GLSCRP
GIYANI LOCAL SCALE CLIMATE RESILIENCE PROGRAMME

WATER RESEARCH COMMISSION

A GUIDELINE FOR WATER WISE FARMING

AGRICULTURAL WATER MANAGEMENT SKILLS

Acknowledgements

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The Giyani Local Scale Climate Resilience Programme (GLSCRP) aims to develop and implement activities that will research, develop and demonstrate climate adaptive responses and solutions for optimising water utilisation in drought-stricken areas.

The programme will focus on the Greater Giyani Municipal area within the Mopani district and aims to impact an estimated 5000 beneficiaries over a three-year period in terms of water utilisation, improved water mix, and socio-economic opportunities as responses to climate adaptation.

A 2019 WRC study on droughts and adaptation strategies has highlighted risks to reduced productivity, livelihoods and food security, and an increase in vector and water-borne diseases in communities such as Giyani. Ultimately, climate change impacts on water resources in the Giyani area cannot be underestimated.

The programme has three key areas that will support improving local scale adaptation and resilience in Giyani.

They are:

1) a strengthened enabling environment whereby local authorities, institutions, communities, traditional authorities and market players are mobilised to improve climate resilience and water utilisation;

2) improved energy, ground and surface water solutions developed with communities to optimise and diversify water sources;

3) activities that support livelihoods and local economic development opportunities.

The programme will cover a spectrum of rural and rural residential areas in Giyani, working closely with the Mopani District Municipality and the Greater Giyani Local Municipality. Implementation partners include Tsogang Water and Sanitation as the lead on water projects and infrastructure; Association for Water and Rural Development (AWARD) in support of capacity development and stakeholder engagement, University of the Western Cape (UWC) as the water and energy technical partner and the WRC's TTO Enterprise Development arm on social enterprise development supporting local economic development projects.

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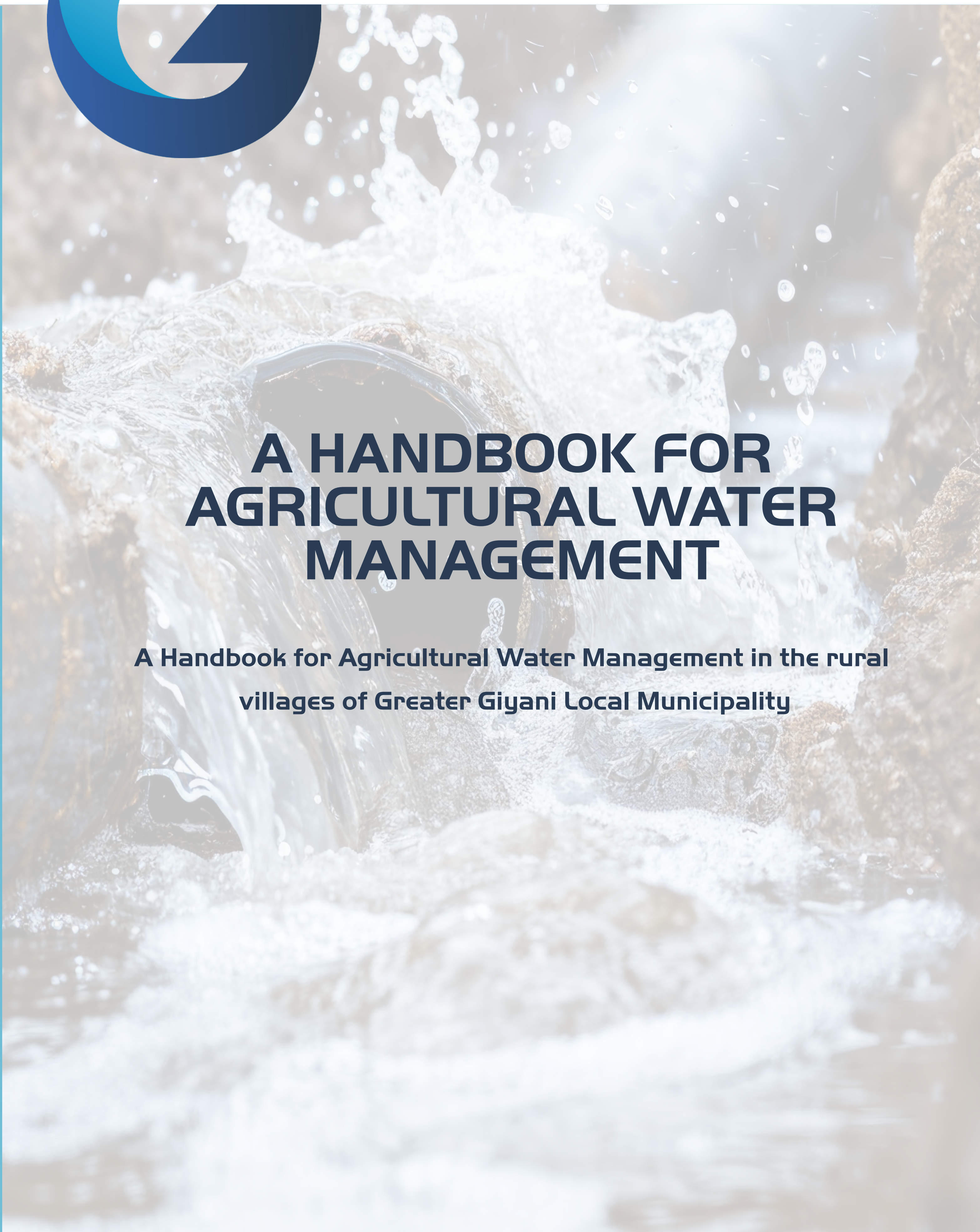

A HANDBOOK FOR AGRICULTURAL WATER MANAGEMENT

A Handbook for Agricultural Water Management in the rural villages of Greater Giyani Local Municipality

ABOUT THIS GUIDELINE

The Agricultural Water Management Skills guideline equips farmers with essential skills for efficient and sustainable water use in agriculture, addressing water scarcity and climate challenges.

Key skills include irrigation management techniques such as drip and sprinkler systems, which minimize waste, and soil moisture monitoring to apply the right amount of water for optimal crop growth. Practices such as crop selection and rotation help align water use with crop needs, while water quality assessment ensures irrigation water is safe. Rainwater harvesting, conservation practices such as mulching and no-till farming, and efficient storage and distribution systems further reduce dependency on fresh-water sources. Proper equipment and techniques prevent over-irrigation, and awareness of water legislation helps farmers stay compliant. Together, these skills enhance food security, protect the environment, and promote sustainable water use, critical for meeting the needs of a growing population amidst climate challenges.

Who is the guideline for?

This guideline is for farmers, agricultural specialists, and stakeholders aiming to address water scarcity, climate change, and sustainability challenges. It helps optimize water use, enhance resilience, and minimize environmental impacts while maintaining productivity, offering tools to conserve water, comply with regulations, and secure long-term water availability.

What does the guideline contain?

The Agricultural Water Management Skills guideline provides a comprehensive approach to managing water resources sustainably in agriculture. It emphasizes the importance of developing water management skills to address challenges such as water scarcity and climate change. The guideline covers key areas, including crop water use and water productivity, outlining strategies to optimize water use for better yields. It offers adaptive solutions to reduce water usage, with a focus on efficient irrigation methods, improved irrigation management, and tailored crop management techniques.

Additionally, the guideline provides soil management practices to enhance moisture retention and outlines micro-climate regulation strategies to mitigate water loss due to environmental factors. Together, these components equip agricultural professionals with practical skills to conserve water while maintaining productive and resilient farming systems.

How to use the guideline?

To effectively use the agricultural water management skills guideline, farmers and agricultural professionals should begin by familiarizing themselves with its core components, which include the importance of water management skills, crop water use, and water productivity. They can then implement adaptive solutions tailored to their specific farming context to reduce agricultural water usage. This involves selecting appropriate irrigation methods, enhancing irrigation management practices, and optimizing crop management techniques that align with water availability.

Additionally, practitioners should focus on improving soil management to enhance moisture retention and apply micro-climate regulation strategies to mitigate water loss. By applying these guidelines, farmers can develop a comprehensive water management plan that maximizes water efficiency, promotes sustainable practices, and ultimately supports the long-term viability of their agricultural operations.

INTRODUCTION

AGRICULTURAL WATER MANAGEMENT

Agricultural water skills, also known as agricultural water management, are essential techniques and practices that revolve around the responsible and efficient use of water resources in the field of agriculture. Water is a finite and increasingly scarce resource, making it imperative for agricultural professionals to develop and apply skills that optimize its use for crop production and animal husbandry. These skills encompass a wide range of knowledge and techniques, including:

1. Irrigation Management
Efficient irrigation techniques, such as drip irrigation, sprinkler systems, and furrow irrigation, are crucial for delivering water to crops while minimizing wastage.

2. Soil Moisture Monitoring
Monitoring and assessing soil moisture levels help farmers determine when and how much water to apply to maintain optimal growing conditions for crops.

3. Crop Selection and Rotation
Matching crops to their water requirements and implementing crop rotation strategies can help maximize water efficiency.

4. Water Quality Assessment
Ensuring that the water used for irrigation or livestock is of suitable quality, free from contaminants, and suitable for its intended purpose.

5. Rainwater Harvesting
Collecting and storing rainwater for agricultural use can supplement conventional water sources and reduce the demand on freshwater supplies.

6. Water Conservation Practices
Implementing conservation practices like no-till farming, mulching, and cover cropping can reduce water evaporation, runoff, and erosion.

7. Water Storage and Distribution
Developing and maintaining efficient water storage facilities and distribution systems for agriculture.

8. Efficient Water Application
Using proper equipment and techniques to distribute water evenly and avoid over-irrigation, which can lead to water wastage and soil degradation.

9. Water Legislation and Regulations
Staying informed about local and national water laws and regulations to ensure compliance and sustainable water use.

10. Climate Adaptation
Adapting water management practices to changing climate conditions, which may bring about increased variability in precipitation and temperature.

Agricultural water skills are crucial in ensuring food security, reducing the environmental impact of agriculture, and mitigating the effects of water scarcity on farming. Farmers and agricultural professionals are increasingly seeking to adopt sustainable water management practices to conserve resources and safeguard the long-term viability of agriculture. These skills play a vital role in addressing the global challenge of feeding a growing population while protecting the environment and ensuring water resources remain available for future generations.

Due to water scarcity, increasing frequency of droughts and extreme events caused by climate change (Figure 1), and the large volumes of water used for irrigation, it is imperative that some measures are implemented to secure efficient agricultural water use.

Drought in agriculture can manifest in two different ways:

AGRICULTURAL DROUGHT

Prolonged insufficiency of available water (soil moisture) during the growth stages of crops, which often results in a reduction in yield.

SOCIO-ECONOMIC DROUGHT

Water demand exceeding the available supply due to inadequate infrastructure.

In an agricultural field, only a portion of the water that is abstracted from boreholes/rivers and applied to crops is consumed productively (Figure 2). Some of it may be lost through surface runoff and deep percolation (it drains in the soil beyond the root system of plants). Some of the water is consumed beneficially (transpiration that contributes to plant growth and yield) and some of it is consumed non-beneficially (evaporation from the soil). To make agricultural water use more efficient, we have to minimize runoff, deep percolation and non beneficial water consumption and maximize beneficial water consumption.

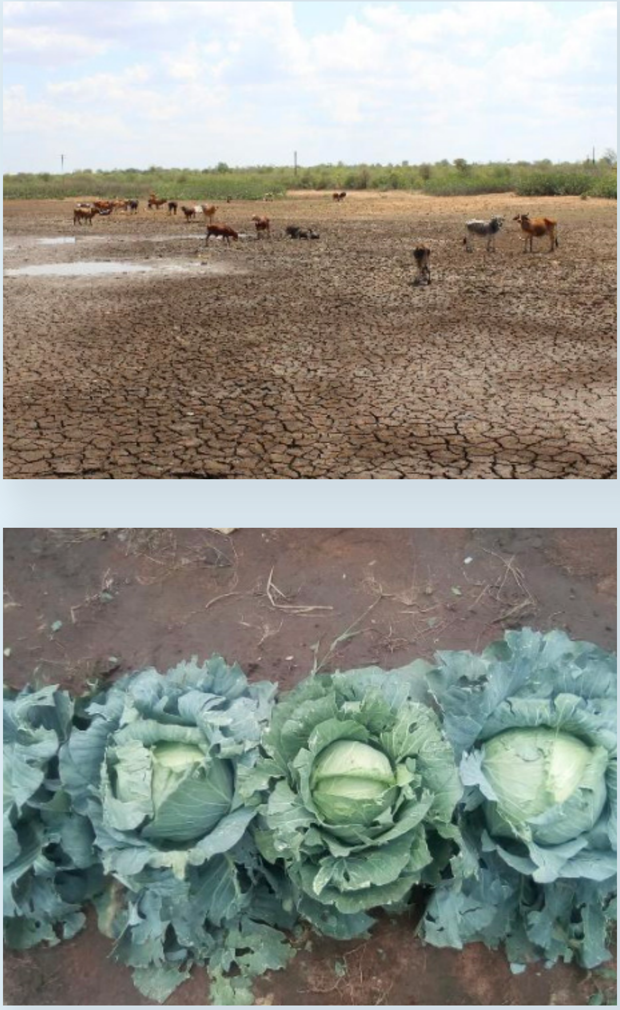

FIGURE 1
On-the-ground effects of extreme weather events due to climatic change: dry dam during the 2016-17 drought (top) and crop damage due to hail storm (bottom)

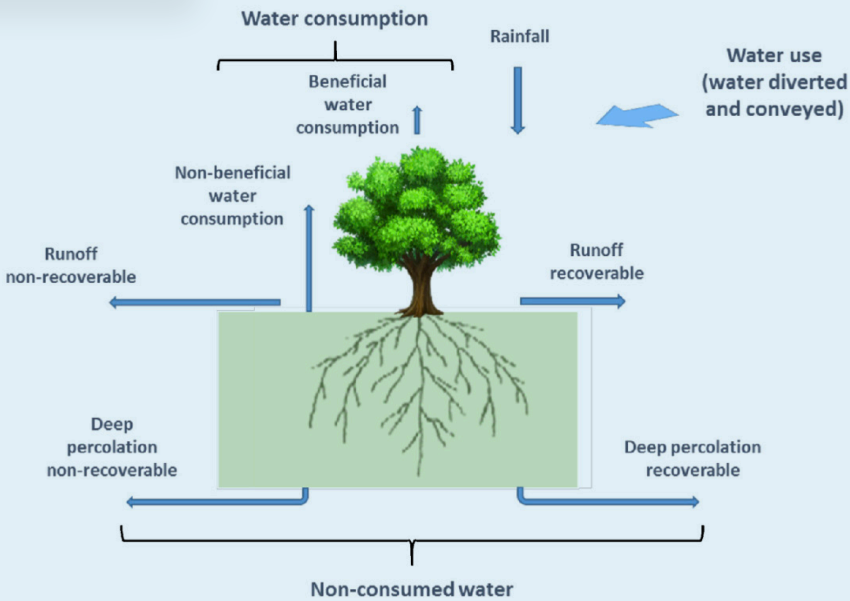

FIGURE 2
Diagram that depicts how water abstracted and applied to the agricultural field is divided into water consumption (beneficial and non-beneficial) and non-consumed water (lost through runoff and deep percolation) (Jovanovic et al., 2020)

CROP WATER USE & WATER PRODUCTIVITY

In order to improve agricultural water use efficiency on small-holder farms, first we have to explain what efficiency means.

Irrigation water use efficiency (WUE) in %
WUE = Water consumed for the intended use.

Water abstracted.

If the system is 100% efficient, all water abstracted from the borehole/river will be delivered for the intended use of irrigating the crops. However, this is very unlikely because some water gets lost along the way of the distribution and storage system (Figure 3). Sometimes more than half of the water is lost through:

- Evaporation from storage tanks/dams
- Linear losses along canals and pipelines
- Leakages of pipes and fittings

Water losses can also occur on the crop field, depending on the irrigation method (Figure 4). The estimated efficiency of irrigation methods are:

- Drip-irrigation (90%)
- Sprinkler and pivot irrigation (80%)
- Flood and furrow irrigation (60%)

The most efficient irrigation method is known to be drip-irrigation. Its efficiency is 90%, if it is well-managed; 10% of the water may be lost due to poor distribution uniformity (when drip laterals are too long) or clogging of drippers (Figure 5).

The efficiency of overhead irrigation (sprinklers or centre pivots) is less, about 80%, because some water gets lost through evaporation and wind drift.

The efficiency is the lowest for flood and furrow irrigation (60%) due to evaporation of water from furrows. In addition, some water gets lost through deep percolation due to uneven distribution along the furrow because the beginning of the furrow always receives more water than the end of the furrow.

FIGURE 3
Water losses can occur through evaporation from dams/tanks, from canals (top) and water leakages (bottom)

FIGURE 4

Irrigation methods: drip-irrigation (top, efficiency 90%), overhead irrigation with centre pivots (middle, efficiency 80%) and surface irrigation with furrows (bottom, efficiency 60%)

FIGURE 5

Clogged drippers cause inefficient irrigation. Clogging and scaling may be caused by precipitates, for example carbonates from hard water

Because water is scarce, it is common to represent agricultural water use in terms of productivity (how much yield we can obtain per m3 of water used). We can then calculated biophysical crop productivity as:

• Crop water productivity (kg m-3)
CWP= kg yield producedm3 of water used

• Farmers are even more interested in income generated. We can then calculate productivity as:

• Economic water productivity (ZAR m-3)
EWP= Profit generatedm3 of water used

On intensive small-holder farms where water is scarce, energy is expensive, markets are uncertain and land is limited, productivity plays an important role to obtain more crop and income per drop of water from less land. It is therefore very important to increase the water use efficiency and water productivity.

REDUCE AGRICULTURAL WATER USAGE

There are many solution and interventions to reduce water use in agriculture or to improve water use efficiency and productivity:

Solutions fit to different irrigation methods:

•Flood
- Land preparation and flow management
- Alternate furrows

• Sprinkler and pivot
- Improving distribution uniformity
- Controlling wind effects

•Drip
- Improving water application and uniformity
- Double drip lines
- Subsurface drip irrigation
- Self-compensating pressure emitters
- Use of appropriate filters and flushing

Irrigation management
•Irrigation scheduling
•Deficit irrigation
•Pulse irrigation

Reuse of wastewater

Plant conditioners
•Anti-transpirants
•Bio-stimulants
•Plant growth regulators

Soil management
•Mulching and crop residues
•Soil management and amendments
- No-tillage with crop residues
- In-field water harvesting
- Soil additives, conditioners, biochar

Micro-climate regulation
•Sheltered cultivation
- Greenhouses, hydroponics, shade-nets
•Wind shields and wind breaks

Crop management
Crop selection and diversification
Under-utilized indigenous species
Shifting of planting date
Optimizing nutrients supply
Increasing plant density and canopy size
Inter-cropping
Integrated pest management

IRRIGATION METHODS

FLOOD IRRIGATION

In flood irrigation, water is applied to the land surface from where it infiltrates into the soil and crop root zone. Some evaporation losses are inevitable because applied water ponds on the land surface before infiltrating into the soil.

Land levelling for basins and furrow irrigation is fundamental for efficient flood irrigation. Flood irrigation efficiency can be improved when levelling is precise, inflow rates are high but non-erosive, and discharge applications are well controlled. Larger irrigation volumes are usually applied at lower frequency compared to other irrigation methods because of operational requirements.

This may result in high deep percolation when the soil has high infiltration rates and distribution uniformity is uneven. Evaporation of water from the soil may be low as the land surface is wetted less frequently compared to other irrigation methods. However, this may increase the risk of crop water stress and reduction in yield when the evaporative demand of the atmosphere is very high (hot and dry days). The recommended frequency of irrigation wettings is orientatively every 5-7 days in peak season. However, this depends on the storage capacity of the soil, the fraction of ground shadowed by the canopy, the crop density and growth stage.

Furrow irrigation is the most common amongst flood irrigation methods on small-holder farms, in particular for row crops such as maize or vegetables (Figure 6). Alternate furrow irrigation (irrigating every second furrow in row crops) may reduce water use with little reduction in yield compared to conventional furrow irrigation.

The general trend is to replace surface irrigation with other more water efficient methods, especially drip-irrigation supported by strong markets of equipment.

SPRINKLER (OR CENETR PIVOT) IRRIGATION

Sprinkler (or centre pivot) irrigation is referred to as overhead irrigation because water is applied from the top to mimic rainfall. Improving water use efficiency can be obtained in the following ways:

- **Improve water infiltration and reduce runoff.**
Sprinklers perform better when the soil infiltration is high. Water application rates must be less than the infiltration rates of the soil to minimize runoff, in other words apply less water to allow the soil to absorb it.

- **Reduce losses due to wind drift.**
Sprinklers perform better when wind is low. Selecting the right sprinkler nozzles is fundamental to reduce evaporation of water droplets. Wind drift may be larger when drops are small, when the canopy cover is small and when sprinkler risers are high.

- **Reduce losses due to evaporation.**
As water is applied to wet the entire land, evaporative losses can be substantial. Water losses occur through evaporation from soil and plant canopy. It is difficult to quantify them; they mainly depend on wind speed and drift, the evaporative demand of the atmosphere, canopy cover, size and coarseness of irrigation drops. In order to reduce losses by evaporation, avoid sprinklers and pressures producing small droplets, avoid irrigation during windy and hot periods of the day (i.e. during daytime) and reduce sprinkler height above the plants. It was found that irrigating by night largely reduces the water losses because of less wind drift and negligible evaporation during the night.

- **Improve distribution uniformity.**
This is another major practice to maximize water use efficiency in overhead irrigation. A proper design of sprinkler nozzles, sprinkler sizes, their spacing, flow rates, water application depths and diameters of piping are fundamental in order to improve distribution uniformity and reduce water losses.

MICRO-IRRIGATION

Micro-irrigation methods include high-tech methods such as drip-irrigation, micro-sprinklers and micro-sprayers (micro-jets), bubblers and subsurface drip irrigation. They require large capital and maintenance investment. These low-pressure irrigation methods consist in wetting a limited portion of the ground targeting the crop root zone. This improves timeliness of irrigation scheduling and reduces soil evaporation. Micro-irrigation is the most water efficient irrigation method.

Water use efficiency can be improved through:
Improve water application and distribution uniformity.

This can be done by properly designing the system and it results in less water use and less costs of investment.

Possible options are:
- Using a single drip line with short dripper spacing for a double row crop when row spacing is small
- Double drip line for each row (e.g. tree rows)
- Micro-sprayers in high infiltration soils (sandy), drippers in low infiltration soils (clay)
- Shorter dripper spacing in high infiltration soils
- Subsurface drip irrigation
- Pressure regulators in large and sloping areas
- Self-compensating drippers in long and sloping laterals. These are recommended for laterals longer than 50 m

Improve irrigation management.

Possible options are:
- Using more frequent and shorter irrigations with drippers and micro-jets
- Using appropriate filters and locations for filters; regular maintenance and back-wash of filters
- De-clogging dripper blockages by tapping them, or by using chemical flushing
- Automation and controllers, although this increases the capital costs

Micro-irrigation with drippers and micro-sprayers is the most common (Figure 7). The benefits of drip irrigation compared to the more traditional methods (surface and sprinkler irrigation) include reduced water use, better control over water losses, less labour, reduced energy consumption and pumping costs, and improved management of water, fertilization (fertigation) and pesticides.

Fertigation consists in mixing irrigation water with precise, small quantities of fertilizer that dissolves in the water. Fertigation is a very common practice with drip irrigation and it allows to supply fertilizer to the crops throughout the season or at times when plants need it the most.

FIGURE 7
Drip-irrigation (top) and micro-sprayer irrigation (bottom)

Despite advantages, managing drip or micro-spray irrigation systems is very demanding, so they are recommended for high-value crops. They are strongly recommended where water resources are limited because of the high water use efficiency. They are especially recommended for tree crops that have a well-developed root system, and the wetted area is in the shade so that soil evaporation is reduced. They were also found to be advantageous in irrigation with saline water because frequent irrigations wash salts out of the root zone and direct contact of saline water with the leaves is avoided (wetting of leaves may cause toxic effects). Micro-sprinklers and micro-sprayers have a wider wetting pattern than drip-irrigation and they may be more affected by wind.

IRRIGATION MANAGEMENT

IRRIGATION SCHEDULING

The goal of irrigation scheduling is to decide when is the right time to irrigate and how much to irrigate. There are numerous methods to schedule irrigations. On small-holder farms, the most common method, but also the most uncertain, is visual inspection of the crop or the "look and feel" method (feeling the moisture of the soil through the fingers). In practice, there are many more scientific methods that can be used for irrigation scheduling. These are based on measurements of soil, plant and atmosphere.

Measurements of soil water content can be done with many devices that are available on the market: tensiometers, neutron probes, electrical resistance probes (gypsum blocks) etc. An example of a portable instrument for measurement of soil water content is shown in Figure 8. It is the HydroSense time domain reflectometry probe. The HydroSense probe has two rods that are inserted in the soil where the root system occurs. The reading of soil water content is almost instantaneous at the press of a button. The irrigation requirement in millimetres is calculated as:

• Irrigation requirement=field capacity-measured soil water content x root depth

• Field capacity depends on the type of soil and it can be determined through soil analysis.

• Root depth can be measured by digging a hole to observe how deep are the plant roots (Figure 9).

• Millimetres of irrigation requirement are multiplied by 10 to convert into m3/ha.

Due to the high cost of this device, consultants can be engaged to use the probe and provide advisory services to small-holder farmers, or likewise officials of the Department of Agriculture. The irrigator needs to ensure that the soil water content within a cropped field keeps between field capacity (upper level) and an allowable depletion level (lower level) that depends on soil texture and crop tolerance to drought. Field capacity and the allowable depletion level can be determined by soil analysis. This advisory role can also be filled by consultants or officials providing services to many farmers at a time.

Plant measurements are generally specialized measurements done for scientific research to study the behaviour of plants under water stress.

Atmospheric (weather) measurements can help the irrigators to calculate evapotranspiration and crop water requirements. Apps have been developed that can provide small-holder farmers with information on when and how much to irrigate based on weather data.

FIGURE 8
HydroSense probe (left). Readings of soil water content are taken by inserting the rods in the soil root zone (above)

FIGURE 9
Root depth can be measured by digging a hole to observe how deep are the plant's roots.

DEFICIT IRRIGATION

In some instances, it is beneficial to reduce irrigation in order to obtain a better quality yield and more income. By reducing irrigation and inducing some plant water stress, vegetative growth (foliage) is reduced, but the yield may improve in quality. This strategy is commonly practiced for some fruit trees and it is called deficit irrigation. Deficit irrigation is recommended in areas that are water-scarce because it saves water, however one has to be aware of the risks of losing some yield. Deficit irrigation is best practiced during crop stages when plants are less sensitive to water stress, for example during the stage of vegetative (foliage) growth. It is called regulated deficit irrigation. It should not be practiced during growth stages when crops are sensitive to water stress. Most crop are sensitive to water stress especially during flowering, fruit setting and fruit growth. During these stages, irrigations should be full.

IRRIGATION COOLING

The occurrence of heat waves is a realistic challenge and their frequency may increase in future due to the effects of climate change. Heat waves can be controlled by applying small amounts of water through short-cycle spray irrigations or by misting sprayers, especially in the early afternoon hours of sunny and hot days. This has a cooling effect, it reduces air temperature and heat shocks to the plants. It can also be used to control cold and frost effects. Irrigation cooling does not replace the normal irrigation schedule; it represents additional water used and it requires installing sprayers, which increases the cost.

CROP MANAGEMENT

Crop management covers a variety of practices. One of them is to choose crops that are better adapted to drought. In areas with limited water availability, crop diversification and use of alternative (emerging, under-utilized, indigenous) crops may play an important role if the markets are favourable.

Fallowing, shifting planting dates and relocating crops and cropping systems can be a crop management option.

Plant density and canopy size also affect the utilization of water and fertilizer. Water use is reduced when supply of nutrients (fertilization) is limited because of smaller plant growth and canopy size. Reducing stand density makes more resources (water, nutrients) available to individual plants, in particular under rainfed agriculture, but it may increase evaporation from the soil and, sometimes, surface runoff. In general, drier conditions are more suited to lower planting density.

Inter-cropping and agro-forestry systems are popular practices to optimize the use of resources (water, nutrients, land and solar radiation energy).

Integrated pest management, that is based on biological control of pests and avoidance of chemical pesticides, strengthens plant health, improves soil fertility and this will also affect beneficially water use.

Reuse of domestic wastewater for agriculture can free up some water for other uses. Domestic wastewater quality is favourable to agriculture because it contains residual nutrients (nitrogen and phosphorus) and it can reduce the need for fertilization. Wastewater should be reused according to guidelines to prevent microbiological contamination and epidemics, especially when leafy vegetables are grown for fresh consumption.

Recent technologies have been researched and developed that make use of plant conditioners: **anti-transpirants, bio-stimulants and plant growth regulators.**

Anti-transpirants are chemicals and compounds that, when sprayed on the leaves, form a protective barrier layer that reduces transpiration. They can be emulsions of wax, latex or plastic, and polymers. They can also be reflective materials, such as kaolin or calcium carbonate, to increase reflection of solar radiation and reduce water use. Other compounds are metabolic inhibitors (ABA, acetyl salicylic acid, fulvic acids, chitosan) that close stomata on the leaves and reduce transpiration of plants.

Plant bio-stimulants are any substance or microorganism applied to plants to enhance nutrition efficiency, stress tolerance and/or crop quality traits. These can be: humic and fulvic acids, protein hydrolysates, seaweed extracts, silicon, chitosan, inorganic compounds (Al, Co, Na, Se and Si), strobilurin, beneficial fungi and plant growth promoting bacteria.

Plant growth regulators include both plant hormones, also called natural plant growth regulators or phytohormones, and chemicals manufactured in the laboratory and given artificially to the plants. These substances are used to control plant development, improve production, and therefore they can have beneficial effects on water use.

SOIL MANAGEMENT

Many soil management practices exist that affect water use. These are especially applied to the top soil, which is the most dynamic soil layer.

MULCHING

Mulching is an old practice of covering the soil surface to reduce surface runoff and soil evaporation, improve crop growth, regulate soil temperature, suppress weeds and improve soil health. Different materials can be used for mulching: bark chips, straw, grass or other plant material, stones or plastic sheets, and humic substances.

Organic mulches and crop residues not only reduce soil evaporation, but they also improve infiltration and soil water storage and retention, in addition to incorporating organic matter in the soil (Figure 10). Plastic mulches are also available on the market, some of them made of bio-degradable material so that they don't need to be removed and disposed after harvest. Sprayable bio-degradable polymer coatings are being researched. Mulching is often used in combination with other practices, such as deficit irrigation, tillage and organic manure, to get optimal results in terms of reducing water use.

FIGURE10
Mulching with residual plant material.

FIGURE 11
Implement for conservation tillage. The depth of tillage is kept to a minimum when planting.

SOIL TILLAGE

Conservation tillage or no-tillage is practiced to improve soil water infiltration capacity and reduce soil evaporation through no-tillage or minimum tillage with specialized agricultural implements to minimize disturbance to the top soil (Figure 11). The benefits of conservation agriculture materialize mainly in soils with high water holding capacity, under intensive cropping with increased nutrient availability, and after many years. The disadvantages are mainly the increased risk of water losses through deep percolation, especially in soils with low water holding capacity and with relatively low nutrient availability. Conservation tillage is often used in combination with a mulch of crop residues on the soil surface. It can be a long-term sustainable practice in dryland agriculture in combination with correct fertilization rates.

IN-FIELD RAINWATER HARVESTING

In-field water harvesting techniques consist in capturing and augmenting water in the soil by channelling even small rainfall of low intensity into planting pits, contour trenches, furrows and terraces (Figure 12). This practice can improve crop yields, in particular on rainfed small-holder farms. Land preparation for in-field water harvesting is often used in combination with other practices, such as mulching with organic material and plastic.

SOIL ADDITIVES AND CONDITIONERS

Soil additives and conditioners represent old agricultural practices that improve soil water retention properties and fertility. For example, organic manure is a soil additive/ conditioner. More recently, new materials have been introduced.

Biochar is a soil conditioner derived from organic material by pyrolysis. Pyrolysis consists in heating wood at very high temperature without oxygen in pre-prepared furnaces. The properties of biochar are variable depending on the parent material and manufacturing process. Addition of biochar to the soil increases porosity, soil water and nutrient retention capacity, soil structure and stability of aggregates (Figure 14). It also affects soil microbiology. Similar effects were reported for other soil amendments such as humic substances and compost, gypsum, organic waste material, organic polymers, coal fly ash and zeolites. Other materials to increase soil water retention include superabsorbent hydrogels that have high swelling capacity to absorb water and nutrients for slow release

FIGURE 12
In-field rainwater harvesting by planting rows in furrows.

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FIGURE 13
Biochar application to an agricultural field.

MICRO-CLIMATE REGULATION

SHELTERED CULTIVATION

Alteration of climatic conditions such as solar radiation, temperature, wind, humidity can be done by sheltering crops, for example in greenhouses, to reduce water losses and improve conditions for crop growth and agricultural water use efficiency. Cultivation in greenhouses serves to protect crops from radiation (sunburn of fruits), extreme weather (e.g. wind, hail), pests and to regulate micro-climate. The micro-climate inside greenhouses is very complex and different designs and materials add to the complexity (e.g. open-wall screen, glasshouses, small tunnels, screen material, mesh, colour etc.). Differences to open air are enormous in terms of solar radiation, air temperature, relative humidity and wind. Water use of crops is generally lower in greenhouses than open air. Under greenhouses, the concentration of CO2 (the raw material for plants) and humidity are expected to increase. It was found that humidification in a greenhouse with fog sprayers contributes to increased yields and reduced water needs. Intensive cultivation under greenhouses or shade nets, such as in hydroponics (Figure 14), also facilitates the supply of water and nutrients (or nutrient solutions). Hydroponics are installed to grow crops in vertical shelves that reduce greatly the need for land (Figure 14).

Windbreaks and wind shields such as trees can mitigate extreme winds that cause soil erosion, sand-blasting, crop mechanical damage and lodging, and they may affect micro-climatic variables such as soil radiation (through shading), temperature, humidity, heat and evaporation. This may result in changes in water and nutrient needs. Trees in agroforestry systems perform a similar role as windbreaks. The effects of tree windbreaks depend on their roughness, height, orientation, canopy density and distance from the cropped fields. Warmer, more humid and less windy conditions usually occur in areas sheltered from wind. Lower wind speed and more humid conditions reduce water needs. Higher yields can be expected in sheltered areas, except when crops compete for resources with the windbreak plants (e.g. shaded areas affect crop growth, crop's root systems may compete for water and nutrients with windbreak plants etc.).

FIGURE 14
Cultivation under shade nets in hydroponics. Growing plants in vertical shelves reduces the need for land, energy and it improves the supply of water and nutrients in furrows.

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