to cope with a wide range of design conditions. The types of water distribution systems developed for perennial irrigation are thus not appropriate for spate systems as canal capacities are determined for a relatively narrow and predictable range of design conditions. Canals used for spate irrigation are much larger, wider and with control structures to absorb the scour expected for the largely turbulent flows.

Figure 8.2 Spate irrigation intake *(source: FAO 2010)*

Diversion structures

A diversion structure is a structure constructed across a stream or watercourse to divert a regulated quantity of the river water towards a canal. It helps to raise the water level in a watercourse to enable the water enter a canal system. A diversion structure also regulates the supply of water into a canal or to an irrigation command area. Depending of design, it can control the entry of silt and other materials into a canal. In order to function efficiently, a diversion structure should include the following parts; a weir, scouring sluice, canal head regulator, and guide walls. Diversion Structures can be:

- Temporary diversion structures – usually made of compacted earthen bunds
- Permanent diversion structures – made of concrete, bricks or gabions.

In spate schemes the cropped areas are determined in part by the level of risk that farmers are prepared to accept before constructing and maintaining canals and field bunds and preparing their fields. While the fields near the head of a scheme may receive multiple irrigations, those near the tail may only receive water occasionally.

Site selection for diversion weir

A narrow, straight, well-defined part of the stream/watercourse is selected, where a hard layer on the stream banks and bed. The section should have suitability for the spill way. If possible, it should be near the area to be irrigated. It should be possible to construct a take-off canal without excessive digging or filling. The site should be easily accessible. The water control structures used in spate irrigation should include:

- Diversion structures/intakes,
- Spate canals and water control/dividing structures; and
- Bank protection and river-training structures.

Construction of the bunds

Factors considered in the design and construction of soil bunds:

- The location and height of the bund are chosen in such a way that they do not cause unwanted flooding of other areas.
- In case of a diversion bund across the watercourse with a single off-take, the preference is for the bund to be constructed as an arc or at an angle to the direction of flow of the watercourse, to dissipate the energy of the flood.

In case of a cross-bund with off-takes at both banks, the bund will be constructed in a straight line; depending on the height of the bund and the slope of the land, the cross-bund may serve several upstream off-takes. The preference is to construct the soil bund with loamy soil. Gravel and saline soils should be avoided. The latter would lead to cracking of the soil bund and early breaching before overtopping occurred.

Preferably the soil bund should be developed in layers, with each layer being 1 – 1.5 m thick. Compaction can be achieved by bulldozer, animal action or by hand. The soil bund is reinforced by intermixing it with vegetation, by laying brushwood along the lower toe or by stone pitching. In some cases short wooden poles are driven into the most exposed and vulnerable sections to fix the bund to the river bed and to reinforce the bund. Generally care is taken to avoid animals trespassing and trampling on the structure, as this would weaken the soil bunds.

8.5 Water management and control

Field water management in spate irrigation systems is as important as effective water diversion. Owing to the great temporal and special variation of its floods, the nature of spate irrigation does not allow farmers to follow a predetermined irrigation schedule where water quantities are applied to a crop when it is needed.

Temporary diversion embankments are constructed across a river/dry valley to divert spate flows to adjacent arable areas. These embankments are made of riverbed sand, stones and brush wood with no provision for gates or spillways (figure 8.3). The irrigation water is let into a field, or series of fields, until they are flooded to a depth of at least 20 cm. It is recommended to divide flows into proportions which farmers can manage. Earthen structures are relatively cost effective to build but require considerable maintenance and repairs during the irrigation season to remain functional.

Figure 8.3 (a) Spate flow diversion structure (a) Sorghum grown with spate irrigation
(photos courtesy of M. Tesfai)

The design of the command area also plays an important role in field water management. Maintaining a compact irrigated area can increase the possibility of a second irrigation and the water productivity of the second irrigation can be higher than the first. Smaller command areas encourage more investment in pre-irrigation land preparation and bund maintenance, making it easier to operate. Field bunds play an important role in field water application. They should be higher in areas where water supply is less reliable, while they remain relatively low where water supply is frequent and abundant.

The maintenance of field bunds has a profound impact on water productivity in spate irrigation. Maintaining field bunds is an individual responsibility with a collective impact because, if bunds in one field are neglected, the water will move across the command area in an uncontrolled fashion, not serving large parts of it and causing field erosion at the same time.

Sedimentation

Stream beds and banks are continually affected and eroded by large floods. This has implications for associated spate irrigation schemes. Stream beds can be significantly lowered (both locally and permanently) during the passage of large floods and leave the invert of traditional intakes well above the new scoured stream bed level, so that it is impossible to divert water into the canal system.

Sediment transport is dominated by the finer sediment fractions. The proportion of silt and clay in the sediment load varies widely during and between floods and between catchments but typically ranges between 50 and 90 percent of the total annual sediment load. The sand load transported in suspension in stream flows, which will be diverted to canals even at well designed intakes, is also relatively fine as compared with the parent bed material.

Providing engineered structures (bed bars or low overflow weirs) to control stream bed levels is a viable option, but can be difficult to justify in small spate schemes or where the stream course is wide. The ability to cope with changes in stream beds and high sedimentation rates in the command areas and canals is critical to the success of spate irrigation. New intakes and canals have to be designed to cope with changes in stream bed and/or field levels rising up to 50 mm/year. When new diversions are proposed, the following measures are recommended:

Intakes associated with permanent raised weir structures should be provided with effective sediment sluices that are designed to be operated during the very short periods when flood flows exceed the diverted flows. Small settling basins designed to trap coarse sand, gravel, and larger sediments, before they can enter, settle and block canals, are also an option in these situations, provided that they are designed for easy, affordable and cost-effective removal of sediment by farmers' organizations immediately after floods.

Trash Deflector

Canals used with spate irrigation water sometimes carry huge loads of trash and debris. If not taken out they can clog the system or cause breach in embankments. A trash deflector can be constructed from steel pipes and cables to deflect trash away from the canal intake and towards the sluiceway *(figure 8.4)*.

Figure 8.4 Trash deflector at canal intake *(source: FAO, 2010)*

The key features of the structure include a anal intake incorporating a curved-channel sediment excluder and a low-cost, short concrete weir, with a breaching section or fuse plug that connects the weir to the far bank. A short settling basin, designed to be excavated by bulldozer, was constructed in the canal head reach. A conduit near the canal head runs under the stream to supply water from the main canal to the irrigated areas located on the opposite bank of the stream.

River training

River training involves the reshaping and dredging of the river bed to ensure that the river does not change course in the event of excess flooding. This can be expensive, but is cost-effective in the long run due to the protection it provide. River training can be incorporated in spate irrigation design because the scouring of stream banks, undercutting at the outer curves of meanders and sedimentation at the inner curves during large floods erodes away valuable irrigated land and threatens farms and canals running parallel to the stream banks. It is usually difficult to justify protection against such damage from large floods with conventional river-training works, because of the high costs involved when compared with the low value of the land and the crops that are grown. Often the best option is a combination of vegetative protection and mechanical control measures. All river training and bank improvements must form part of a complete plan to ensure that problems are not treated in isolation with the result that they are just moved to another location (figure 8.5).

Figure 8.5 Spate flow diversion system with river training *(source: FAO, 2010)*

8.6 Advantages of spate irrigation

In many arid environments, the classical approach to water management through storage of river water in reservoirs is not practical owing to the very high sediment loads transported during floods. In such regions, the useful life of reservoirs is usually very short. Spate irrigation offers more attractive development options when appropriate models can be identified.

8.7 Limitations of spate irrigation

Spate irrigation is implemented bearing high levels of risk and uncertainty. This is due to the unpredictable nature of rainfall events, their timing, quantities and consequent flood volumes. Sometimes, there are occasional very large floods occur which wash away diversion structures. The main flood flow may change course leaving the channel from which the water was intended to be diverted.

Sedimentation is a major problem in spate irrigation. The high sediment loads cause command areas to rise and block intakes and channels. However, sedimentation processes can be manipulated for the benefit of farming by building up on nutrients transported with sediments from upstream catchments to maintain soil fertility. Spate irrigation is as much about sediment management as it is about water management.

Maintenance of spate irrigation embankments is quite labour intensive; and is usually done through community initiatives. Earthen bunds and the embankments used with spate irrigation are more likely to breach as floods rise due to over-topping or piping under the embankment. Sometimes, dykes get partially or completely washed away and have to be rebuilt to again divert water to the fields.

In areas with silt soils or calcareous soils, soil crusting can affect water use efficiency. Such soils may form surface crusting, which can reduce the infiltration rate by 20–40 percent and thereby affect the amount of residual soil moisture. Continuous flood irrigation may lead to a hard compact layer. Clay particles carried in the floodwater are washed down the profile and make it difficult for the plant roots to reach the water, which leads to a reduction in productivity. One option to address this problem would be to break the hard pan every two to three years by chiselling, using a heavy power unit.

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