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Understanding and applying drip irrigation for sustainable agriculture

Compréhension et application de l'irrigation goutte à goutte pour l'agriculture durable

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Foreword

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International Workshop Agreement IWA 20 was approved at a workshop hosted by the Swedish Standards Institute (SIS), in association with the Standards Institution of Israel (SII), held in Stockholm, Sweden, in August/September 2016.

Introduction

Dwindling vital natural resources, such as land and water, and rising world population pose a constant threat that could develop into a future food and water crisis. Given the limited availability of water and land resources, the amount of food grown today needs to be increased to meet the demands of tomorrow. Reduction of available water for human consumption needs be addressed. As direct consumption of fresh water by populations cannot be decreased, the amount of water consumed by agricultural uses needs to be reduced and allocated for domestic or industrial use.

Drip irrigation addresses water scarcity and other environmental considerations. Its use can save large amounts of water (over 50 % of water can be saved for certain crop types), and can increase yields.

Drip irrigation not only addresses the need to reduce water consumption and increase yield, but also requires less labour and energy for operation, leading to lower costs to farmers due to reduced usage of labour, fertilizers and other chemicals.

Drip irrigation relates to sustainability agriculture issues, and can be used in dry areas, in saline soil with saline water, and in steep-sloped topographies, where other irrigation methods cannot be practiced.

Drip irrigation is easy to handle and operate once installed. It is suited for automation and remote operation by computer or mobile phone. The system's simplicity makes it easy to install, operate, maintain and repair.

Other than irrigation, the drip irrigation method is used as a delivery system for fertilizers and other agrochemicals. Drip's advantage as a delivery system is its ability to optimize fertilizer usage, and distribute it exactly where needed, in the root zone, while minimizing its release to the environment.

Adoption of drip irrigation can help achieve sufficient fresh water availability for domestic use and sufficient food quantity and quality for reasonable pricing, while increasing farmers' income with yield increment and cost reduction, and ensuring food security.

The purpose of this document is to review the benefits of the drip irrigation method in relation to other practiced irrigation methods, and to outline a future standardization roadmap.

Understanding and applying drip irrigation for sustainable agriculture

1 Scope

This document reviews drip irrigation in comparison to major irrigation methods available and practiced today by farmers worldwide. This document reviews the benefits of drip irrigation, such as increased yield, reduced water consumption, reduced energy consumption, lower environmental impact, reduced contamination of groundwater and surface water, reduced greenhouse gas emissions and reduced labour.

This document also reviews some of the limitations of drip irrigation.

This document does not provide a technical specification for the implementation of drip irrigation.

The qualities of drip irrigation referred to in this document apply to systems manufactured in accordance with ISO 9261 or equivalent standard.

This document is intended to be used by agricultural policymakers, infrastructure providers, water supply regulatory bodies and authorities, and food chain and farmer cooperatives interested in developing agricultural policies to preserve natural resources and funds. This document is also intended to be used by farmers and smallholders interested in applying an economic agricultural method.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
application efficiency
ratio between the amount of water consumed by the plant and the amount of water applied in the field

Note 1 to entry: Application efficiency units are normally presented as the percentage of water consumed by the plant in relation to the amount of water applied.

3.2
chemigation
injection of agrochemicals, such as pesticides, herbicides or other growth-enhancement products, to the irrigation system, together with irrigated water

3.3
drip irrigation
irrigation method whereby drippers are installed along a polyethylene (PE) pipe of between 10 cm and 1 m, from which water is released at a given capacity (e.g. 1 l/h)

3.4
evaporation
type of vaporization of a liquid that occurs at its surface and goes into a gaseous phase that is not saturated with the evaporating substance

3.5
evapotranspiration
combination of the water transpirated through the plant and the water evaporated through the soil surface

3.6
fertigation
injection of soluble fertilizers into the irrigation system together with water

3.7
irrigation efficiency
amount of productivity (yield) in relation to the amount of water applied

Note 1 to entry: Irrigation efficiency units are normally presented as the weight of yield per volume of water applied.

3.8
sprinkler irrigation
method of applying irrigation water that is similar to natural rainfall

Note 1 to entry: In sprinkler irrigation, water is distributed through a system of pipes, usually by pumping, and then sprayed into the air through sprinklers so that it breaks up into small water drops that fall to the ground.

Note 2 to entry: Sprinkler irrigation is also referred to as overhead irrigation.

3.9
surface irrigation
group of application techniques, such as flood irrigation and furrow irrigation, in which water is applied and distributed over the soil surface by gravity

Note 1 to entry: Surface irrigation is the most common form of irrigation throughout the world. It has been practiced in many areas, and has remained virtually unchanged for thousands of years.

3.10
transpiration
process of water movement through a plant and its *evaporation* (3.4) from aerial parts such as leaves, stems and flowers

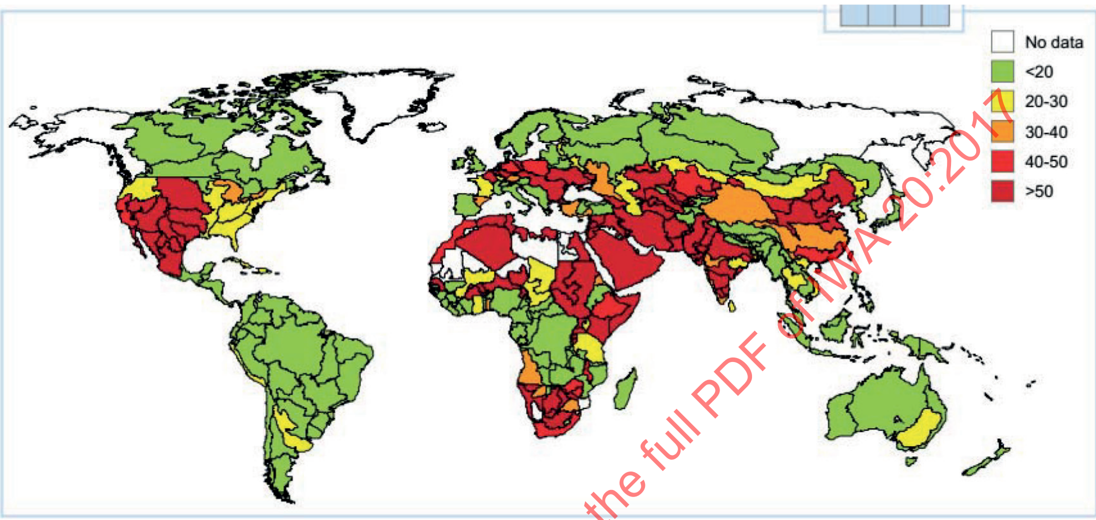
Note 1 to entry: In transpiration, water is necessary for plants, but only a small amount of water is taken up by the roots used for growth and metabolism.

4 Global environmental changes

4.1 Water scarcity

Climate changes on a global scale over the past years have led to extreme conditions such as strong storms with heavy precipitation on the one hand and long and dry periods of elevated temperatures on the other. One major consequence of these changes is the constant reduction of available fresh water worldwide. Water scarcity already affects every continent around the world. Approximately 1,2 billion people, almost one-fifth of the world's population, live in areas with physical water scarcity, and 500 million people are approaching this situation. Another 1,6 billion people, almost one quarter of the world's population, face economic water shortages (where countries lack the necessary infrastructure to take water from rivers and aquifers). Water scarcity is among the main problems that many societies and the world will be facing throughout this century. Water use has been growing at more than twice the rate of the population in the last century and although there is no global water scarcity as such, an increasing number of regions are chronically short of water.

Water scarcity is both a natural and human-made phenomenon. There is enough freshwater on the planet for seven billion people, but it is distributed unevenly and too much of it is wasted, polluted or unsustainably managed. While 1,6 billion people are currently subjected to severe water scarcity, it is projected that that this figure will reach 2,4 billion by 2030. Figure 1 shows the projected water scarcity worldwide in 2030. According to this, most of Europe and Asia, as well as the US, will suffer severe water stress.

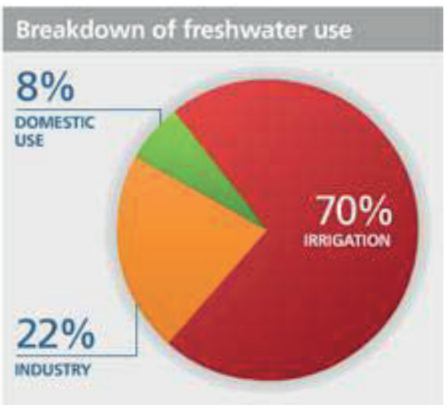


NOTE 1 The different colours stand for water stress, percent of total renewable water withdrawn.

NOTE 2 Source: IFPRI and VEOLIA water project[18].

Figure 1 — Projected water scarcity in 2030

As illustrated in Figure 2, most available water is consumed by agriculture. For this reason, the most significant moves to save water should be carried out in this sector. A more efficient irrigation system can have a positive impact on global water availability. In developing countries where there is water scarcity, such as in Africa, more than 80 % of the freshwater is used for agriculture to provide basic food for the population. An efficient use of water in agriculture can drastically increase freshwater availability for domestic use in these countries.



NOTE Source: UN water (2013)[14].

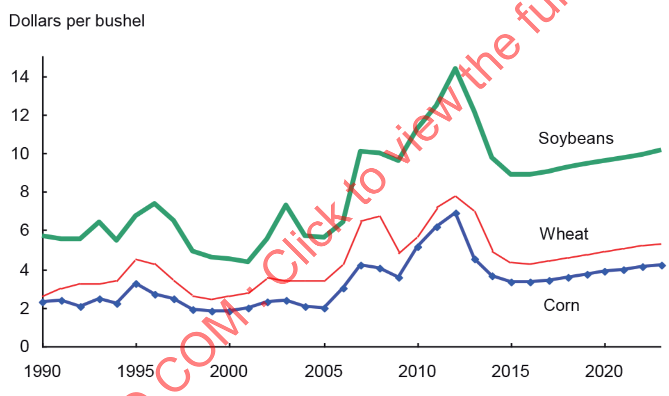
Figure 2 — Global water consumption by sector

4.2 Food scarcity and prices

By the middle of the 21st century, as the world's population reaches around 9 billion, global demand for food, feed and fibre will nearly double while crops may be increasingly used for bioenergy and other industrial purposes. New and traditional demand for agricultural produce will, as a result, put growing pressure on already scarce agricultural resources. While agriculture will be forced to compete for land and water with sprawling urban settlements and increasing industry demands, it will also need to serve across other major fronts: adapting and contributing to climate change mitigation, helping to preserve natural habitats, protecting endangered species, and maintaining a high level of biodiversity. Furthermore, in most regions, fewer people will be living in rural areas and even fewer will be farmers. As such, they will need new technologies to grow more on less land and with less manpower.

The productivity of rice is projected to dip by 17 %, and the productivity of maize is projected to drop by 6 % by the middle of the 21st century. A report by the International Food Policy Research Institute (IFPRI) has stated that food prices will rise even without climate change, but that global warming will aggravate matters. It concludes that prices are a useful single indicator of the effect of climate change on agriculture.

Wheat prices are projected to grow by almost 40 % without climate change, but could rise as steeply as 194 % with climate change, according to the IFPRI report. Rice prices are projected to rise by 60 % without climate change, and by up to 121 % with climate change. Maize prices are expected to surge 60 % without climate change, and by up to 153 % with climate change. Figure 3 shows projected prices of some commodity crops in the US.



NOTE Source: USDA website[13].

Figure 3 — US farm level prices of corn, wheat and soybean

4.3 Land degradation

Land degradation is the result of a combination of several processes such as soil erosion, soil salinity, chemical contamination, desertification, nutrient depletion, and water scarcity.

Land degradation has been occurring for a long time, and continues to affect soil worldwide, particularly in sensitive and vulnerable areas such as tropical and South Africa, Southeast Asia, South China, North-central Australia, Central America, Southeast Brazil, Alaska, Canada and Eastern Siberia. Some of the causes of land degradation are man-made or natural processes with human inputs as an accelerator. Due to recent climate changes, the world has experienced longer drought periods and stronger rain and storm events. These cause a gradual reduction in natural vegetation that helps stabilize soil during water runoff. But with the absence of vegetation and stronger water runoff, soil is subjected to erosion forces by water and wind. Afforestation, toxic chemical soil contamination, mining activities, and soil salinity are examples of man-made causes of soil degradation that reduce available cropland for food production. Currently, 18 % of the degraded land is cropland, 25 % central forests, and 17 % north forests.

A paper published by the Food and Agriculture Organization of the United Nations (FAO) in 2014[19] recommends several methods to achieve sustainable agriculture, while increasing food quality and quantity and reducing water consumption. One key element suggested is to use water more efficiently in order to grow more food with fewer resources.

5 Irrigation

5.1 General

Fresh water and fresh healthy food are basic human resources that should be provided everywhere, at all times, for everyone. In today's world, large dry regions suffer from water shortages, others suffer from food scarcity, and others suffer from both. Food and water scarcity are two of the main concerns for developed and developing countries and global organizations, as well as for many individuals experiencing drought and hunger.

Agriculture is the clear connection between water and food supply. Food production requires crops, crop production requires water, and water is related to increased crop production. The relationship between water supply and crop production, however, is not one-dimensional. A given crop production can be achieved through less irrigated water; that is, higher yields can be achieved with the same amount of water applied (i.e. water use efficiency). Increased water use efficiency can be achieved by simple, efficient irrigation practices.

For all irrigation methods, water applied in the field is not 100 % transferred into plant biomass. Some of it spreads into the soil by deep percolation or runoff. Some of it evaporates from the soil surface or wetted leaves, while the remaining water captured in the root zone ("effective water", as illustrated in Figure 4) is used by the plant for biomass production. The rate of transpiration is related to the plant canopy cover and air evaporation conditions. When less water is lost as runoff, deep percolation and evaporation, the relative portion of effective water is increased and higher effective use of water is achieved.

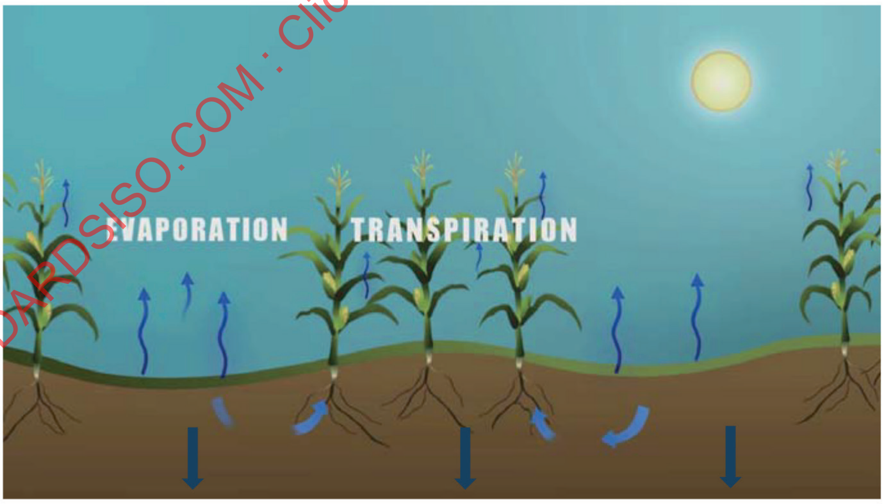


Figure 4 — Water evaporation and transpiration in the field

5.2 Common irrigation methods

Rain-fed agriculture covers 80 % of the world's cultivated land and accounts for about 60 % of crop production. Today, irrigated agriculture covers 275 million hectares (about 20 % of all cultivated land) and accounts for 40 % of global food production. This shows the relative importance of irrigation in the worldwide global food balance. Current irrigation methods are surface irrigation, sprinkler irrigation (which includes irrigation machines and centre pivots), and micro-irrigation methods such as drip irrigation.

Crop irrigation goes back thousands of years. Ancient Egyptians flooded their fields from the Nile, and the Persians built a network of tunnels for irrigation water delivered to the field by gravity. Gravity flood irrigation remains the most popular irrigation method in developed and developing countries today. The major improvement for this method was the invention of pumps that could deliver water further and higher than the water source. Much research was conducted in surface irrigation (i.e. flood irrigation, furrow irrigation) since the beginning of the industrial revolution and in agro science to improve efficient use of water. Formulae to calculate irrigation periods, field slopes and furrow structure were developed to design and plan furrow irrigated fields. Surface irrigation offers advantages of simplicity, visibility (i.e. the farmer can see water along the field), and easy control, and when excluding pumping costs, it can be a low-cost irrigation system.

The next step in irrigated farmlands was the development of sprinklers and similar products such as rain guns and pivots. In these methods, the water is delivered via buried or surface pipes at high pressure and high flow rates. Sprinkler irrigation can be easily installed, used and then relocated at the next field. Sprinkler irrigation not only maintains uniform water distribution on the soil surface, which can be advantageous for some crops, but also irrigates bare soil not containing plants (i.e. in row crops), which reduces efficient use of water.

Drip irrigation was invented in the mid-1960 by an Israeli water engineer who developed a method for delivering a small amount of water directly to where it is needed, i.e. the root zone. In drip irrigation, only a small portion of the soil that is needed for the plant's water supply is wetted while the rest of the soil remains dry. Major progress was made in drip irrigation products and know-how, including the introduction of better raw materials and new solutions for all crop types. The emitter discharge rate in drip irrigation systems has dropped over the years. While the first emitters had a flow rate of 8 l/h or more, today, agricultural irrigation emitters produced according to ISO 9261 specifications have flow rates of less than 1 l/h with a low probability of clogging. Flow rate reduction leads to less required energy for system operation, which means that a larger area can be irrigated simultaneously. The flow rate should be adjusted to the plant's needs, power availability, water availability, and other local conditions.

6 Advantages of drip irrigation

6.1 Crop production

Drip irrigation used at optimal scheduling in a given field can increase yields by tens to hundreds of percent compared to other irrigation methods. Reports show that drip irrigation has led to an increase in sugar cane yield of 133 % in India with a 50 % reduction in water usage compared to flooded plots. They also show an increase of 16 % in potato yield in China with a 33 % reduction in water usage compared to sprinkler irrigation. Results like these are due to improved water management by supplying the exact quantity of water at the right time and at the right place.

Drip irrigation enables not only water delivery to the plant's roots, but also fertilizer and other supportive nutrient delivery (see 6.5). To achieve high yields, the right amount of water and nutrients need to be applied to the plant at the right time and at the right place, according to the plant's needs. In surface irrigation, water quantity applied by each irrigation event is high, and the time between two applications may be long (i.e. days to weeks).

In surface irrigation, the plant can be subjected to oxygen stress for a few hours at the beginning of irrigation due to soil flooding. On the other hand, it can suffer from water stress just before the next irrigation due to large time intervals between irrigation application and available water depletion.

In sprinkler irrigation, yields can be relatively high, since water can be applied in much shorter intervals, depending on the farmer's ability to reinstall sprinklers in the field or the centre pivots. With sprinkler irrigation methods, time intervals are a matter of days, which enables effective irrigation scheduling.

Drip irrigation scheduling enables short intervals between irrigation events, i.e. irrigation can be applied once every few minutes, several times a day, once a day, or every few days. Irrigating in short intervals enables maintaining relatively constant water content at the root zone, and preventing over-irrigation or water stress for the plant. In drip irrigation, farmers can apply the right amount of water at the right time according to the plant's needs, and can immediately react to sudden extreme conditions such as heat, which requires additional water.

Figure 5 shows the amount of water required for drip irrigation compared to flood irrigation in order to meet the plant's water demand during the growing season. A large portion of the water applied on the field in flood irrigation does not reach any root and is not consumed by the plant, while in drip irrigation, over 90 % of the applied water reaches the plant root system and is consumed by it. The result is higher water productivity in drip irrigation in terms of water volume per yield weight.

NOTE Source: Netafim website[17].

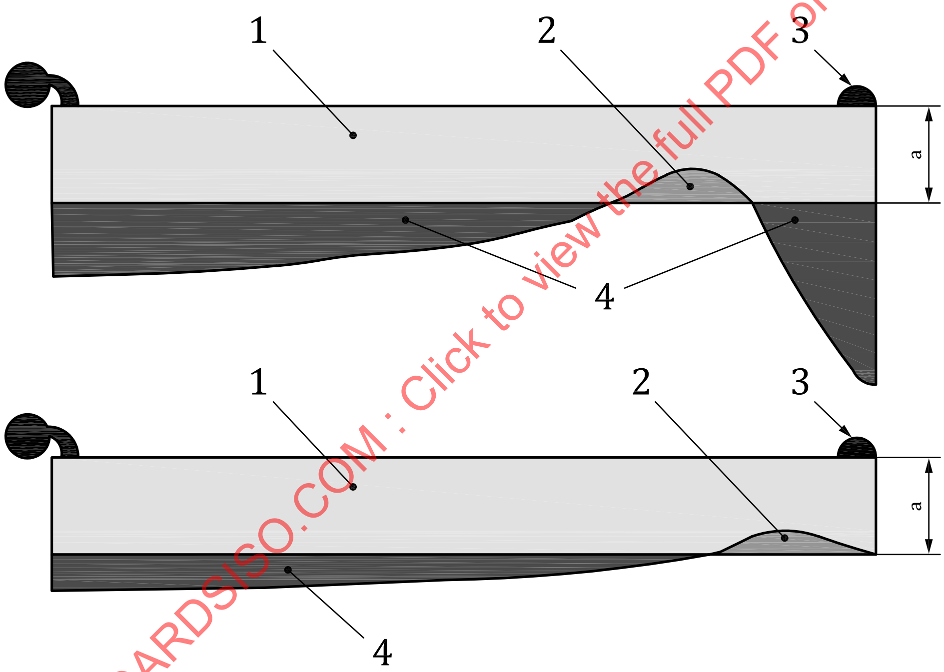
Figure 5 — Crop production and water-use efficiency

Increased plant transpiration is connected to increased yield; in order to enable more transpiration for the plant, more water is required. Figure 5 shows that in flood irrigation, more water is applied to the field, yet yields are lower compared to crops that are irrigated by drip, which uses less water. Therefore, drip irrigation displays higher productivity compared to other irrigation methods available.

6.2 Water distribution in the field and irrigation efficiency

One of the factors affecting yield uniformity is water distribution across the field. Sections of a field that receive less water than other sections have lower yield potential.

In surface irrigation, controlling and adjusting water distribution in the field is not trivial, and depends on the field's slope and furrow maintenance. Figure 6 illustrates water supplied at one end of the field that flows along the soil surface toward the other end of the field, while some of it penetrates the soil, making it available for plant consumption. Because water is applied from a single point, the soil that is close to the water source becomes wetter than the soil at the end of the row, and a large quantity of the water percolates to deep soil layers and the groundwater. Surface coverage of water by surface irrigation varies according to the irrigation method applied (e.g. surface, furrow border). With some methods, there is full coverage of the soil surface with water in crops not grown on ridges, while with furrow irrigation, the channels are filled with water while the ridge stays relatively dry (see Table 1). In both cases, a large portion of the soil without plants is irrigated. In addition to the wasting of applied water, there is higher water loss due to evaporation and the boosting of weeds.



Key

1 stored soil water
2 deficit
3 dike
4 deep percolation
a active root zone

NOTE Source: University of Nebraska–Lincoln[12].

Figure 6 — Surface irrigation water distribution plan

Table 1 — Irrigation method efficiency

Irrigation system	Application efficiency %
Centre pivot	75 to 85
Sprinklers	70 to 80
Furrow	45 to 65
Basin	60 to 75
Precision-level basin	65 to 80
Surface drip	85 to 95
Subsurface drip	> 95

NOTE Source: University of Nebraska–Lincoln[12].

Surface irrigation relies on gravity flow of water on the soil in accordance with the slope. Surface irrigation methods can be applied only in flat areas that are adequately levelled. Suited for most crops, surface irrigation is restricted to flat areas such as plains and valleys. In sloped areas, this method is not feasible without major engineering intervention.

Sprinkler irrigation enables more uniform water distribution across the field compared to surface irrigation except in windy conditions. Wind can dramatically affect water distribution around the sprinkler and strong wind conditions may lead to more uneven water distribution across the field. In such cases, farmers are required to operate the irrigation system in appropriate weather conditions that can change from day to day. Due to full coverage of the soil by water with sprinkler irrigation, boosting of weed growth and water evaporation from the soil can also occur. Sprinkler irrigation can be applied in sloped areas such as hills and valleys, since water is applied by pressure. Due to the slope, massive water runoff can occur during irrigation since the infiltration rate of water is lower than the water application rate, which results in free water on the soil surface that is subjected to gravity.

Drip irrigation is characterized by uniform water distribution across the field. Basic emitter types are not pressure compensating; and are limited to shorter runs and moderate slopes. Advanced emitter types are pressure compensated resulting in a nearly constant flow rate, across a wide pressure range. This enables longer lateral runs of up to 400 m without losing flow rate uniformity. One of the major advantages of pressure-compensated drip irrigation systems is that they can be used in sloped fields where surface irrigation cannot be applied. Discharge rates of modern emitters are very low (as low as 0,4 l/h), particularly lower than most infiltration rates of most-heavy soils, thereby preventing runoff.

Drip irrigation is limited to a close area around the dripper (i.e. 40 cm to 80 cm wide wetted area along the laterals) so no unnecessary soil is irrigated, resulting in less weed emergence and less water evaporation.

6.3 Water evaporation from soil surface

Because soil has capillary forces resistant to water evaporation, evaporation from the free water table to the atmosphere is larger than water evaporation from bare soil. As a result, more water is lost by evaporation from surface irrigation compared to drip irrigation (see Table 2). Although drip irrigation intervals are shorter than furrow irrigation intervals, the absence of free water on the soil surface reduces total water evaporation. Furthermore, the total area being wetted in furrow irrigation is much larger than in drip irrigation, which leads to a larger evaporation area. In addition, water content after a furrow irrigation event is much higher than in drip irrigation, resulting in an evaporation rate that is accordingly higher for furrow irrigation. To further reduce water evaporation, subsurface drip irrigation can be applied at depths that provide all the needed water yet keeps the top soil dry, thus further preventing water evaporation.

Similar to surface irrigation, sprinkler irrigation is subject to high water evaporation due to full area irrigation. In sprinkler irrigation, much of the water emitted from the sprinkler lands on the plant canopy and evaporates from the plant rather than reaching the soil. This can also cause salt burning on the leaves when irrigating with low-quality water.

Table 2 — Efficiencies of different irrigation methods

Irrigation efficiencies %	Methods of irrigation		
	Surface	**Sprinkler**	**Drip**
Conveyance efficiency	40 to 50 (canal) 69 to 70 (well)	100	100
Application efficiency	60 to 70	70 to 80	90
Surface water moisture evaporation	30 to 40	30 to 40	20 to 25
Overall efficiency	30 to 35	50 to 60	80 to 90

NOTE Source: Sivanappan (1998)[20]

6.4 Dry harvest

Typically, irrigation is stopped prior to harvest. During the time between the final irrigation and harvest, soil may be dried and run over with harvest machines and tractors. For continuous harvests (e.g. alfalfa), irrigation is continued until harvest and resumed immediately afterward.

When surface irrigation is practiced, the soil is not sufficiently dried and “wet harvest” needs to be conducted in muddy conditions. This causes operational difficulties as well as damage to field levelling, soil compaction and furrow shape.

In furrow irrigation, a long period of time might be required after the entire field has been harvested even if there is no damage to the furrow or field slope.

In drip irrigation, water can be applied one day prior to the harvest and even during the harvest. The first irrigation following the harvest can be applied immediately. Drip irrigation also enables in-season cultivation and other aeromechanical practices, such as spraying, which are hard to execute in furrow irrigation due to mud.

6.5 Irrigation as a delivery system

The main role of an irrigation system is delivering water to the soil where it is absorbed by the plant. In addition to water, plants need an adequate amount of fertilizers (e.g. nitrogen, phosphorous, potassium) and micro-nutrients.

While all irrigation methods are mainly designed for water delivery to the soil, drip irrigation can also be used as a delivery system for a wide range of chemicals (chemigation) and fertilizers (fertigation).

Fertilizers can be applied in the field by several methods such as solid fertilizers spread on the soil surface or foliar fertilizer applied directly on the plants’ leaves. These two methods require manual labour and equipment, which requires dry soil particularly for the farm machinery and equipment.

Another easy cost and labour-saving method is applying fertilizers with irrigation water (i.e. dissolved solid or liquid). When applying fertilizers along with irrigation water in furrow irrigation, more fertilizer needs to be added because not all the water applied on each irrigation ends up being consumed by the plant; some of it evaporates, some of it is turned to runoff, and some of it percolates to deep soil layers and the groundwater. Considering that irrigation water contains some fertilizer concentration, an environmental risk is caused due to groundwater and surface water contamination. Moreover, in surface irrigation, distribution of water across the field can be uneven and if fertilizer application is conducted using water-soluble fertilizers, it will unevenly distribute the fertilizer, which may cause spatial variability and yield loss.

In drip irrigation, the irrigation system can be used as a delivery system. Fertilizers applied through the drip irrigation system end up precisely in the root zone, where it is needed, with minimal losses to deep soil layers. Fertilizers can be injected into the irrigation system automatically by a pump located adjacently to the main valve resulting in a field that is fertilized and irrigated at the same time. This saves time, money, increases fertilizer-uptake efficiency; and reduces fertilizer loss to the environment.

Drip irrigation systems directly apply fertilizer to the root zone as well as essential materials such as mycorrhiza for plant symbiosis, and herbicides and pesticides. The method has none to very minimal environmental impact, since all chemicals are delivered to the root zone exactly where they are needed.

6.6 Water infiltration, water budget and the environment

Crop irrigation is a part of the global water cycle. Irrigation water comes from pumped ground water, surface water from rivers and lakes or reservoirs.

Sustainable agriculture is crucial for the future of our ecosystem and for the preservation of our water sources in terms of quantity and quality. Degradation of water bodies, both surface and subsurface, occurs when water withdrawal exceeds its refilling rate, or when water quality drops to levels that prevent reuse. Surface irrigation and sprinkler irrigation require large quantities of water beyond the plants' requirements. Therefore, large quantities of water need to be pumped from a source, thereby reducing its water budget.

In furrow irrigation, some of the irrigated water is used by the plant, while the rest goes to the groundwater, surface runoff, back to the stream, or evaporates. The implication is that the amount of water applied exceeds the required amount to supply the plant's needs adequately. The first direct impact is high pumping and water costs, unless water is free or delivered at a low cost. In drip irrigation, the amount of water delivered to the field is lower, and since less water is pumped at lower pressure, smaller pumps are required, leading to energy and water savings.

Two scales should be considered when comparing water balance in surface irrigation and drip irrigation:

— basin scale;

— farm scale.

Water balance at basin scale in surface irrigation is supposedly even, since infiltrating water can be pumped later, and runoff is returned to the stream where another farm can capture and use it. In any case, water quality degradation resulting from use should be considered: while the first farm upstream receives fresh water, the last farm receives water, pesticides/herbicides, and other chemicals that were added to the water in farms upstream, along with elevated salinity. This is the case for surface water and groundwater.

With surface irrigation at farm scale, as farmers apply more water than needed by the plant, there are high water and energy costs due to water percolation and runoff. In both basin scale and farm scale, a high evaporation rate causes considerable water losses to the atmosphere compared to other irrigation methods. With drip irrigation, most of the water applied to the field is used by the plant for evapotranspiration and biomass production. Using the same amount of water with drip irrigation enables larger areas to be irrigated compared to other methods.

Sustainable agriculture also relates to the reduction of the human footprint on the environment. Chemicals, such as pesticides, weed control and fertilizers, are applied daily in the field for different uses in order to support plant development. Some of these chemicals can exceed their target area of impact and reach the environment via soil, groundwater or surface water. The main vector transporting the chemicals into the environment is water. Wherever water flows, it carries many types of dissolved materials such as salts and chemicals. In surface irrigation or sprinkler irrigation, these materials can be rapidly leached to and contaminate the groundwater as well as water used by other consumers downstream.

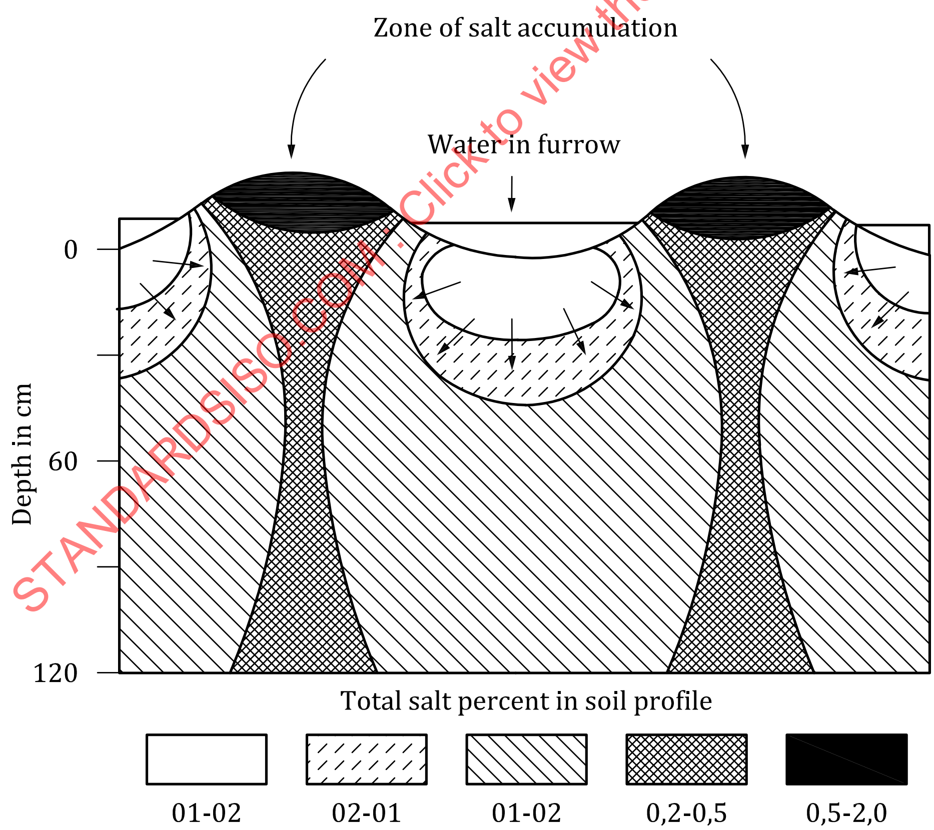
Since less water is required in drip irrigation compared to other irrigation methods; and since the water is applied directly where needed (at the root zone), the amount of chemicals applied and used is drastically lower. Furthermore, in drip irrigation, there is almost no deep drainage of water from the root zone (with the exception of intentional leaching of salts), so chemicals do not exceed the root zone area and contamination of the environment is avoided. The use of fewer chemicals in drip irrigation leads to lower chemical manufacturing, environmental degradation and farmer costs.

6.7 Soil and water salinity

When water evaporates from the soil surface, contained salt accumulates on the surface and may later be dissolved back into the water, reach the root zone, and cause salinity stress to the plant. In every irrigation method, salt is accumulated on the soil surface, but the amount and location of salt in relation to the plant varies.

In sprinkler irrigation, 100 % of the surface is wetted at the same time, similarly to a rain event. The water percolates into the soil in a uniform water front and carries salts away from the root zone into the groundwater. A sufficient amount of water should be applied to ensure the removal of salts down in the soil profile.

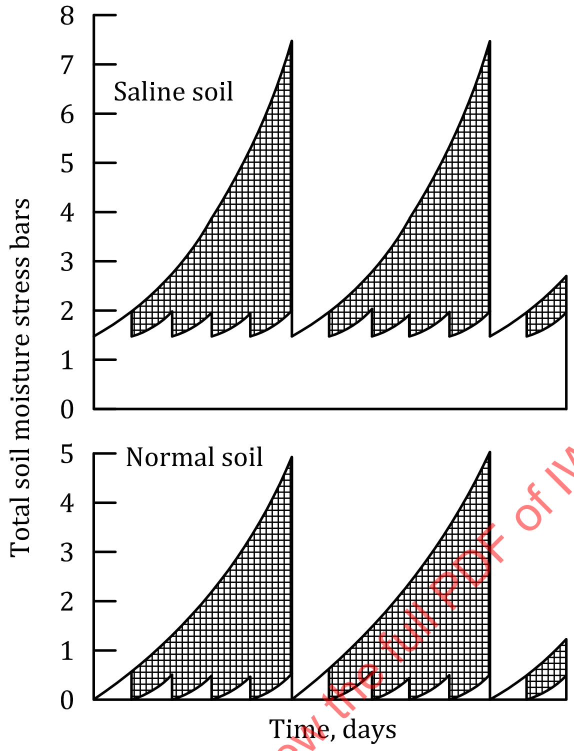
Furrow irrigation is usually considered a good method to prevent salt accumulation due to large, deep percolation that can wash salts away from the root zone. However, furrow irrigation can promote salt accumulation on the furrows' edges and ridge between two furrows (see Figure 7). Furthermore, salt can accumulate on the edges of the wetting front in the soil profile, right above the root zone. Therefore, the flushing of salts in furrow irrigation occurs only beneath the furrow and not in the entire soil profile.



NOTE Source: FAO website[11].

Figure 7 — Salt accumulation in soil profile in furrow irrigated field

In drip irrigation, salt also accumulates on the edges of the wetted "bulb" under the dripper, but the roots are kept within the borders of the wet area and away from the salty soil. Furthermore, drip irrigation's high frequency keeps the soil relatively moist, and therefore, salt levels are relatively lower. In contrast, with furrow irrigation, low frequent irrigations cause higher salinity levels in the soil as shown in Figure 8.



NOTE Source: FAO website[11].

Figure 8 — Salinity levels as a consequence of irrigation interval timing in normal and saline soil

Salt accumulation in the soil occurs with relatively low salinity water sources. But where there are shortages in available freshwater to support the population and agricultural needs, saline water at levels of up to 4 dS/m is used for irrigation. Moreover, degradation in soil fertility and the shortage of new available cropping area lead to the use of relatively saline marginal soils. In saline water or saline soils, the salinity effect on crops is reduced by maintaining a high moisture level in the soil.

With furrow irrigation, maintaining high moisture levels can be done only if irrigation is applied every day. This requires a high water and energy investment which is not practical and often not available.

With drip irrigation, daily application is common practice, and in dry areas with light and coarse soils, irrigation can be repeated several times per day. Furthermore, emitters with a flow rate as low as 0,5 l/h can be used, so that a daily irrigation event can keep the soil constantly wet for several hours. Therefore, drip irrigation systems can reduce the salinity effect by keeping a high moisture level in the soil, and can be used in saline soils or with saline irrigation water.

6.8 Soil and land conservation

Soil erosion is part of land degradation occurring worldwide (see 4.3). Some of it is natural caused by storms and heavy rain; but some of it is man-made in cropland as illustrated in Figure 9.

Figure 9 — Soil erosion by water in a furrow irrigated corn field

Figure 9 shows soil erosion by water runoff in a furrow irrigated corn field. Soil particles are collected by the high water flow energy, and settle where the water energy is lower. Therefore, considerable quantities of soil are translocated away from the fields after years of surface irrigation practice. Together with the soil particle translocation, chemicals and fertilizers leave the field to the environment.

Soil erosion is less common in sprinkler irrigation although it may occur in excessively irrigated steep-sloped fields. When using drip irrigation, soil erosion is prevented due to the low emitting rate of drippers. Water emitted from the dripper infiltrates the soil and free water flow on the soil surface is prevented.

6.9 Energy saving

Surface irrigation is a low-energy consumer that was practiced before pumps were invented. This method is applicable in fields near rivers where a river channel can be dug and directed toward a field. Dams and diversions can be opened and closed based on need with no required energy investment.

Today, fields are located far from water sources. In most cases, the water source is groundwater which needs to be pumped out from the ground. Since a large amount of water for surface irrigation is required, there is a need to lift large quantities of water from underground to the field level, which leads to high energy consumption.

Sprinkler irrigation requires less water than surface irrigation and therefore consumes less energy. However, sprinklers and centre pivots use high pressure to disperse the water far from the sprinkler. In order to reach high pressure requirements, there is a need to use high energy-consuming pumps; which increases farmers' costs.

In drip irrigation, less water is used to irrigate a given area which results in a smaller pump running at a lower pressure compared to more water-consuming methods (see Table 3).

Drip irrigation's low energy consumption enables operation solely by solar power. Some drip irrigation equipment manufacturers offer the small Family Drip System®[1] which is a comprehensive kit suitable for smallholders in developing countries who grow self-consumption crops. The kit comprises a small solar panel and an electric pump capable of pumping water from a small creek or a barrel to irrigate up to a 250 m^2 field. Irrigation control is not required, since the pump is self-triggered by sunlight.

1) Family Drip System® (FDS) is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

Table 3 — Irrigation methods' required pressure for operation

Irrigation method	Typical pump pressure bar[a]
Sprinklers	6 to 9
Centre pivot (low pressure)	3 to 6
Centre pivot (medium pressure)	5 to 8
Hose-pulled traveller	3 to 14
Drip	0,3 to 3
NOTE Required pressure for source pumping is not included.	
[a] 1 bar = 100 kPa.	

6.10 Treated wastewater irrigation

Current water scarcity challenges are encouraging policymakers to seek alternative water sources for domestic and agricultural uses. Enabled by improved technology and reduced costs, a growing number of desalination plants are being built worldwide to mitigate freshwater demand for domestic uses. However, since desalinated water is too expensive for irrigation, alternatives need to be considered.

One traditional alternative that has been used in many countries is the agricultural and domestic use of treated wastewater for irrigation. About half the water consumed by domestic consumers is flushed away as wastewater which contains substantial organic matter, salts and nutrients. Once the unwanted substances are removed, the treated wastewater can be used for agriculture irrigation.

Treated wastewater for irrigation offers several advantages:

— It is reliable, year-round water source

— It contains nutrients (e.g. nitrogen and phosphorous) that plants need

— It produces sludge, which serves as an organic matter additive for soil application

One disadvantage of treated wastewater is that it contains additional salts that can accumulate in the soil and leach into the groundwater. Still, drip irrigation can be practiced under salinity conditions and with salty irrigation water in order to avoid yield losses-(see 6.7).

Another disadvantage is domestic source of wastewater may contain pathogens that pose a potential risk to those exposed to the water or to those consuming crops irrigated with treated wastewater.

Barriers that are designed to mitigate risk and prevent direct contact between wastewater and edible crops are specified in ISO 16075-2.

Since drip irrigation is sensitive to clogging, particularly when low-quality treated wastewater is used, proper manufacturing, installation, maintenance, adjusted filtering systems and occasional flushing (as will be described in the future ISO 20419) should be practiced in order to substantially extend system durability.

6.11 Labour savings

Labour is one of the largest resources invested annually in agriculture. Labour is also the only resource that can be minimized; by replacing irrigation workers with automation.

While surface irrigation and sprinkler irrigation need labour to continuously operate dams and irrigation sets, drip irrigation can be automated and easily controlled on site or remotely operated by just one person (see EN 15099-1).

Operating a drip irrigated field is also scalable: one person can manage the operation of several fields simultaneously. See Table 2 for a comparison with other irrigation methods.

7 Drip irrigation limitations

Although drip irrigation is adjusted for various types of crops, soils and climates, it does have a few limitations.

— Initial start-up costs are relatively high even though return on investment is relatively short. Some governments, international aid organizations and/or development agencies subsidize installation.

— Although one person can operate a set of drip irrigation systems and thereby save on labour, initial installation can take a few days or more depending on the project size, and requires know-how and planning.

— Drip irrigation systems are subject to emitter clogging, mainly with low-flow rate emitters, if they are not protected by proper filtration systems that are adjusted to any type of water, as specified in ISO 16075.

Annex A
(informative)

Role of governments: National investment as a driver of growth

Government investment can determine whether or not agriculture can create a sustainable livelihood in low-income communities. Implementation of an agricultural support system can generate positive impacts. An investment in drip irrigation equipment and infrastructure can be the determining factor leading to poverty alleviation and higher income for poor farmers who are hard-pressed to compete. Governments in low-income economies should support policies that make agriculture in general, and drip irrigation in particular, a vehicle for poverty alleviation while protecting environmental resources on which low-income farmers depend. These agencies should focus on specific targeted goals to achieve an effective subsidy model.

Since most effective agricultural advances are led by technology and are supported by strong government policy, governments can make meaningful investments that will serve their countries for many years to come by working with the private sector and NGOs.

Governments and policymakers should take the initiative to strengthen agricultural innovation and cooperate with private funds, banks and industry. The relationship between government and private participants is important to benefit local populations, strengthen rural communities, and secure future food resources.

A successful drip irrigation project can generate primary benefits for communities, public institutions, and governments, and generate secondary benefits for private industries. The primary objectives are focused on local outcomes, while secondary objectives address wider project benefits.

The following steps can be followed leading up to a project:

— create a task force to explore opportunities

— establish an investment policy

— initiate cooperation with financial institutions

— implement transparent project development

Infrastructure is one of the key challenges that governments throughout the world face, with certain regions urgently requiring investments. However, the benefits of infrastructure investments should be considered. Improved infrastructure creates new growth opportunities across a variety of sectors in the economy. New infrastructure drives the growth of agriculture, manufacturing and service sectors and reduces barriers to intraregional trade. For most countries, this is a critical component in transitioning to higher value production. Without such an investment, an increase in productivity and economic diversification will be diminished and may lead to a deceleration in growth rates.

The following conditions should be followed by a public-private partnership to ensure maximum outcome of a drip irrigation program: awareness of its benefits should be raised; stakeholders should fully understand the benefits before providing necessary support to achieve stated goals; technology should not be deployed in a manner that will adversely affect farmers' interests.

A subsidy model requires the support of a focused group of advocates. To initiate a subsidy model successfully, there is a need for several advocates to lead the project and promote the benefits of implementation. Advocates may include:

— government leaders, ministries, and local and/or territorial government bodies;

— influential community members;

— third parties such as non-government organizations;

— international institutions;

— private industry and bankers.

Farmers are primary stakeholders in a drip irrigation project and they need to be educated about its benefits. They should also be important community advocates for government investment. They will need initial support from the educational campaign to truly understand the potential benefits of the new technology. Once the initial awareness campaign is completed, they should also receive agronomic training for using drip irrigation systems properly.

To ensure long-term project viability, all relevant government ministries should understand and support the efforts to modernize agriculture. Key national or local offices may include natural resources, rural development and education.

Annex B
(informative)

Drip Irrigation implementation

B.1 Installation, agronomic training and capacity building

Drip irrigation installation does not necessarily require professional labour, however, several basic installation rules should be followed so that the system can operate without failure.

Farmers can learn about the installation of any drip irrigation system in the field. A professional contractor should be used for large-scale fields where bigger pumps and filtration systems are required, and for conducting lines that need to be installed.

Any drip irrigation system is composed of a water source, filtration, pump, sub-mains to conduct the water, and dripper lines across the field.

Figure B.1 shows a Family Drip System® layout. The source of the system's pressure is an elevated tank that should be about 1 m above the laterals. The water tank can be filled by buckets from the nearest water source. This system will use much less water than a flood system of the same area.

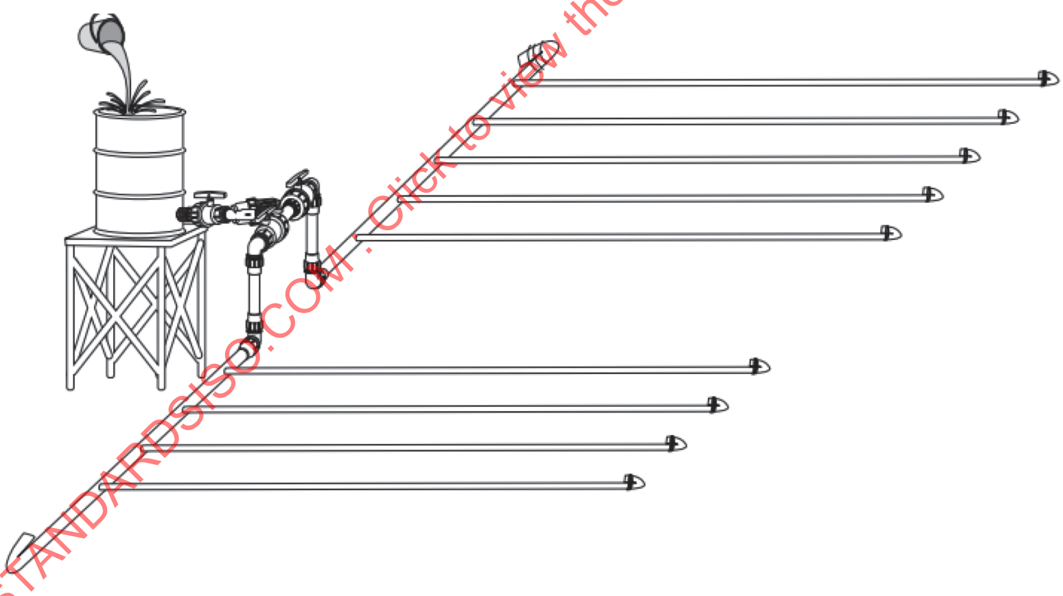


Figure B.1 — Family Drip System® kit for small fields

B.2 Drip irrigation infrastructure

As shown in Figure B.1, the infrastructure required for drip irrigation is smaller than that required for flood irrigation.

Once drip irrigation infrastructure is installed, little maintenance is required, since the dripper lines and conducting pipes can be sustained for years. In contrast, when it comes to flood irrigation infrastructure, the channels are prone to collapsing and require frequent maintenance.

B.3 Use of solar power as an energy source for drip irrigation systems

To increase labour savings in the implementation of a drip irrigation system, the main water tank can be filled by using a small electric pump operated by solar power.

The use of an electric pump is very easy and can facilitate water pumping from a water source without connecting to the power network.

The electric pump is operated by solar power that is renewable environmental energy.

B.4 Factors for success

B.4.1 Water availability in-line – Comparing various methods

Drip irrigation uses up to 50 % less water than flood irrigation. Considering the infrastructure needed to conduct the water, particularly in relation to low water availability, drip irrigation uses less water and smaller conducting pipes or channels compared to flood irrigation. This results in long term water and cost savings for farmers.

B.4.2 Comparison of different methods and technologies

B.4.2.1 Ease of access of technologies

Flood irrigation is used across the globe. It does not require special parts but does require labour for irrigation channel digging. Drip irrigation is now also available worldwide with leading brand manufacturers having penetrated many countries where they can easily supply systems and replacement parts.

B.4.2.2 Ease of installation, operations and maintenance

While flood irrigation requires labour for irrigation-tunnel digging, drip irrigation installation takes only a few minutes. Laterals are easily spread on the soil surface and connected to the water source before the system is ready to operate.

B.4.2.3 Associated cost estimates for different irrigation methods

Flood irrigation costs are relatively low, since no parts are required. However, it involves high labour costs and time investments for irrigation-channel digging and irrigation operation, all the while using much more water and delivering lower yields.

In drip irrigation, farmers have a higher initial capital investment to purchase the system but since crop quality is better and yields are higher, the return on investment is very fast so that their income is rapidly increased compared to flood irrigation.

Furthermore, installation, maintenance and operation time are saved in drip irrigation.

Annex C
(informative)

Used material disposal and recycling

C.1 Existing approaches

Drip irrigation products (i.e. pipes, dripper lines) are made of medium and low-density polyethylene (PE) which is easy and preferable to recycle. To recycle PE as a raw material for producing new dripper lines, the old equipment should be flushed out of all solid contaminates such as mud and plant residues. The PE then needs to be chopped to pieces and melted down to form small PE granules, which are ready to be used over again in a similar way as a prime material (new PE).

Recycled PE can be used to manufacture new dripper lines, but is limited to up to 40 % in heavy-walled products (<1 mm wall thickness) and 0 % in thin-walled products. For other plastic industry products, PE from dripper lines can be up to 100 % of the total material.

The only exception to dripper line recycling is pressure-compensated (PC) dripper lines. PC dripper lines contain a silicon diaphragm that regulates the pressure with the dripper, enabling it to maintain the same flow rate under various pressures. Since silicon is an elastomer, it does not interact with the PE. Therefore, when the silicon is melted together, it weakens the PE strength, making it non-useable. However, in most recycling plants worldwide, silicon is removed from the PE during the recycling process, enabling the PE to be used safely.

The main constraint of dripper line recycling is the collection of dripper lines from the field to the recycling plant. Usually the distance between the source and the recycling plant is great, which leads to high transportation costs. In addition, the dripper line is recoiled very roughly and its weight-to-mass ratio is very low, further increasing costs.

A main issue in dripper line recycling is the price of the prime material (new PE), which is mainly affected by global petroleum prices. In some cases, it is not economically viable to recycle an old dripper line when prime PE prices are nearly identical to recycled prices.

C.2 Best practice of different countries

The main contribution of PE waste in agriculture is sheets for greenhouses and net houses, with the PE from the dripper line representing a small percentage of the waste. Since regulations in most countries forbid the burning of old PE products, PE waste landfill is also used. More and more countries are supporting and promoting recycled PE from agriculture. Several factories recycle old PE into burning products via chemical separation of its ingredients. It is estimated that only 10 % of all dripper lines are recycled, while the majority are still being burned or landfilled.

Annex D
(informative)

Impact of drip irrigation on sustainability

D.1 Environmental impact of drip irrigation

D.1.1 Energy

Drip Irrigation is a pressurized irrigation method like centre pivots and sprinklers. Among irrigation methods, drip irrigation requires very low pressure to operate, starting from 3 m of elevation (or even 1 m with Family Drip System®), compared to sprinkler irrigation, which requires at least 30 m to operate.

Flood irrigation is the method with the lowest energy costs. However, this advantage is negated if the used water source is groundwater instead of surface water. When groundwater pumping, particularly in high volumes – as is the case for flood irrigation – is required, flood irrigation requires more energy and becomes less economical than drip irrigation.

D.1.2 Greenhouse gas (GHG) emissions

Agriculture is responsible for most GHG emissions worldwide. GHG emissions include crop fields and gases produced by animal digestion. In crop fields, GHG emissions occur when water is logged on the soil surface, and therefore, reduces oxygen availability. Lack of oxygen in the soil creates a chain of chemical transformations of some of the substances into gases.

The major reactions are the transformation of organic matter into methane (CH_4), which is the most destructive GHG. Another GHG being emitted from crop fields is nitrous oxide (N_2O). This gas is transformed into a GHG when the lack of oxygen initiates anaerobic bacteria to utilize the oxygen in the nitrogen fertilizer (NO_3) and emits the nitrous oxide as a gas. Anaerobic conditions occur in the soil when heavy rain or irrigation is applied and water is logged on the soil surface.

Among all agricultural irrigation methods, flood irrigation is responsible for most GHG emissions. This is because a large amount of water is applied on the soil surface at once, which saturates the soil for a relatively long period of time. The crop most associated with GHG emissions is rice, which is traditionally irrigated with constant flooding of water. In addition, due to the reduction of nitrogen fertilizer in the soil resulting from gas emissions, more nitrogen fertilizer needs to be added to meet the plant's requirements. This leads to more GHG emissions, reduced nitrogen efficiency, and increased costs.

In sprinkler irrigation, the soil gets less saturated and for a shorter time period compared to flood irrigation resulting in lower GHG emissions. In drip irrigated fields, not all of the soil surface is irrigated, and the irrigation intervals are shorter (1 to 3 days), with a smaller amount of water applied each time. In this irrigation method, the soil receives an adequate amount of water along with sufficient concentration of oxygen to support aerobic microbial activity, producing significantly less GHG emissions. Furthermore, drip irrigation requires less fertilizer resulting in less nitrogen being available for production of GHG emissions compared to sprinkler and flood irrigation.

Figure D.1 shows that in most cases, flood irrigation exhibits higher values of N_2O gas emissions from the soil compared to drip irrigation. The only exception is where standard tillage is applied with no legume cover crop (ST-NCC). In all other cases, the gas emissions from flood irrigated fields is dramatically higher than in drip irrigation.

