# A TRAINING MANUAL ON WATER USE EFFICIENCY IN AGRICULTURE

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Caribbean WaterNet
Cap-Net
UWI St. Augustine Campus
Faculty of Food and Agriculture
Global Water Partnership Caribbean

# A Training Manual on Water Use Efficiency in Agriculture

The drafting of this training manual was coordinated by Caribbean WaterNet (Cap-Net UNDP), The Faculty of Food and Agriculture of The University of the West Indies (UWI) St. Augustine Campus in partnership with the Global Water Partnership-Caribbean (GWP-C).

The manual was written by Dr. Gaius Eudoxie of The Faculty of Food and Agriculture, UWI St. Augustine (Lead Author), Bryan Smith, Jaye Thompson and Joseph Lucas. It was edited by Dr. Ronald Roopnarine (Faculty of Food and Agriculture, UWI St. Augustine & Caribbean WaterNet) and Gabrielle Lee Look (GWP-C). A Training Manual for Water Use Efficiency in the Agriculture Sector developed in 2011 by GWP-C, was used as a reference document for this manual.



The training manual can be downloaded from the following websites:

**www.cap-net.org**
**www.gwp-caribbean.org**
**www.sta.uwi.edu/ffa**



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# Foreword

Caribbean WaterNet (Cap-Net UNDP), The Faculty of Food and Agriculture of The University of the West Indies (UWI) St. Augustine Campus and the Global Water Partnership-Caribbean (GWP-C), have developed this Training Manual on Water Use Efficiency in Agriculture, to build capacity for improved water management and productivity in the sector. The publication builds on the 2011 Training Manual for Water Use Efficiency in the Agriculture Sector, which was developed by GWP-C with the support of Caribbean WaterNet. The Training Manual aims to:

- Demonstrate the benefits of improved Water Use Efficiency (WUE).
- Provide examples of demand calculation models for WUE in the agriculture sector.
- Demonstrate methodologies for assessing the economic benefits of improved WUE.
- Explain the potential impacts of climate change on water resources use in the sector.
- Initiate discussions at management levels that will make provisions for the adaptation of WUE measures.
- Foster discussions on retrofitting the industry with WUE devices.

The lead author of this manual is Dr. Gaius Eudoxie (Faculty of Food and Agriculture, UWI St. Augustine), with co-authors Bryan Smith, Jaye Thompson and Joseph Lucas. Input for the development of the training manual was provided by Dr. Ronald Roopnarine (Faculty of Food and Agriculture & Caribbean WaterNet) and Simone Lewis (GWP-C). This knowledge product will be used as a training tool throughout the Caribbean and serves as both a participant handbook and facilitator's guide.

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# MODULE 1

## Water Resources, Climate Change and Use Efficiency

### Goal

The purpose of this module is to describe the nature and distribution of freshwater resources within the Caribbean, highlighting the supply and demand conflicts and the interaction with climate change. It also introduces basic principles of water use efficiency (WUE) and how it can be used to optimize use of a finite resource.

### Learning Objectives

**At the end of this module, participants are expected to:**

- Describe the main sources of freshwater for agriculture and understand supply and demand constraints.
- Understand the role of climate changes on freshwater resources and agricultural water use efficiency.
- Understand WUE as applied as a technological tool towards sustainable agricultural water use and increased resilience to climate change.
- Distinguish among commonly used efficiency terminologies.
- Calculate WUE using standard relationships and available data.
- List factors affecting WUE and practices that will enhance and increase it.

# Introduction

Freshwater resources represent approximately 2.5 % of global water resources, with an even smaller percentage being readily accessible with current technology. While the amount of water has remained relatively constant over time, the distribution is naturally affected by geography, geology and climate. On a regional scale, large variability exists among member countries with regards to total renewable water resources (TRWR), with a few countries categorized as water scarce (Eudoxie and Wuddivira, 2014). Increasing populations has created greater demand for freshwater resources, coupled with water pollution and climate change, this has resulted in a declining trend in renewable freshwater resources **(Figure 1)** and the potential for water conflicts even where available resources exceed demand. Traditionally, we have been inefficient users of water in many facets of our existence. From domestic, to industrial and agricultural use, efforts have not been directed at increased efficiency of water use as the resource has been mostly available. However, changing climates and lifestyles may result in further increases in water use, placing many countries into water scarcity.

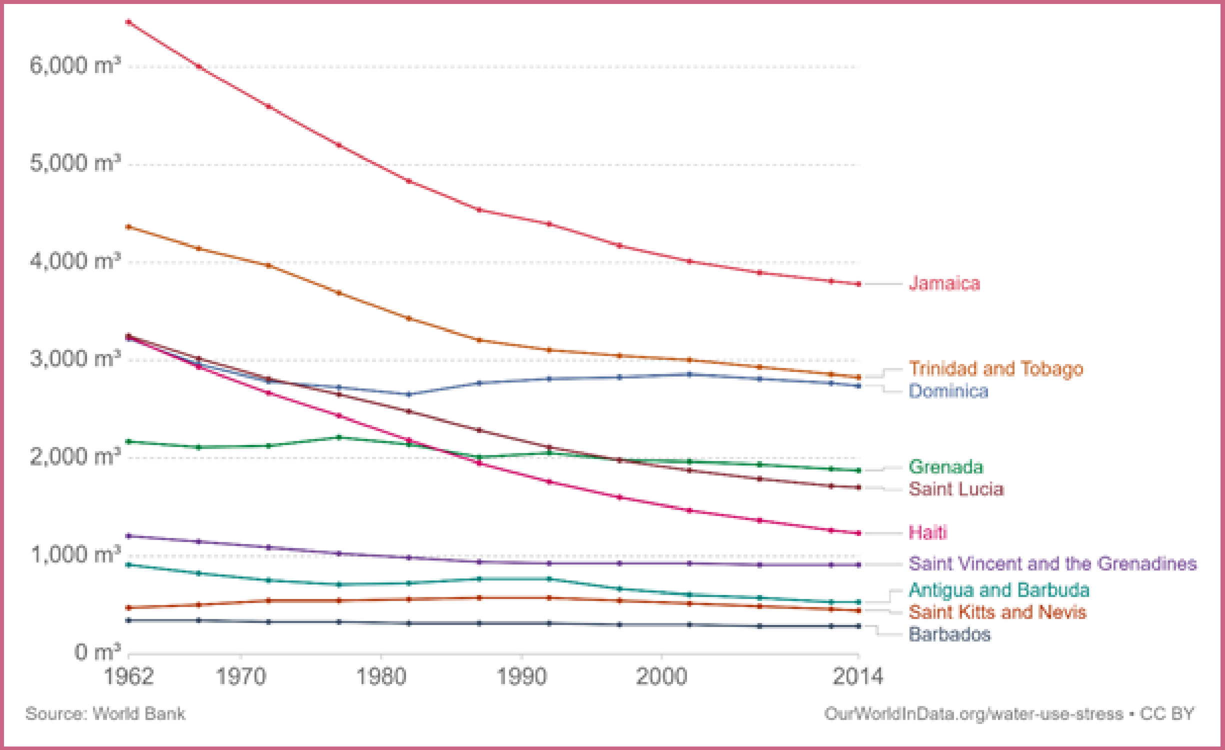


**Figure 1:** Renewable freshwater resources per capita for selected Caribbean countries

## Water Sources and Distribution

Within the region, freshwater resources are restricted to surface and groundwater and desalination. Desalination is particularly important to calcareous countries lacking surface water sources but requires high energy inputs and produces an environmentally concerning by-product. Most countries depend on surface water **(Table 1)** and contain perennial streams and rivers supplemented by reservoirs for storage. Jamaica and Barbados, with significant calcareous geology have a high dependence on groundwater. Where TRWR exceed 2000 mm year-1, water supply satisfies demand.

However, the bimodal distribution of precipitation and limited surface storage capacity produces periods of water stress and reduced water availability. The severity and frequency of water stress and drought conditions have over recent time caught the attention of policy makers particularly the 2009/2010 event (Box 1). As demands for finite freshwater resources increase, their efficient use becomes more important. Greater attention to the agricultural sector in recent time and the desire for increase food production, places emphasis on agricultural water use.

**Table 1:** Main freshwater sources for selected Caribbean Countries

| Countries | Water supply | | |
|---|---|---|---|
| | Surface | Ground | Desalination |
| Antigua | | | XXX |
| Barbados | | XXX | |
| Dominica | XXX | | |
| Grenada | XXX | | |
| Guyana | XXX | | |
| Haiti | XXX | | |
| Jamaica | | XXX | |
| Saint Vincent & the Grenadinesa | XXX | | |
| Saint Lucia | | | |
| Trinidad and Tobago | XXX | | |

XXX signifies the largest source

N.B. All countries practise rainwater harvesting to varying degrees. In Grenada, the dependencies of Carriacou and Petit Martinique are almost 100% reliant on this source. Also, desalination is the main source in the Grenadines islands of St. Vincent and the Grenadines, but on mainland St. Vincent, nearly 100% is surface water.

Source: Global Water Partnership, 2014.

**Box 1:** Impacts of the 2009 to 2010 Drought on Caribbean Countries.
Source: Farrell et al. (2010)

- Between March 2009 and February 2010, low rainfall was mirrored across the majority of the Caribbean to varying degrees, in particular the eastern Caribbean, where rainfall was in the lowest 10% (some as record lows) of recorded totals for February.
- By March 2010, on the island of Dominica, banana production declined by 43% compared to the previous year, resulting in a significant reduction in banana exports and foreign exchange.
- In Trinidad and Tobago, food prices increased 6.9% in March, 6.3% in February and 2.7% in January 2010.
- In Grenada, there was a 150% increase in the amount of bush fires that also had an impact on agricultural production and cultivation with a number of farms being affected.
- In St. Lucia, the only large reservoir was depleted, threatening to run out of water within a short period potentially affecting more than 50% of the population and the majority of the tourism and business community (CEHI and GEF-IWCAM, 2010).

## Water Use in Agriculture

Agriculture competitively consumes > 70% of global freshwater withdrawals and consequently demands prudent attention for sustainably managing these resources. The contribution of agriculture to GDP varies among Caribbean countries but averages below other sectors, except in a few territories. This is also reflected in lower shares of withdrawals **(Figure 2)**. However, the sector remains important to food security and livelihoods and employs a significant amount of the work force, especially in rural communities.

As countries move towards achieving sustainable development, attention is being directed at expanding and investing in the sector. Water management is a critical component of a successful outcome. Agriculture, which inherently implies changes in land use, also indirectly alters water resources through modification in hydrologic regimes and watershed budgets. It also contributes to water quality issues and water pollution, which in turn restricts use. Attempts at sustainable management of freshwater resources must incorporate practices and technologies enabling sustainable land management.

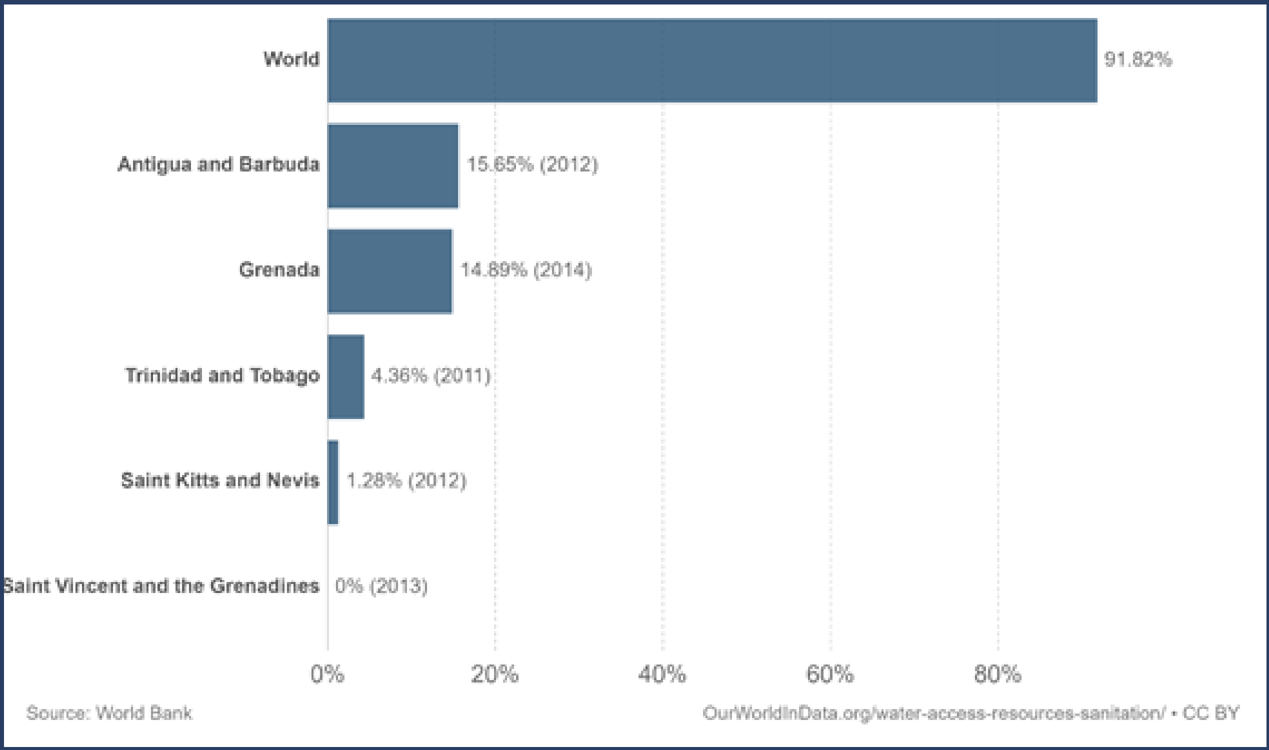


**Figure 2:** Agricultural water as a share of total water withdrawals, 2016 for selected Caribbean countries

## Climate Change and Water Resources

Climate change affects the nature and distribution of freshwater resources as well as water management practices. Changes in the hydrological cycle due to climate change can lead to diverse impacts and risks, and they are conditioned by and interact with non-climatic drivers of change and water management responses (Jiménez Cisneros et al. 2014) **(Figure 3)**.
The fourth assessment report (IPCC, 2007) noted the following pertaining to the potential impact of climate change on freshwater resources:

1. The observed and projected impacts of climate change on freshwater systems and their management are due mainly to increases in temperature and sea level, local changes of precipitation, and changes in the variability of those quantities.
2. Warmer water, more intense precipitation, and longer periods of low flow reduce water quality, with impacts on ecosystems, human health, and reliability and operating costs of water services.
3. The negative impacts of climate change on freshwater systems outweigh its benefits.

Increasing CO2 concentration, increasing temperature and increasing variability on precipitation present challenges in managing agricultural water use. Understanding the impacts at plant and crop (canopy) scales, will foster mechanistic and practical approaches to sustainable use.

As reflected by the low water withdrawals for agriculture in the region, production follows the bimodal precipitation pattern and is mainly constrained to the wet season between June and December. Investment in irrigation infrastructure and technology remains low, partly associated with small scale farming and unavailability of crop water use and evaporative demand data. A new paradigm centered on data driven decision-making is required in response to the changing climate and increasing non-climatic drivers on water resources. Deciphering and validating appropriate technologies for small farms is important for risk resilience.

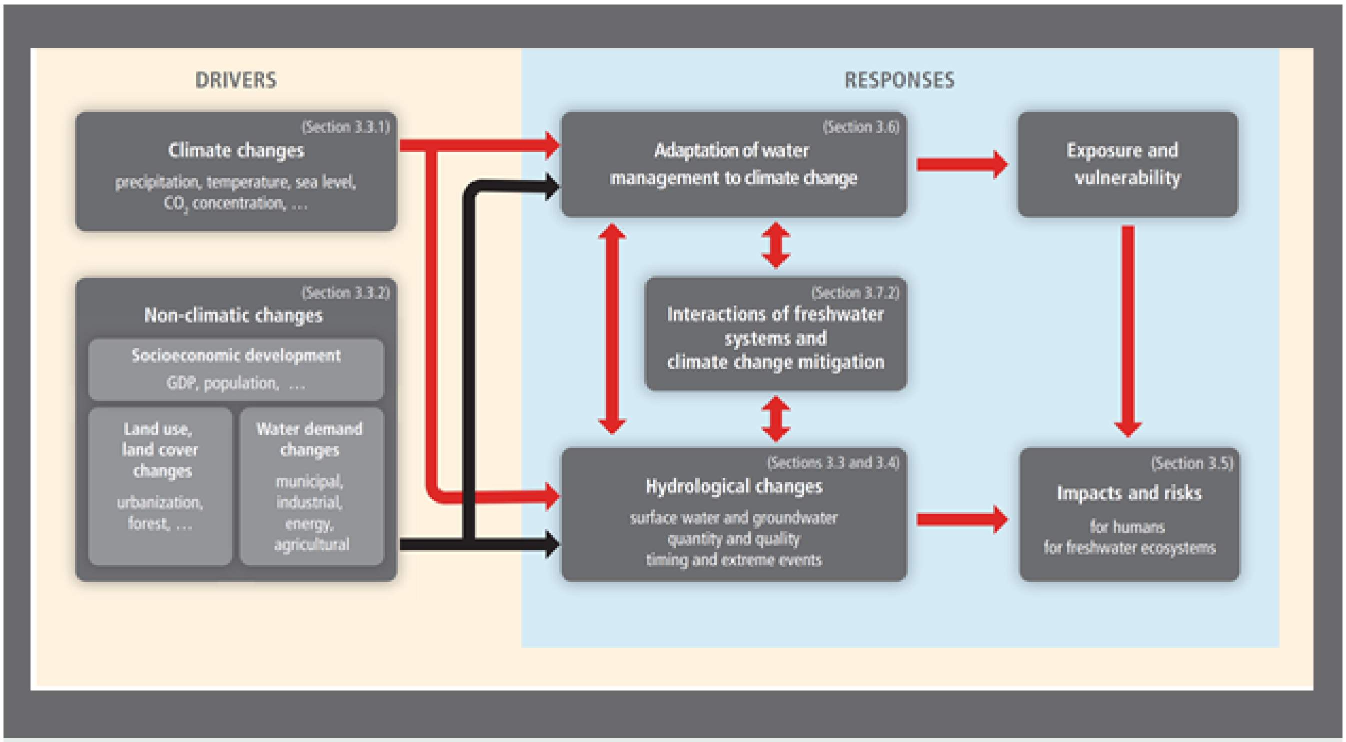


**Figure 3:** Climatic and non-climatic drivers and their impacts on freshwater resources. Source: Jiménez Cisneros et al. 2014

Water management at the farm level is constrained by poor monitoring, low technology use and limited knowledge of agricultural water management. Among the myriad of barriers to increasing production and resilience, efficient use of water is primary. Whereas, access to water may be the most pressing policy issue under agricultural water management, efficient use of the resource and actions to preserve its quality follow close behind. Gerten et al. (2011) postulated that climate change will increase the water demands to produce a given amount of food, irrespective of whether production is rainfed or irrigated. This signals that the proportion of water used for agriculture will increase, with the need for improvements in water use efficiency (WUE).

## Water Use Efficiency

Water use efficiency is an important concept that when applied at farm level can have a notable impact on water use and quality. Agronomically, WUE refers to "biomass (yield) produced per unit of water transpired," which according to **Figure 4**, would increase proportionally with increasing crop water uptake and availability. WUE has also been defined based on irrigation, where efficiency is based on the ratio between effective water use (crop uptake) and actual water withdrawals. When applied in that context, other relationships can be derived to measure the efficiency of the system.

**Box 2:** Terminologies used to express different relationships between agricultural water supply and use

**Water Use Efficiency (WUE)** refers to the ratio of water used in plant metabolism to water lost by the plant transpiration.

**Irrigation Efficiency (IE)** is the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation.

**Application Efficiency (AE)** is a performance criterion that expresses how well an irrigation system performs, when it is operated to deliver a specific amount of water. AE is defined as the ratio of the average water depth applied and the target water depth during an irrigation event.

**Conveyance Efficiency (CE)** is the ratio of the volume of irrigation water delivered by a distribution system to the water introduced into the system.

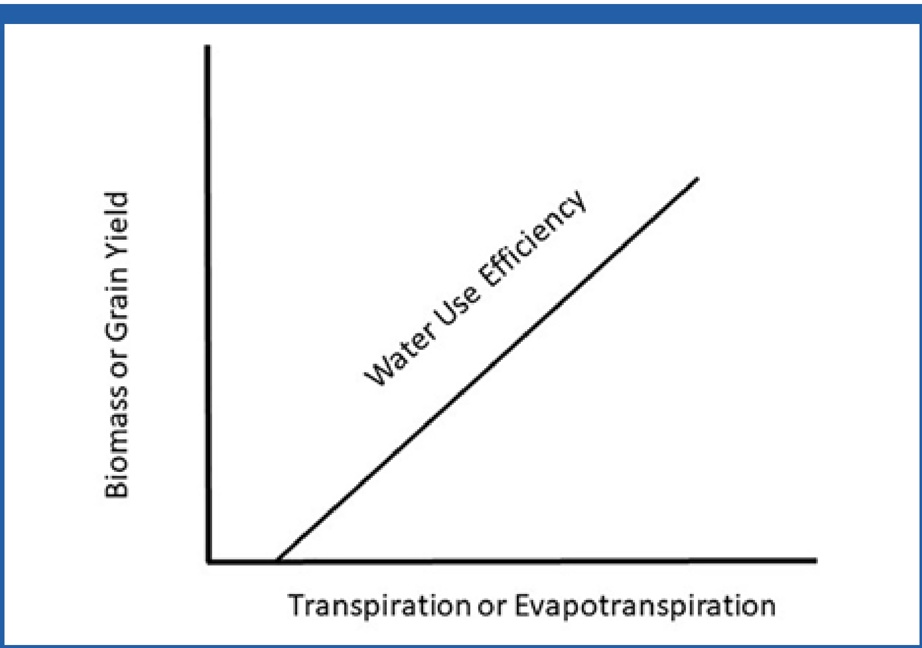


**Figure 4:** Water use efficiency as a function of crop water use relative to biomass (yield). Source: Hatfield and Dold, (2019)

At the plant level WUE is determined by the soil-plant-atmosphere continuum and the transpiration demand placed on the leaves by the prevailing climatic conditions. Climatic variability affecting evapotranspiration are relatively constant throughout the year in the Caribbean, attributing variability in WUE to available soil water, crop growth stage and genetic variance. Predicted increases in surface air temperature will widen the potential difference between plant and atmosphere, resulting in increased transpiration and demand for water. If that is not countered by increase soil water availability (natural or irrigation) WUE will decrease. However, under increase CO2 saturation, plant growth and development is expected to increase, which may buffer water losses from transpiration.

At canopy scale, evaporation is included as a contributing loss process affecting WUE. It is at this level that the understanding of soil conservation, crop husbandry including integrated soil fertility management and irrigation technology can make the biggest impact on WUE. These are among a network of factors (listed below) affecting WUE:

- Climatic conditions (temperature and evaporative potential)
- Soil properties including depth, organic matter and clay contents
- Crop genetic variability
- Irrigation efficiency
- Crop and irrigation management

Nitrogen and phosphorus are both known to have a positive influence on WUE through enhancing root development and root access to an increase soil volume. Grzebisz et al. (2013) stated that adequate potassium fertiliser was important in alleviating short-term moisture stress, increases WUE. Kirkham (2005) reported that the advent of micro-irrigation technology led to the gradual improvement in WUE in Israel, changing a supply driven water content approach to irrigation scheduling, to a demand and more consistent water availability (potential) approach, reducing water losses and plant water stress. Intrinsic soil properties such as clay and organic matter content that are strongly correlated to available soil water, also affect WUE. Increasing soil organic matter increases water holding capacity and proportion of plant available water. Additionally, it improves soil health and contributes to better plant growth and access to a larger soil volume.

Practices including conservation tillage produce similar mechanistic responses by reducing evaporation and improving soil health through organic matter accrual. Ali et al (2017) reported that tied ridging improved WUE and the capability of soil to keep moisture which is reflected in high crop production. This suggests that there is substantial scope for improving irrigation water use efficiency of crops by adoption of conservation tillage. Improving WUE is a climate-smart technological approach useful for adaptation but necessary for sustainability. It proposes increased productivity and income and lower social and environmental costs.

## Measurement of WUE

Mathematically, WUE is the ratio crop dry weight per unit area (DW) to crop evapotranspiration (ET). **Expressed as an equation:** WUE = DW/ET

Depending on the crop and objectives, dry weight can be vegetative, reproductive or both. Typically, similar units are used or both variables; kg/ha dry matter per kg of water transpired, but other expressions are accepted. Kirkham (2005) noted that WUE can also be measured at the leaf level using portable gas analyzers that measure both leaf photosynthetic and transpiration rates. However, agricultural water management requires canopy level and field scale monitoring and interventions.

Reporting of WUE should clarify whether transpiration of evapotranspiration was in the determination, as evaporation can be controlled through soil and crop water conservation (e.g. weeding), which may influence crop available water and use efficiency. Traditionally, DW would be determined by harvesting the crop and allowing it to dry to constant mass at 65-70˚C. This weight would be divided by the amount of water the crop received. Weighing lysimeters have also been used through a water balance approach to estimate WUE. Lysimeters **(Figure 5)** are used to measure percolation beneath the vegetation root zone and water use through evaporative processes from vegetation (Howell, 2005). They can also measure 'net' additions to the soil from precipitation or irrigation.

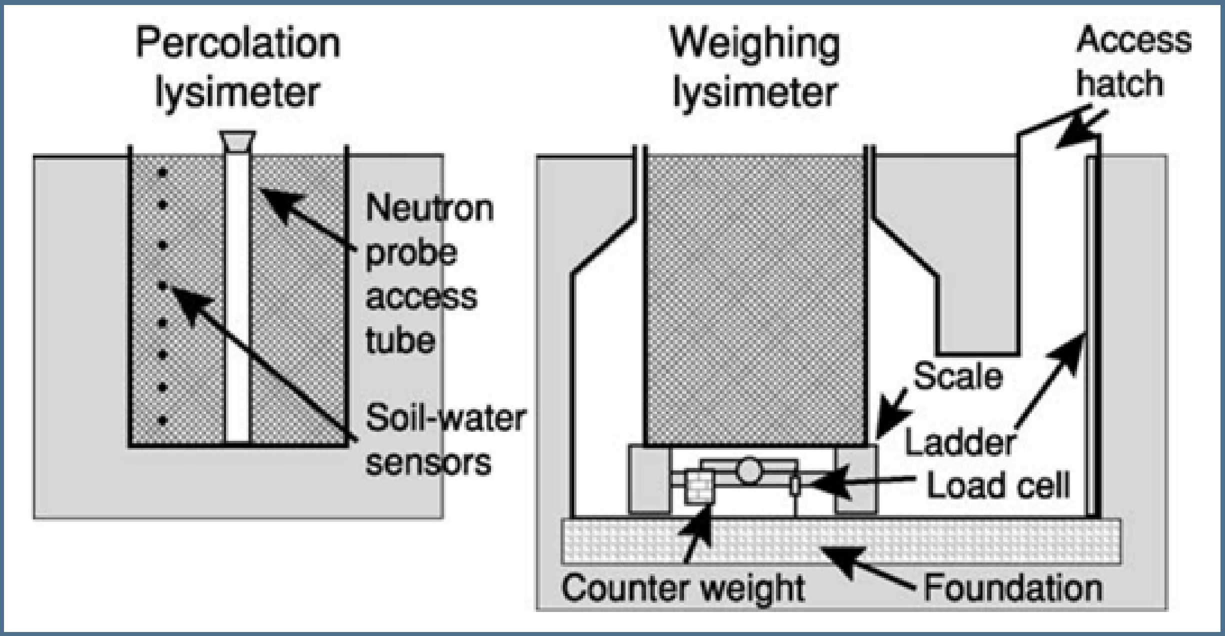


**Figure 5:** Schematic of a lysimeter. Source: Howell, 2005.

# Lessons Learnt

1. Water availability for agriculture varies spatially and temporally among Caribbean SIDS.
2. Climate change impacts affect the quantity and quality of water resources.
3. Competition for freshwater resources require sustainable management.
4. WUE is an effective tool in managing agricultural water use.
5. WUE = DW/ET
6. Climate change trends will have positive and negative impacts on WUE.
7. Climate smart tools and technologies are effective for increasing WUE.

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# MODULE 2

## Crop Water Use

### Goal

This module introduces the soil, plant, atmosphere water continuum and the processes responsible for crop water uptake and use. Additionally, it addresses the factors affecting water use efficiency, particularly climate and the models and tools that can be used to estimate and measure crop water use.

### Learning Objectives

**At the end of this module, participants are expected to:**

- Describe the flow of water through the soil plant atmosphere continuum and elaborate on factors affecting the process.
- Determine and/ or calculate crop water use, using established models and meteorological available data.
- Determine irrigation requirements from soil data and crop water use/ requirements.
- Understand the changing demands for water for various crop families related to growth and development.

# Introduction

Crop water use refers to water that is used by a crop for cooling (transpiration) and growth and development (metabolism). Evapotranspiration (Et) is a good indicator of crop water use, as > 99% of absorbed water is lost through transpiration (Hillel, 1999). Transpiration is the water lost to the atmosphere from small openings on the leaf surfaces, called stomata, whilst evaporation is the water lost from the soil. Principally, crop water use equates to water demand and hence crop water requirements; a part of which may be required from irrigation. The irrigation requirement is thus strongly related to Et and more specifically crop Et. The latter distinction considers the influence of the crop canopy on the microclimate and Et rate.

Crop water use is dynamic and influenced by climate, soil and plant factors through the soil-plant-atmosphere continuum (SPAC). An invisible water potential system from pore spaces in the soil, through vascular tissue in the plant to be lost to an unquenchable atmosphere based on differences in water potential **(Figure 1)**. Change in the water potential across the continuum affect the availability, uptake and loss of water by crops and their overall productivity. The large gradient between the water potential in the leaf and atmosphere particularly in the tropics, places added pressure on crops and increases their water use.

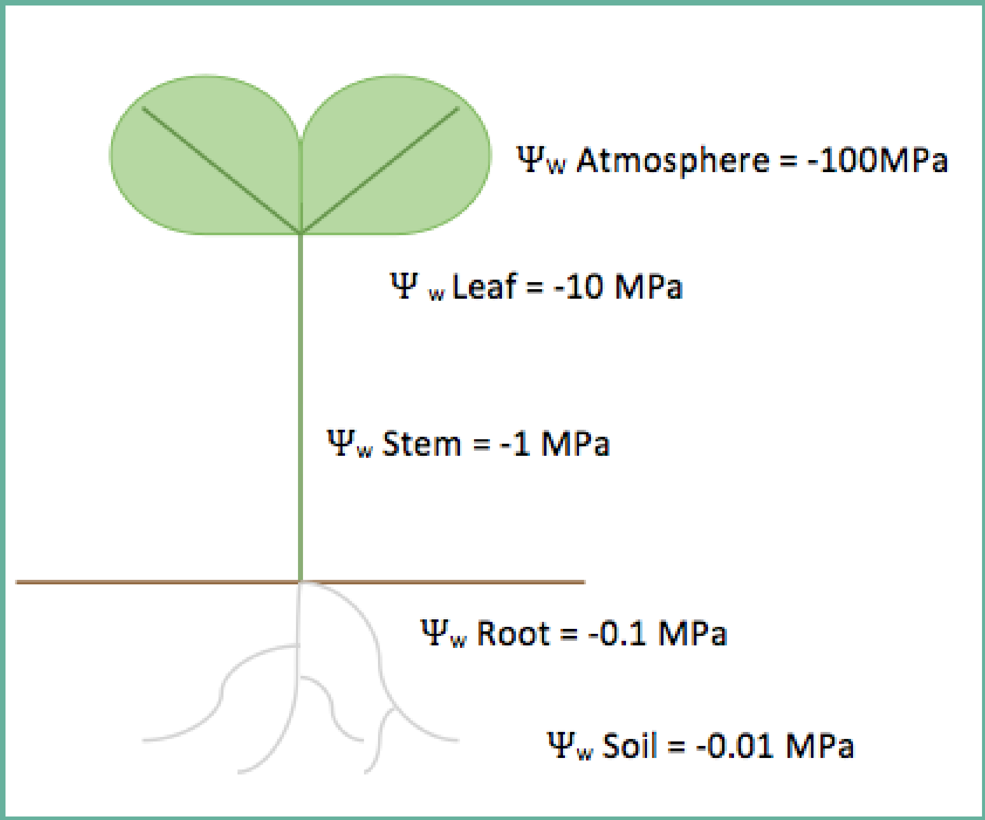



**Figure 1:** Soil plant atmosphere continuum.
Source: https://en.wikipedia.org/wiki/Soil_plant_atmosphere_continuum

Crop water use is also temporarily linked and dependent on crop developmental stage, increasing with growth, peaking at late vegetative into early reproductive and then declining during senescence. This implies that the irrigation requirement varies similarly over crop growth stages, to which attention must be paid in developing schedules. A thorough understanding of crop growth, canopy influences, atmospheric pressures and soil conditions will contribute to improved management of crop water use leading to increased WUE.

## Climate Influence on Crop Water Use

Climatic variables including temperature, humidity, and solar radiation influence crop water demand and loss, as well as soil surface water loss **(Figure 2)**, which has an indirect effect on water availability. Climatic conditions that produce high temperatures and low humidity, as typical of the Caribbean, contribute to high rates of transpiration and evaporation. Under such conditions, water use efficiency can be reduced as most of the water will be lost through evaporation and transpiration. The condition is modified during the wet season where precipitation is greater than Et, supplying the soil with adequate amounts of water to maintain a positive potential balance. Wind, which removes moisture filed air from around the leaf and soil surface, significantly contributes to the sharp potential gradient and high flux between these pools and the atmosphere. Hence as a crop develops and establishes a canopy, the effect reduces. This is also true for water loss via evaporation due to increase canopy cover.

Future climate projections of increasing temperature and CO2 concentration, as well as increased rainfall variability will add complexity to managing crop water use. At the plant level, increasing content of atmospheric CO2 may prompt stomata to remain open to maximize productivity, as the expense of water lost. This is particularly concerning in an atmosphere of elevated temperature, which will widen the potential gradient between leaf and atmosphere and soil and atmosphere facilitating greater water loss via Et.

In periods of low rainfall, crops will be exposed to water stress and supplemental irrigation will be required. Downscaled projections of the Caribbean predict a wetter wet period, with a greater total rainfall amount. However, attributable to fewer but more intense storms. Under this scenario, less soil water is expected due to accelerated runoff and erosion, which might reduce water use efficiency even though precipitation would be greater than the current baseline. The use of appropriate climate-smart technologies is important to mitigate against these future possibilities **(covered in Module 5)**.

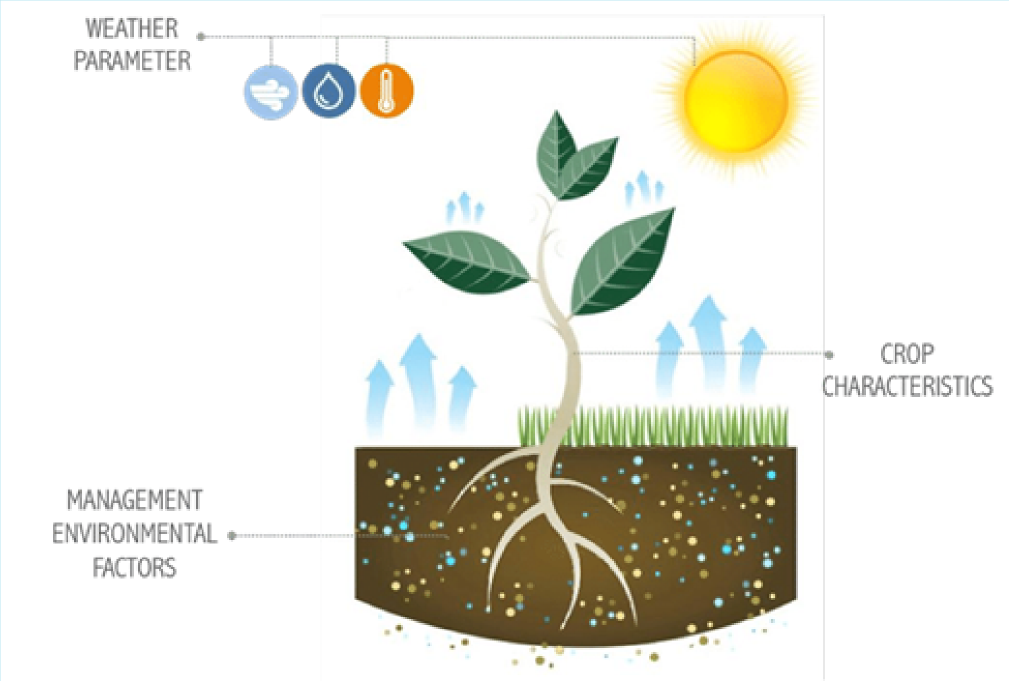



**Figure 2:** Factors affecting evapotranspiration.
Source: DOI:10.13140/RG.2.2.24862.23360 Abdellatif and Valdenebro (2016)

## Soil Influence on Crop Water Use

Although soil is ubiquitous, its role and function in crop production is largely overlooked. Soil is the unconsolidated mineral and/or organic material on the immediate surface of the Earth, that serves as a natural medium for the growth of land plants. In addition to its primary role in supporting crop production, it also provides several ecological services **(Figure 3)**.

A notable secondary function of soil is water regulation and purification. Although soils vary in the capacity to perform this function, they all participate in the hydrological cycle at watershed scale and are an important component of agricultural field water balance.

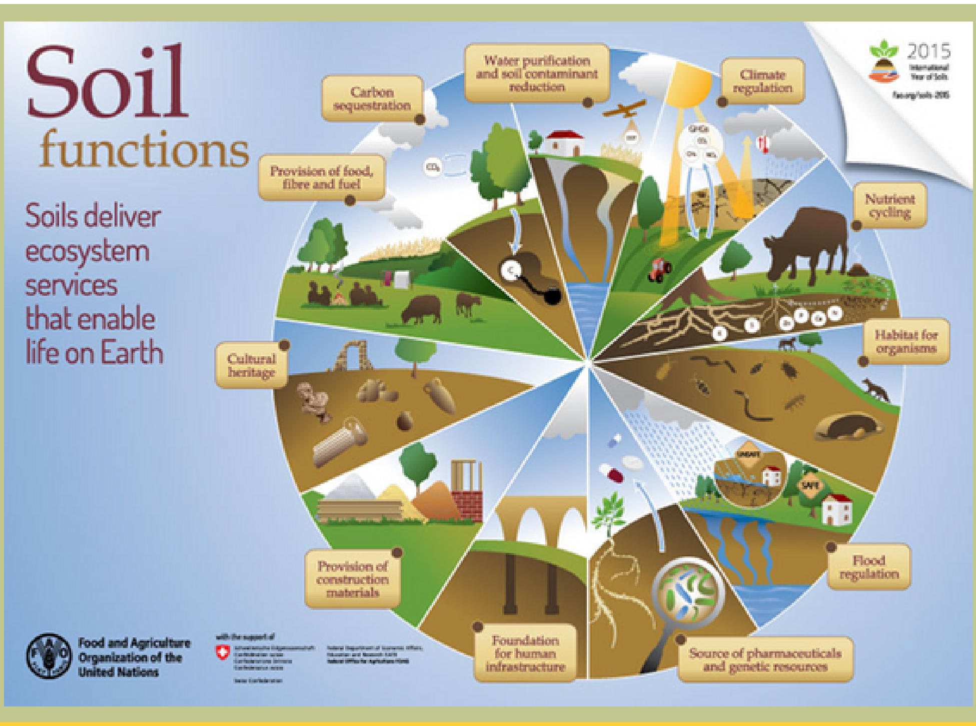
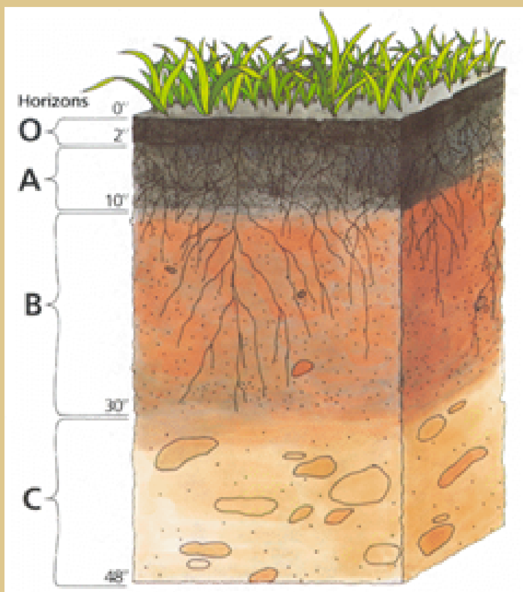



**Figure 3:** Functions of soils. Source: UNFAO

Soils are formed from combinations of:

1. Parent material
2. Topography
3. Climate
4. Organisms and
5. Time **(Figure 4)**

The combinations of these factors together with soil forming process, yield large variability in final soil properties and classification, even at small spatial scales, evident by the large number of unique soil series across all Caribbean countries. Soils show diversity geospatially across the landscape and vertically along the "soil profile." The occurrence of different soils across the landscape with contrasting properties and soil profiles, presents challenges and the need for precision control over water management.




A soil profile is a vertical cross-section of the soil, made of layers running parallel to the surface. These layers may be defined as soil horizons.

A soil horizon is a layer parallel to the soil surface whose physical, chemical and biological characteristics differ from the layers above and beneath. Horizons are defined in many cases by obvious physical features, mainly colour and texture.

Soil scientists use the capital letters O, A, B, C, and E to identify the master horizons, and lowercase letters for distinctions of these horizons. Most soils have three major horizons - the surface horizon (A), the subsoil (B), and the substratum (C). Some soils have an organic horizon (O) on the surface, but this horizon can also be buried. The master horizon, E, is used for subsurface horizons that have a significant loss of minerals (eluviation). Hard bedrock which is not soil, uses the letter R.

**Box 1:** Soil Profile


**Figure 4:** Soil forming factors and processes. Source: UNFAO

Soil texture refers to the composition of the soil in terms of the proportion of small, medium, and large particles (clay, silt, and sand respectively) in a specific soil mass. Texture influences the ease with which soil can be worked, the amount of water and air it holds, and the rate at which water can enter and move through soil. It is a primary property with a significant influence on soil water retention, movement and availability to plants. The soil water budget is largely dependent on texture, with sandy soil having low retentive capacity. This implies that such soils are prone to leaching and free drainage.

Clay soil has large retentive capacity, but much of that water may also be unavailable to plants, as it adheres strongly to the clay particles. Loam soils possessing similar amounts of the three particles have the largest pool of available water **(Figure 5)**. The resultant behaviour of different soil textures, creates the need for precise management of water to ensure plant availability and efficient use. Soil texture can be determined by rubbing moist soil and forming ribbons with the thumb and index finger. The consistency and length of the ribbon increases with increasing clay content.

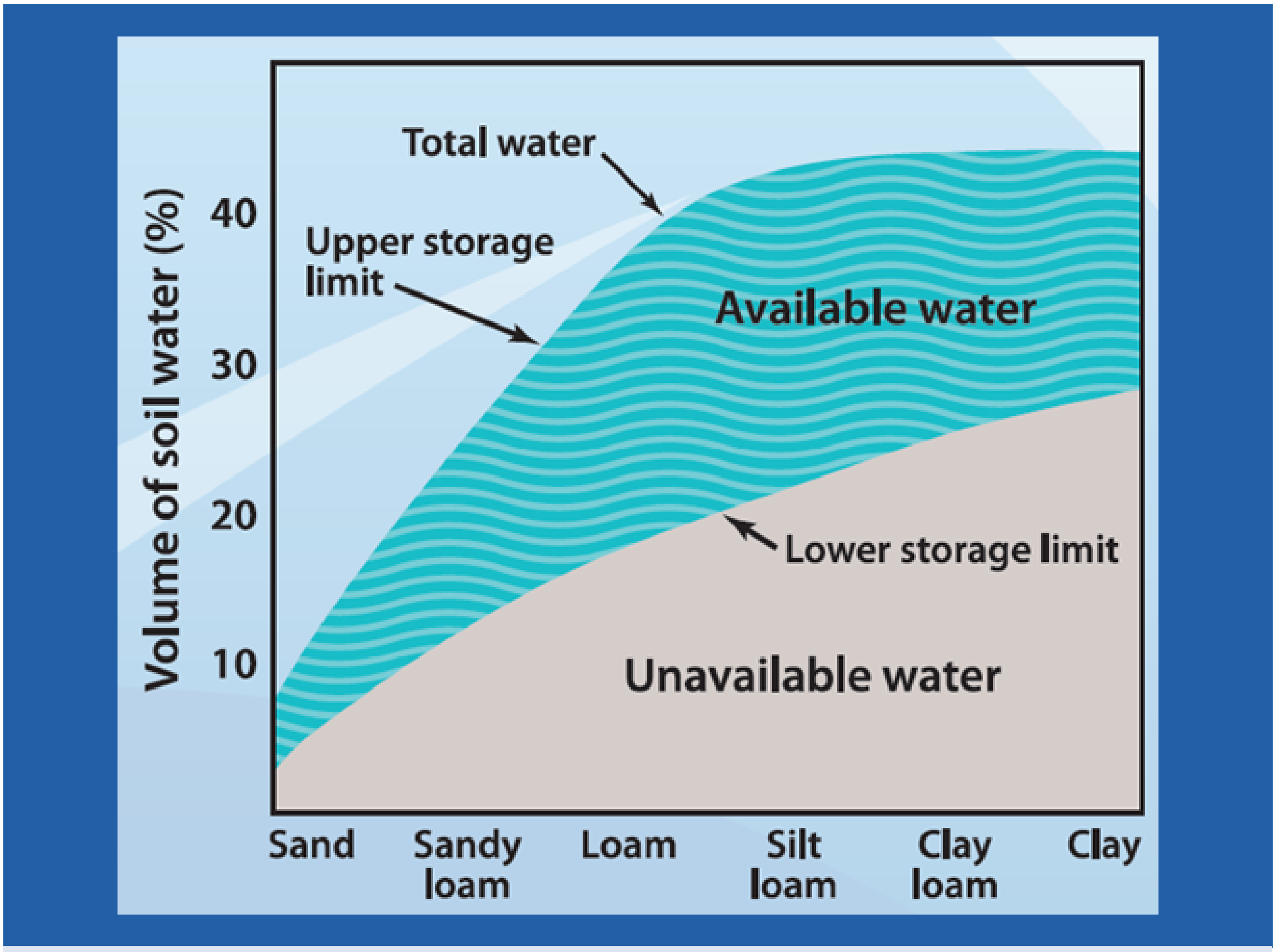



**Figure 5:** The relative amounts of water available and unavailable for plant growth in soils with textures from sand to clay (Kramer, 1983)

Soil structure is the arrangement of soil particles into secondary units called aggregates. The development of soil structure is influenced by soil forming factors and processes. Soil structure influences many important water related properties including infiltration, water retention, aeration, and drainage. When there are stable aggregates, it results in a network of soil pores (uniform distribution of macro, meso and micropores) that allows for rapid exchange of air and water with plant roots. The opposite is true for compacted soil where the aggregates have been destroyed. Movement and exchange of water between soil and plant roots are hindered. Structured (aggregated) soils are also able to retain a significantly greater amount of available soil water, which infer that they will increase WUE.

It is important to maintain good soil structure as it helps the movement of water, air and nutrients throughout the soil facilitating water uptake. In sandy soils aggregate stability is often difficult to maintain due to low organic matter, low clay content and resistance of sand particles to stick together. The inclusion of appropriate organic matter among other techniques to be discussed in **Module 5**, can improve soil structure.

The structure and texture of soil will have an impact on the water infiltration rate and thus on water management efficiency. Water losses from evaporation or runoff will significantly be reduced or increased when the structure of a soil is changed. Also, in dry arid areas where irrigation is done on a frequent basis, this causes the soil structure to become fragile. It is therefore important before selection of an irrigation system, that time is taken to establish the state of the soil structure that allows for high WUE. Farming methods, such as flood irrigation that permit sudden wetting, especially of soil with poor structural stability, encourage the formation of crusts at the surface. The impact of water drops from sprinklers can have an immediate adverse impact on unprotected surface soil if the aggregate stability is low. Irrigation suitability analysis is an important precursor to mitigate against these possibilities.

Crop water use is influenced by soil water content, which varies temporally and spatially. As soil dries, it becomes more difficult for a plant to extract water from the soil. At field capacity (maximum plant-available water content) **(Figure 4)**, plants use water at the maximum rate. When the soil water content drops below field capacity, plants use less water, moderated by internal physiological mechanisms. At low soil moisture contents, water uptake is limited by the soil condition irrespective of plant adaptations. Evapotranspiration is greater when the soil or crop surface is wet, especially early in the growing season and decreasing correspondingly with increasing dry conditions.

## Crop Influence on Crop Water Use

Water use efficiency varies substantially among species and genotypes (cultivars) within species. The option to cultivate crops that are adapted to low moisture conditions is confronted by the market driven demands for particular commodities. The option to improve plant response through breeding and biotechnology are viable mechanisms. Crop improvement has focused mainly in understanding the genes regulating transpiration and specifically stomatal functioning. Breeding to improve WUE has proved ineffective due to the poor relationship between WUE and yield, especially under conditions of intermittent rainfall of irrigation (Sheshshayee, 2003).

Crop water use can be regulated at the physiological level through the following mechanisms (Bacon, 2009):

1. Stomatal regulation via abscisic acid (ABA) under conditions of increase water stress.
2. Osmotic adjustment within roots as soil water potential decreases, which may provide an adaptive response by maintaining root water potential at hydraulic levels sustaining the SPAC.

However, such adaptations may negatively affect productivity and economic yield under water stress conditions, limiting their overall potential at suitable breeding markers. While crops have evolved mechanisms to adapt to water stress and improve WUE, these physiological traits are not very suitable for crop improvement.

## Determining Crop Water Use

Crop water use differs in terms of daily water needs and the duration of their total growing period. Consequently, crop type is a key factor that influences irrigation water needs. Crops with high daily needs and a longer total growing season, require much more water than those with relatively lower daily needs and shorter growing seasons. Potential evapotranspiration (ET0) represents the maximum evapotranspiration rate that can occur based on climatic factors and unlimited water availability. It can be measured from a reference crop or estimated from models using climatic and soil data.

However, the water requirement of a crop is usually less than ET0, as there are crop factors that influence the process of evapotranspiration. These include the growth stage of the crop, the leaf coverage that provides shade to the ground and other particulars of the crops that make the effects variable across crop species. Accounting for these factors via a crop-specific coefficient (Kc) allows for conversion of ET0 to crop evapotranspiration (ETc). ETc represents the evapotranspiration rate of the crop under standard conditions (no stress conditions). When calculating ETc, identification of the growth stages of the crop and their duration must be done to select the proper Kc coefficient to be used. Equation 1 presents a simplified calculation for determining ETc.

**Figure 6** shows a general relationship between crop and potential ET, where the greatest disparity occurs during early crop development. Although ETc is more precise and tailored to improving WUE, by determining variations in crop water demands and use over the growing season, either estimation (ET0 and ETc) provides opportunities to schedule irrigation and improve WUE. Such empirical data is critical to approaches to improve WUE and is a necessary precursor for the Caribbean. Crop or potential ET can be used to estimate irrigation requirement (IR) (Equation 2), which satisfies ½ of the objective of irrigation scheduling, by identifying water needs in excess of precipitation (P).

$ETc = Kc \times ET0$ ........................................ Equation 1

$IR = ETc(ET0) - P$ ........................................ Equation 2

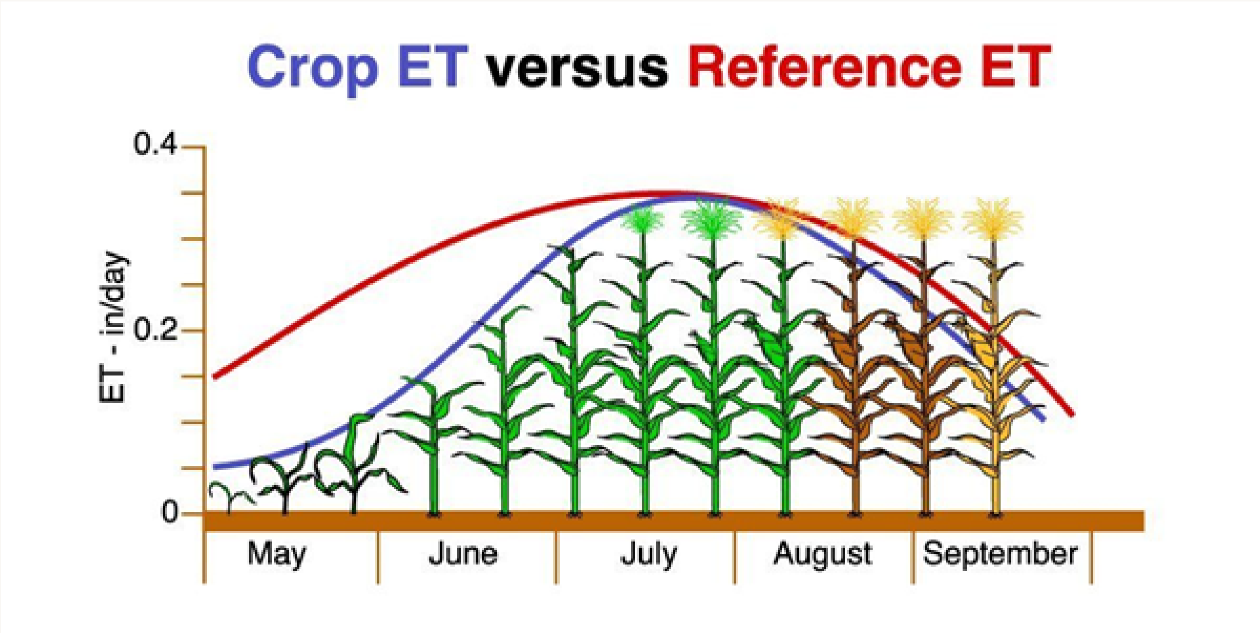



**Figure 6:** Comparison and variations in crop and potential ET over growing season.
Source: https://mesonet.k-state.edu/about/evapotranspiration/

A key step towards reducing irrigation water needs is selecting those crop varieties that have a lower water demand but that still provide sufficient added value and satisfies consumer preferences.

In the Caribbean, the major crops including Hot peppers, Corn (Maize), Cassava and Tomatoes have relatively similar mean crop water demands, although the range is great. The crops all require water at all stages of growth but it should be noted that during the flowering, fruiting or bulking stages plants require a lot more water **(Figure 6)**.

# Lessons Learnt

**From this module, it is clearly understood and observed that:**

1. Crop water use refers to water that is used by a crop for cooling (transpiration) and growth and development (metabolism).
2. Evapotranspiration is a good indicator of crop water use.
3. Crop water use is influenced by climatic, soil and crop variables.
4. Potential and crop ET can be measured and/ or estimated and used for determining irrigation requirements based on the equation: IR = P – ET0(ETc).
5. Evapotranspiration and crop water use varies over the growing season, peaking during flowering, fruiting, and bulking.
6. Soil water content near field capacity is most readily available to be used by plants from either rainfall or irrigation.

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# MODULE 3

## Irrigation Technologies

### Goal

This module comparatively assesses the various methods used to artificially control the distribution of water for agricultural production, system components, layout and installation. Irrigation efficiency and application efficiency will be discussed in relation to water use efficiency. The module also highlights the advantages and disadvantages of the different irrigation systems, as well as their suitability based on physical constraints and cropping system.

### Learning Objectives

**At the end of this module, participants are expected to:**

- Compare suitability and efficiency of irrigation systems based on physical land layout and cropping systems.
- Identify the components and typical layout of a micro irrigation system.
- Understand irrigation and application efficiency and compare across irrigation systems.
- Optimize water use efficiency for different irrigation systems.

# Introduction

Field Irrigation is necessary when plants cannot satisfy all their water needs through precipitation. As described in **Module 2**, field irrigation is used to meet the deficit between a crop's optimal water needs and what it receives from precipitation (irrigation requirement). Field irrigation can be facilitated through different systems, differing in requirements and efficiencies. Irrigation suitability is a prerequisite process to understand site specific constraints to irrigation. It further elucidates the applicability of different irrigation systems based on soil, land, crop and water source interactions.

Efficient water management through suitable irrigation systems will help improve water use efficiency. However, a thorough understanding of the system and associated technology is warranted to truly improve efficiencies. Irmak et al. (2011) stated that irrigation efficiency is generally defined from three points of view:

1. The irrigation system performance
2. The uniformity of water application
3. The response of the crop to irrigation

The authors further posited that these efficiency measures are interrelated at temporal and spatial scales creating a range of possibilities to estimate and improve efficiency. Estimation of irrigation efficiency requires an understanding of both physical and operation conditions that influence the extraction, delivery and availability of water by the crop.

Conveyance efficiency (Ec) is typically defined as the ratio between the irrigation water that reaches a farm or field to that diverted from the water source (Irmak et al. 2011). It is expressed as:

$Ec = (Vf / Vt) \times 100$ ........................................................................................................ Equation 1

Where

Ec = water conveyance efficiency (%)
Vf = volume of irrigation water that reaches the farm or field (acre-inch)
Vt = volume of irrigation water diverted from the water source (acre-inch)

Conveyance efficiency is lower for surface open systems compared to pressurized conduits. It also decreases with length of the transmitting system. It can contribute significantly to low irrigation efficiency and WUE. Application efficiency (Ea) is a measure of the fraction of the total volume of water delivered to the farm or field to that which is stored in the root zone to meet the crop evapotranspiration (ET) needs (Irmak et al. 2011). It estimates the amount of water conveyed that goes towards crop requirements. Ea is expressed as:

$$Ea = (Vs / Vf) \times 100 \quad \text{Equation 2}$$

Where

Ea = water application efficiency (%)
Vs = volume of irrigation water stored in the root zone (acre-inch)
Vf = volume of irrigation water delivered to the farm or field (acre-inch)

Application efficiency is affected by water loss from sprinkler system via evaporation of droplets in the air and moved by wind. While this efficiency is greatest for micro irrigation, it is never 100 % due to losses between application and soil adsorption. It should also be noted that high application efficiency does not necessarily translate to high WUE or productivity, as the amount of water may be lower than crop water requirements or the water may be partitioned in soils and present in unavailable forms. **Table 1** shows the potential application efficiencies for well-designed and managed irrigation systems. Micro-irrigation has the highest efficiencies and smaller range. However, other systems can attain relatively high efficiencies (> 80%) associated with best management practices.

| *Irrigation System* | *"Potential" Application Efficiency (%)* |
|---|---|
| **Sprinkler Irrigation Systems** | |
| LEPA | 80 - 90 |
| Linear move | 75 - 85 |
| Center pivot | 75 - 85 |
| Traveling gun | 65 - 75 |
| Side roll | 65 - 85 |
| Hand move | 65 - 85 |
| Solid set | 70 - 85 |
| **Surface Irrigation Systems** | |
| Furrow (conventional) | 45 - 65 |
| Furrow (surge) | 55 - 75 |
| Furrow (with tailwater reuse) | 60 - 80 |
| Basin (with or without furrow) | 60 - 75 |
| Basin (paddy) | 40 - 60 |
| Precision level basin | 65 - 80 |
| **Microirrigation Systems** | |
| Bubbler (low head) | 80 - 90 |
| Microspray | 85 - 90 |
| Micro-point source | 85 - 90 |
| Micro-line source | 85 - 90 |
| Subsurface drip | > 95 |
| Surface drip | 85 - 95 |

**Table 1:** "Potential" application efficiencies for well-designed and well-managed irrigation systems. Source: Irmak et al. (2011).

Irrigation efficiency (Ei) is defined as the ratio of the volume of water that is beneficially used to the volume of irrigation water applied (Irmak et al. 2011). In estimating this efficiency, water applied other than for meeting crop requirements may or may not be included. Irrigation water may be applied for alternate reasons including:

- Leaching of excess salts
- Fertigation or chemigation
- Microclimate control (evaporative cooling)
- Seedbed preparation and seed germination
- Irrigation of complementary crops (border crops, windbreaks)

Irrigation efficiency related to crop water requirements is expressed as:

$$Ei = (Vb / Vf) \times 100 \quad (4)$$

Where

Ei = irrigation efficiency (%)
Vb = volume of water beneficially used (acre-inch)
Vf = volume of water delivered to the field (acre-inch)

Irrigation systems are classified as surface, sprinkler, or micro irrigation. Small farm size and limited water availability restrict the use of surface irrigation in the region, except in a few rare circumstances. Variations of sprinkler irrigation dominate the irrigation landscape even though application efficiency is significantly lower than micro irrigation. Pressurized systems with multiple components, pose high capital costs that influence decision-making for small farmers.

However, many farmers remain unaware of the benefits of micro irrigation to irrigation efficiency, application efficiency, WUE and importantly productivity. A discussion on the comparative advantage and contribution to increasing WUE and yield in a changing climate, will lend support to decision-making. Making the right choice can help to provide production profitability where resources are limited and where there is a high cost to water supplies.

## Irrigation Methods, Suitability and WUE

### *Surface Irrigation*

Surface irrigation is the introduction and application of water to the surface of the field by the flow of gravity. The flow is introduced at one side of the field until the entire field is gradually watered. This can be done either by flooding the entire field at once (basin irrigation), or by feeding water into small channels (furrows). Since basin and furrow irrigation methods are by gravity flow and require no sophisticated tools and equipment, they are widely utilized by farmers mainly in Rice and Sugarcane production (Guyana and Trinidad and Tobago) **(Figure 1)** and Dasheen leaf production (Trinidad and Tobago). Distribution and irrigation efficiencies are strongly dependent on soil texture and structure that influence infiltration and water distribution within the profile.

Soils must accommodate flow of water across the soil surface to the end of the plot, while facilitating infiltration and replenishment of soil available moisture. Soils with extremes of texture and/ or compacted are unsuitable for surface irrigation. Low irrigation efficiency is associated with high losses of water from the field. However, where full irrigation is possible with no source constraints, this method is preferred due to the low application costs. The Caribbean excluding the mainland territories of Guyana and Belize have limited freshwater resources, which are under increasing pressure from competing sectors and climate change. When combined with the extent of sloping terrain and unsuitable soils, surface irrigation cannot be considered a sustainable option for improving WUE.

**Natural Conditions**

The natural conditions such as soil type, slope, climate, water quality and availability, have the following impact on the choice of an irrigation method:

**Soil Type:**

Sandy soils have a low water storage capacity and a high infiltration rate. They therefore need frequent but small irrigation applications, in particular when the sandy soil is also shallow. Under these circumstances, sprinkler or drip irrigation are more suitable than surface irrigation. On loam or clay soils all three irrigation methods can be used, but surface irrigation is more commonly found. Clay soils with low infiltration rates are ideally suited to surface irrigation. When a variety of different soil types is found within one irrigation scheme, sprinkler or drip irrigation are recommended, as they will ensure a more even water distribution.

**Slope:**

Sprinkler or drip irrigation are preferred above surface irrigation on steeper or unevenly sloping lands, as they require little or no land levelling. An exception is rice grown on terraces on sloping lands.

**Climate:**

Strong wind can disturb the spraying of water from sprinklers. Under very windy conditions, drip or surface irrigation methods are preferred. In areas of supplementary irrigation, sprinkler or drip irrigation may be more suitable than surface irrigation because of their flexibility and adaptability to varying irrigation demands on the farm.

**Water Availability:**

Water application efficiency (see Annex 4, step 8) is generally higher with sprinkler and drip irrigation than surface irrigation and so these methods are preferred when water is in short supply. However, it must be remembered that efficiency is just as much a function of the irrigator as the method used.

**Water Quality:**

Surface irrigation is preferred if the irrigation water contains much sediment. The sediments may clog the drip or sprinkler irrigation systems. If the irrigation water contains dissolved salts, drip irrigation is particularly suitable, as less water is applied to the soil than with surface methods. Sprinkler systems are more efficient than surface irrigation methods in leaching out salts.

**Box 1:** Natural conditions influencing the choice of irrigation system

**Figure 1:** Furrow irrigation of Sugarcane in Guyana

## Sprinkler Irrigation

Sprinkler irrigation is a method of applying water similar to natural rainfall but spread uniformly over the land surface supposedly at a rate less than the infiltration rate of the soil so as to avoid surface runoff from irrigation. This is achieved by distributing water through a system of pipes usually by pumping which is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground **(Figure 2)**. This system addresses many of the limitation of surface irrigation. It is adaptable to varying terrains and slopes, does not require land leveling, can be used on a range of soil textures, better uniformity among other advantages. Sprinklers are however, not suitable for soils which easily form crusts or possess poor structural stability. This system, similar to surface irrigation works on replenishing available soil water content, it is also unsuitable for the extremes of texture where leaching and our runoff may contribute to low application efficiency for sandy and clay soil respectively.

Irrigation scheduling is very important in mitigating against such losses and improving efficiencies. The mimicry of rainfall results in significant losses of water applied via sprinkler irrigation reducing irrigation efficiency. This can be improved via the use of micro sprinklers which expose less water to climatic loss. Several variations of sprinkler systems are used in the region including the sprinkler hose, which operates without a sprinkler head and need for a riser. This popular option suffers the same fate as its more permanent alternative but can be easily moved, reducing the capital costs for installation.

**Figure 2:** Sprinkler Irrigation. Source Ministry of Agriculture Trinidad and Tobago 2020

**Figure 3** shows a typical layout of a rotating sprinkler head irrigation system. The pump unit is usually a centrifugal pump which takes water from a source and provides adequate pressure for delivery into the pipe system. The mainline pipes which are connected to the pump deliver water to the riser pipes. The check valve ensures that water does not flow back to the pump while allowing water to flow in one direction. The filter ensures that sediments are not allowed into the pressure gauge, riser pipes and the main line. In some cases, these pipelines are permanent, so they are held down by looped metal stakes and are laid on the soil surface. In other cases, they are temporary, and can be moved from field to field.

## Drip Irrigation

Drip Irrigation system involves dripping water onto or beneath the soil at low rates (2-20 litres per hour) from a system of small diameter plastic pipes filled with outlets called emitters or drippers. Water is applied close to the plants so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation, which involves wetting the whole soil profile. With drip irrigation water, applications are more frequent than with other methods and this provides a high moisture content in the soil in which plants can flourish. With clayey soils which can be found throughout the Caribbean, water must be applied slowly to avoid surface water ponding and surface runoff. Also, with sandy soils, higher emitter discharge rates are needed to ensure adequate lateral wetting of the soil.

Drip irrigation was designed to maintain a high water potential in the soil to favouring continued upward water movement through SPAC, reducing plant water stress and improving water use efficiency. Conceptually, it differs from both surface and sprinkler systems through its precision approach and focus on water potential. High irrigation efficiency (95-100%) is associated with lower water pressures and volumes, and higher conveyance and application efficiency. Abd El-Wahed (2013) comparing drip and sprinkler irrigation at different irrigation amounts reported higher WUE and yield at full irrigation (100 % ET requirement) and under drip irrigation. The authors also noted that under limited irrigation, drip irrigation was more efficient and productive. The emitter design is the technology that allows for higher efficiency, especially under limited irrigation.

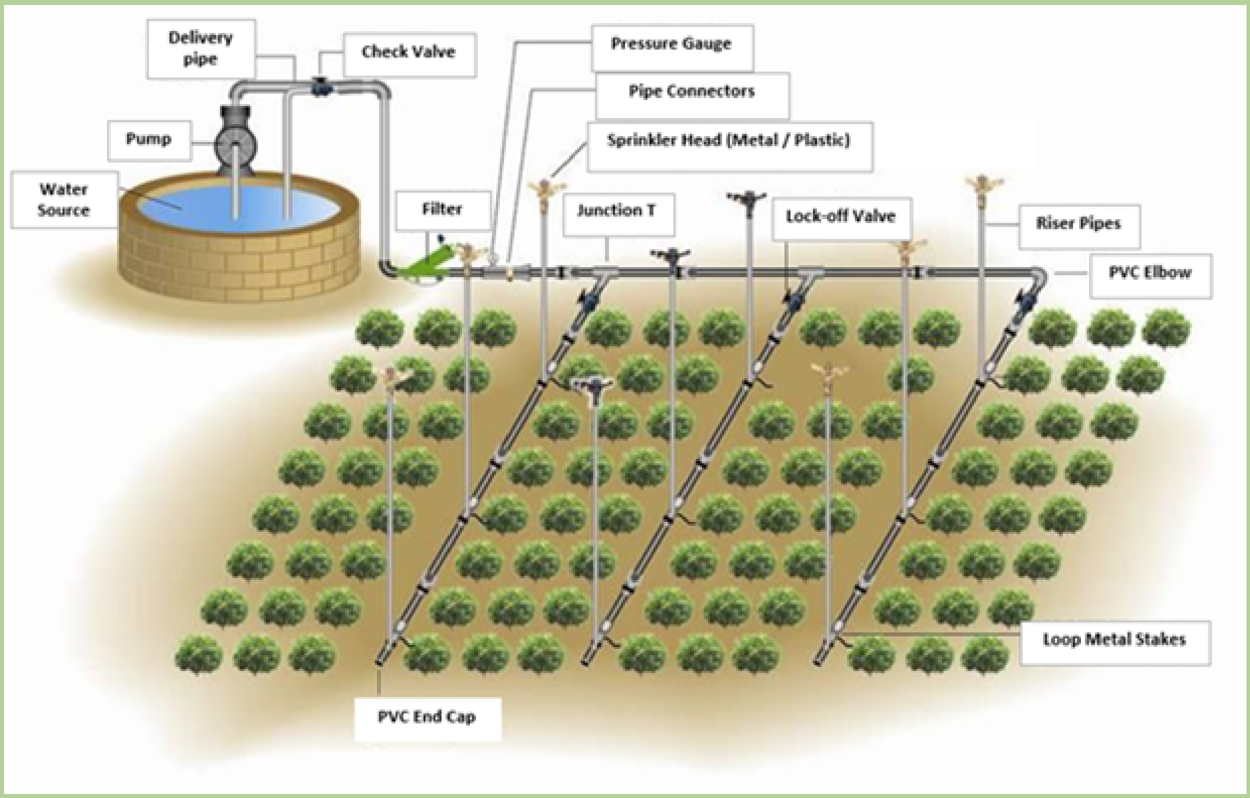


**Figure 3:** Layout and components of a sprinkler irrigation system

The following website provides a description and explanation of the working of an irrigation system and the emitter that runs it: https://www.netafim.com/49de8a/en/bynder/ABBBBAD8-4824-469C-9B0764E5424FA0A8-netafims-unique-drip-technology-v2.mp4.

In drip/micro irrigation, there is no canopy interception or wind drift and there is minimal contact between farm workers and effluent. This provides a good health system where there is protection for the workers and consumers if wastewater is being used. This system is also suitable for water of poor quality (saline water). The ability to combine with nutrient application, increases precision and reduces wastage of both water and nutrients **(Figure 4)**.

**Figure 4:** Drip Irrigation. Source: https://www.netafim.com

The basic layout and components of a drip irrigation system is shown in **Figure 5**. From the water source, whether a tank, well or pond a pipe or line is connected to the pump which delivers the water through the check-valve. The water is then passed through the sand separator, which helps to remove sand or any sediments which may be present in the water supply. The venturi speeds up the flow of the water before it reaches the sand-filter, which further assists in the purification process of the water supply if there is a contaminant present. The water passes through a screen filter and is screened again to help remove any particles that may be present, still in the water supply before it reaches the sublines and the emitters which then irrigates the plants. The different filters and components are needed to help prevent any blockage in the line and the emitters, so efficient water use is achieved.

## Advantages

- High water application efficiency (suitable for water scarce areas).
- Crop yield per unit of water use is high.
- Decreased energy requirements in pumping.
- Reduced salinity hazard.
- Fertilizer or nutrient loss is minimized as it is applied directly to the plant.
- Reduced labour costs as it can be highly automated.
- Suitable for difficult land terrains and marginal lands.
- Drip irrigation is most suitable for row crops (vegetables, soft fruit), tree and vine crops where one or more emitters can be provided for each plant.
- Drip irrigation is suitable for any type of soil.

## Disadvantages

- High initial cost of installation.
- High maintenance requirements (emitter clogging when water with sediments, algae, fertilizer deposits, salts and dissolved chemicals such as (Ca) and iron are used).
- Restricted plant root development.
- Salt accumulation close to plants (along the edges of the wetted zone).
- Life of tube is less due to continuous exposure to sun.

**Box 2:** Advantages and disadvantages of drip irrigation

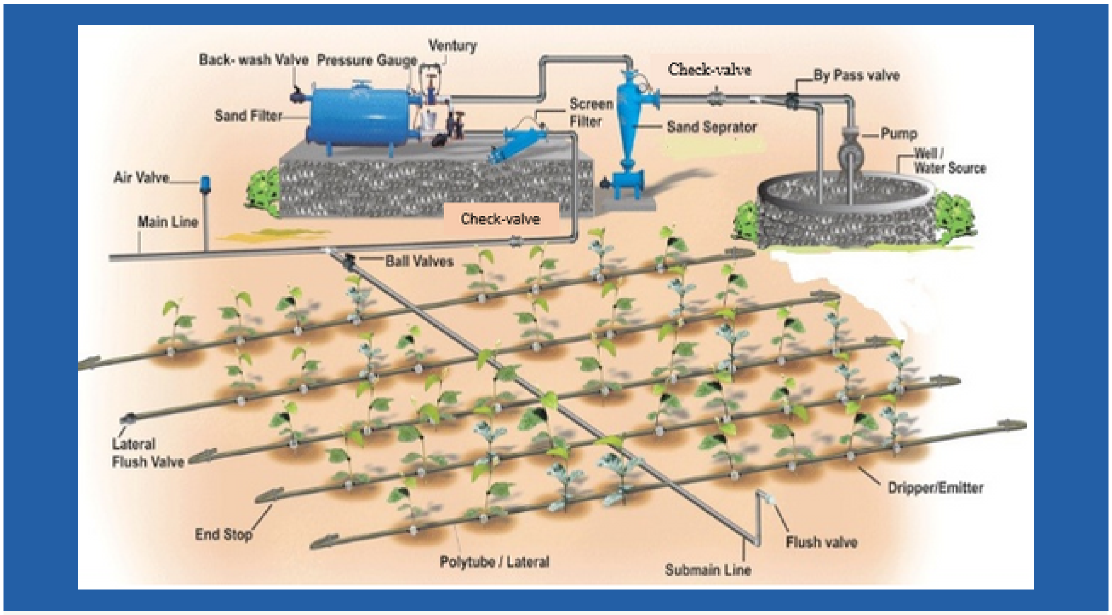


**Figure 5:** Layout and components of a drip irrigation system

# Lessons Learnt

1. Field irrigation efficiency is strongly dependent on conveyance, application and crop water use efficiencies.
2. There are three classes of irrigation systems: surface, sprinkler and drip (micro) irrigation. Their suitability depends on natural conditions including soil, landform, climate and water availability and quality in addition to the producer's investment potential.
3. Drip irrigation has the highest capital investment but also the greatest opportunity for improving WUE.
4. Drip irrigation is also the most sustainable and resilient system.

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# MODULE 4

## Irrigation Scheduling and Monitoring Technologies

### Goal

The purpose of this module is to describe the elements of irrigation scheduling, answering when and how much to irrigate. These questions are answered in the context of monitoring devices and technological systems, which can be leveraged to give greater insight into the significant factors which influence the need to irrigate yet utilize water efficiently.

### Learning Objectives

**At the end of this module, participants are expected to:**

- Describe irrigation scheduling and its benefits.
- List and describe the factors which affect irrigation scheduling.
- Understand different methods of determining the moisture status of soils and how they help answer the questions of when and how to irrigate.
- Identify monitoring devices and systems for decision support.
- List the steps in designing an irrigation schedule.

# Introduction

Irrigation is the artificial application of water to agricultural or horticultural lands to meet crop water requirements. While there are different irrigation systems with varying efficiencies dependent on climatic, edaphic and technological conditions, they all aim to provide the crop with an optimal water environment. Noting the finite freshwater resources and the competing demands, understanding when it is most appropriate to irrigate and how much to irrigate are important concepts towards improving WUE.

Most farmers do not monitor or estimate crop water use and base their scheduling on adhoc and anecdotal evidence such as the duration of irrigation and visual observation (as indicators of soil field capacity). This typically results in water deficits or excesses with the latter, a major source of environmental concern and sign of low irrigation efficiency. Further attention is directed to climate change realities which may negatively affect both surface and groundwater storage.

Technology has provided farmers with quite a few monitoring and assessment tools that can serve as precision support and provide data for immediate and medium to long-term planning for water use. **Figure 1** describes the approaches to irrigation scheduling that can be soil, climate or plant based.

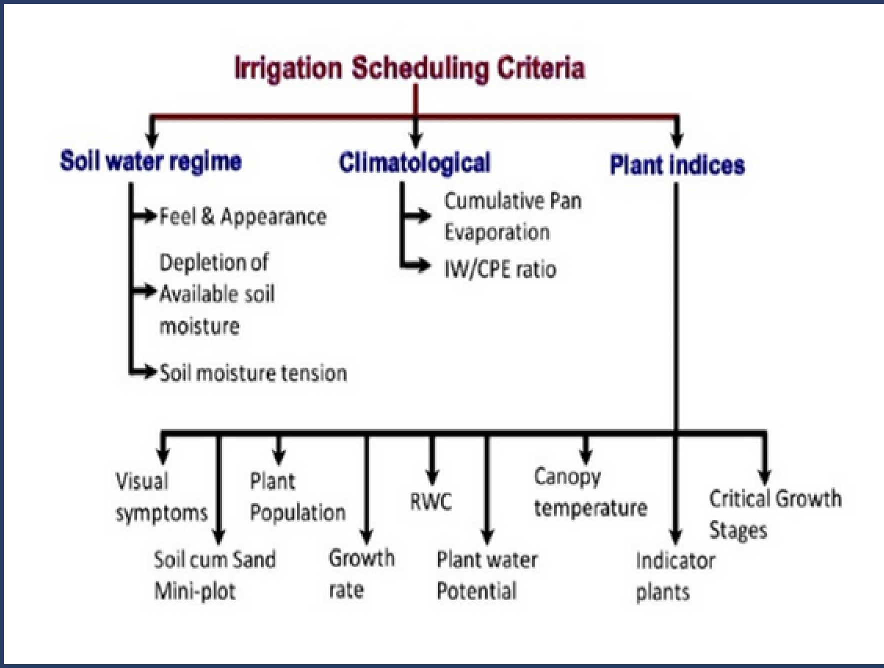


**Figure 1:** Approaches to irrigation scheduling. Source: https://www.slideshare.net/babukakumanu/irrigation-scheduling-72682103

## Irrigation Scheduling

Irrigation scheduling is the process of determining the frequency and constancy of applying controlled amounts of water to crops. It considers the crop and the amount of water the crop uses via the process of evapotranspiration (Crop Water Use-Module 3).

***Benefits of irrigation scheduling include:***

- It optimizes crop yields.
- Ensures best management of water resources.
- Significantly decreases soil and nutrient loss due to excessive runoff or leaching.
- Helps maintain soil health (aeration, structure, flora and fauna).

***Major factors which affect Irrigation Scheduling are:***

- Soil Type: Texture and Structure
- Crop Type
- Climatic Factors
- Land Management

## Soil Type: Texture and Structure

Soil texture and structure affects the way that plants interact with water and determine how irrigation is scheduled. Texture refers to the sizes of particles within the soil, increasing from clay to sand. Smaller clay particles coalesce, reducing the sizes of pore spaces, which affects the rate of water movement, thus retaining a greater amount of water relative to sands. This implies that sandy soils will hold less water and will lose that water faster, requiring more frequent irrigation. Additionally, because these soils have low WHC they hold less water implying that a shorter irrigation event is required to maintain adequate water conditions.

Soil structure, although commonly overlooked, is important for the irrigation scheduling, as it too has an impact on plant rooting ability and growth, and water flow through the soil. Soil structure is the arrangement of soil particles into aggregates and are characterized by their shape, size and distinctness. Soil structure has a great effect on the distribution of pore sizes with the soil profile, affecting water content and flow. Management practices such as crop rotations, tillage, and the addition of organic matter, which influence the soil structure in a positive way, may significantly increase the overall beneficial effects of irrigation scheduling. These crop management factors are described in the following module **(Module 5)**.

## Crop Type

Crops vary in their water consumption both daily and at different growth stages. Therefore, it is important to consider the type of crop(s) planted when considering irrigation needs. Even physiological characteristics such as rooting behaviour (shallow vs. deep) is important as deeper-rooted plants will have water for a longer period than their shallow-rooted counterparts.

In the Caribbean context, common crops such as Sugar Cane with long growing seasons and high daily water requirements, have a higher water requirement than Hot Pepper which has a shorter growing period and lower daily water requirement. It is evident therefore, that to reduce irrigation needs, crops with lower water demands should be selected where possible. The advancement of agriculture in areas of plant breeding and genetic engineering means that environmentally suitably tailored crops are at the disposal of farmers and should be considered.

## Climatic Factors

Climatic factors are variables of the weather which contribute to the question of when and how much to irrigate. These include the amount of precipitation which affect the soil available water; windspeeds which can influence evapotranspiration, and temperature or available sunlight which influence water availability, evapotranspiration and the growth rate of crops. All these climatic variables influence irrigation requirements. Most Caribbean countries experience a bi-modal climate with a dry season characterized by low precipitation and high ET. During this period, the climatic demand and irrigation requirement are high.

## Land Management

Land management influences soil structure, determining to some extent how much water the soil can hold, as well as the rooting capability of plants being grown. Undisturbed soil has greater pore spaces which enables the soil to hold more available water and air for plants. Compaction reduces the size of pores, which further reducing the available water holding capacity and the water transmitting capability **(Figure 2)**. Soil can be compacted and lose its quality due to:

- Overcultivation
- Trampling by livestock
- Heavy machinery
- Heavy raindrops
- Some Irrigation methods

Good management dictates that the soil structure is either improved or preserved through thoughtful consideration, planning and implementation of agricultural best practices. Conventional agricultural systems disturb and destroy the soil structure through tillage and exposes the surface to evaporative losses and runoff, which negatively influences WUE.

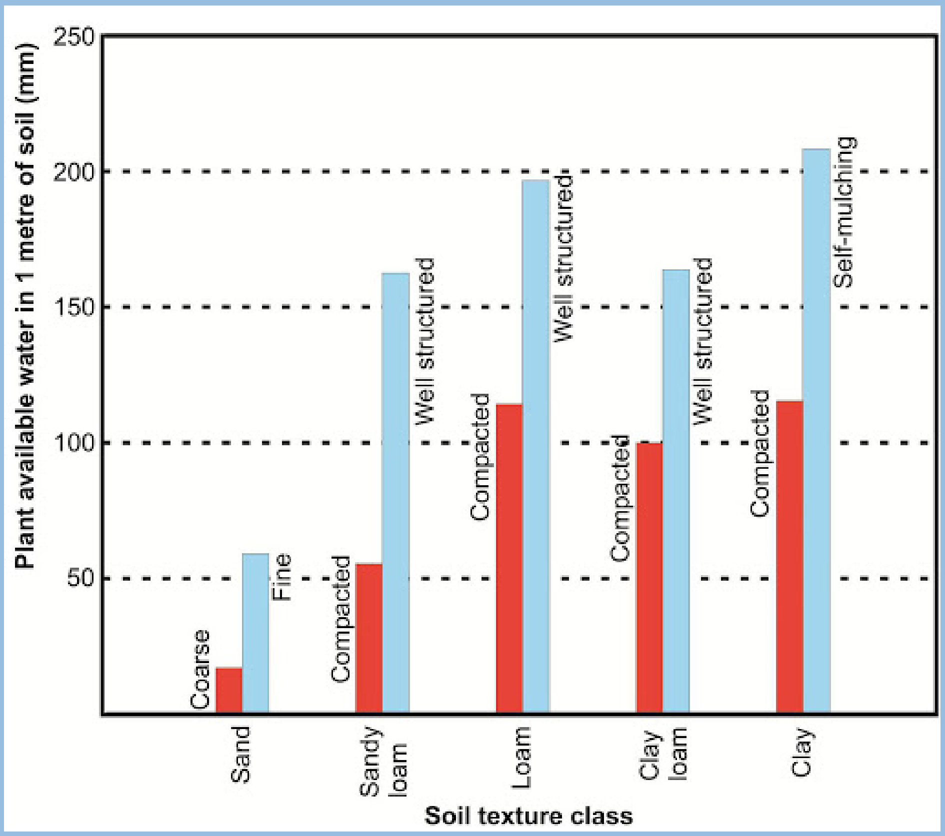


**Figure 2:** Influence of compaction on plant available water. Source: http://www.hort360.com.au/wordpress/wp-content/uploads/2015/03/Healthy-soils-for-sustainable-farms-Ute-Guide.pdf

## Determining When and How Much to Irrigate

***Effective scheduling***

Effective scheduling can be achieved by monitoring how much water the crop has used, the soil moisture status, and by crop growth and development. The following three methods are further described below:

- Climate-based Scheduling (Evapotranspiration (ET) scheduling)
- Soil Moisture Content
- Plant-based Irrigation Scheduling

**Box 1:** Strategies for irrigation scheduling

## Approaches to Irrigation Scheduling

**Fixed Amount:** A pre-determined amount of water is applied at every irrigating event. The length of time between these events is determined by the irrigator's calculation of the crop's rate of water use and the amount of rainfall.  Flood, sprinkler and other irrigation methods such as the lateral move or center pivot irrigation methods are normally managed in this way. It is easy to implement without having to manage control panels.

**Fixed Time:** Water is applied at a specific time, while changing the amount of water applied is based on the accumulative crop water use (minus any rainfall that occurred between irrigations). This strategy is usually applied in turf and micro-irrigation which addresses plant tension over the soil water holding capacity. This approach provides greater control of irrigation efficiency and improves WUE through maintaining optimal soil water conditions. Diligent management of the irrigation system without much labour. This approach is useful under conditions of limited water availability, deficit irrigation and where ET exceeds precipitation, as is the case for the dry season.
It is a climate smart approach.

## Climate-based Scheduling

Climate-based scheduling considers a range of information such as precipitation, crop water use, crop rooting depth and moisture losses from the soil. The water balance equation is used to account for all the incoming and outgoing water from the soil root zone. The "ideal irrigation depth" can be determined using this method, Equation 1.

$Dc – Dp = ETc – P – I + R + DP$ ........................................................................................ Equation 1

Where

Dc = soil water deficit
Dp = soil water deficit (previous day)
ETc = crop evapotranspiration
P = precipitation
DP = deep percolation
R = runoff
I = irrigation

The water balance equation can be adjusted for ET Scheduling since: R and DP are difficult to estimate. A more workable equation is: **Dc = Dp + ETc – P – I**

Considerations for the regional application and use of climate-based irrigation scheduling include:

1. Farmers who are not mathematically inclined may be put off by the mathematics and not be willing to engage in proper water use efficiency.
2. Plug-in information such as ETc is not readily available in the Caribbean, making the method difficult to use. This highlights the need for support systems and frameworks to provide climatic and crop transpiration data.
3. Other methods utilizing sensors may need to be adopted, with capacity building for farmers.

## Irrigation Scheduling Software

Farmers and irrigators must consider many variables to schedule irrigation in a manner that increases the overall WUE. Access, and analysis of climatic data required to accurately forecast ETc and schedule irrigation may be prohibitive. Where available, irrigation scheduling software allows them to leverage data and computing power to improve WUE. Such software mainly contains pre-programmed settings for crops, which only requires farmers to plug in data such as the crop they are irrigating and location amongst other things.

Many scheduling softwares are available to the agricultural stakeholder. CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO. CROPWAT 8.0 for Windows is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions (Smith, 1992). The programme can be downloaded at: http://www.fao.org/land-water/databases-and-software/cropwat/en/.

## Soil-Based Scheduling

Soil-based methods of irrigation use sensors to analyze soil moisture content and/ or potential to determine when and how much to irrigate. Using detailed soil moisture/ potential readings, will reveal information about the moisture status of the soil, but more importantly, the plant root zone. The amount as well as the availability of the water can be determined both spatially and temporally, enabling real time management of irrigation and significantly reducing water wastage, leading to improved efficiency. Below are some sensors that measure soil water content and or potential, that can support irrigation decision.

Conceptually, approaches to irrigation scheduling are based on water content and water potential. The former has been described as the “barrel approach” **(Figure 3)** and the latter the “maintenance approach”. Replenishment of the soil’s available water holding capacity to field capacity, fills the barrel until plant uptakes empties to permanent wilting point. The maintenance approach times irrigation events to ensure that soil water potential does not decrease pass a minimal value, facilitating a positive flow of water through SPAC.

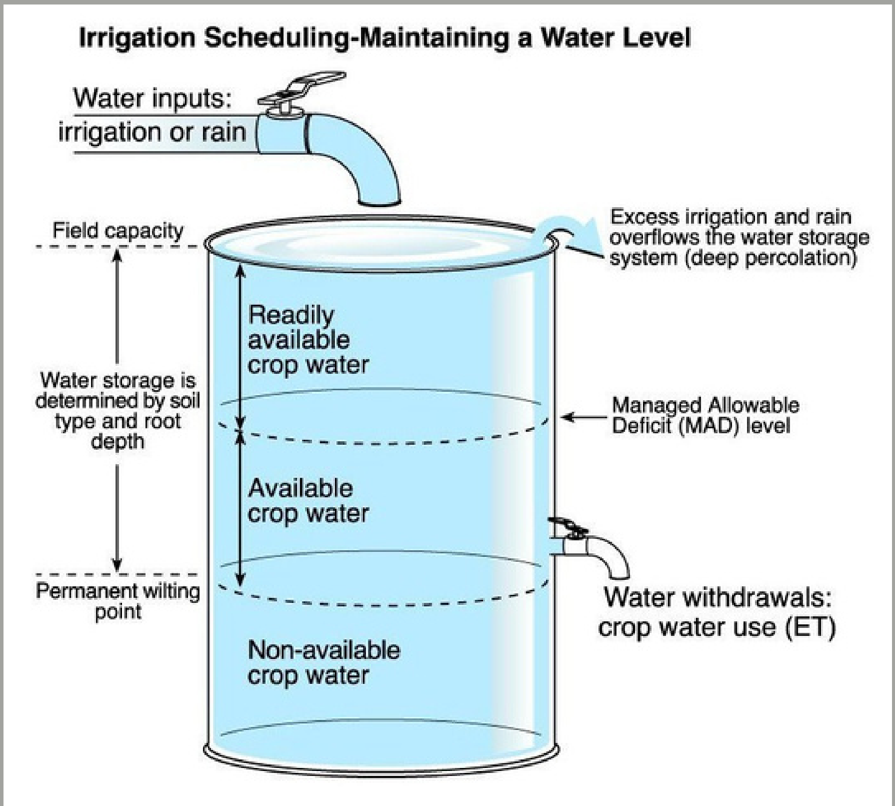


**Figure 3:** Barrel approach to irrigation scheduling (fixed amount).
Source: Kansas State University

## Tensiometers

Tensiometers offer a more responsive solution to crop water demand and relationship to yield, as they measure soil water potential (availability to plant roots). Tensiometers measure soil water potential in the root zone. As soil water content around the root zone decreases, suction (negative pressure) or l is created, decreasing water potential and water is pulled from the tensiometer into the soil, which is then recorded on the gauge or transmitted through a transducer **(Figure 4)**. The recorded negative pressure or tension is a measure of the force that plants need to exert to pull water from the soil. It is worthwhile noting that the volumetric water content corresponding to various soil suction measures, varies across soil texture ad structure **(Figure 5)**.

At a given soil tension (e.g. 100 cbars) the depletion of available soil moisture will be greatest in sandy soils. Tensiometers are field devices now with connectivity potential and data logging capability that can be used to control automated irrigation systems such as in green houses. For suitable soil types (coarse sand soil are not suitable due to non-contact with ceramic tip necessary for equilibrium) tensiometers can improve WUE by providing real time data for decision making. Kukal et al (2005) reported that tensiometer based soil matric suction scheduling helped save 30 – 35 % irrigation water compared to that used with the 2-day interval irrigation.

Tensiometers are limited in the measurement range only being able to measure between 0 to 80 centibars normally and 60 centibars over elevations of 3000 ft. They also require constant monitoring and maintenance in order to work well and can only measure the suction/tension at their positioned depth, meaning that multiple units would be required when making an assessment of the whole plant root zone.

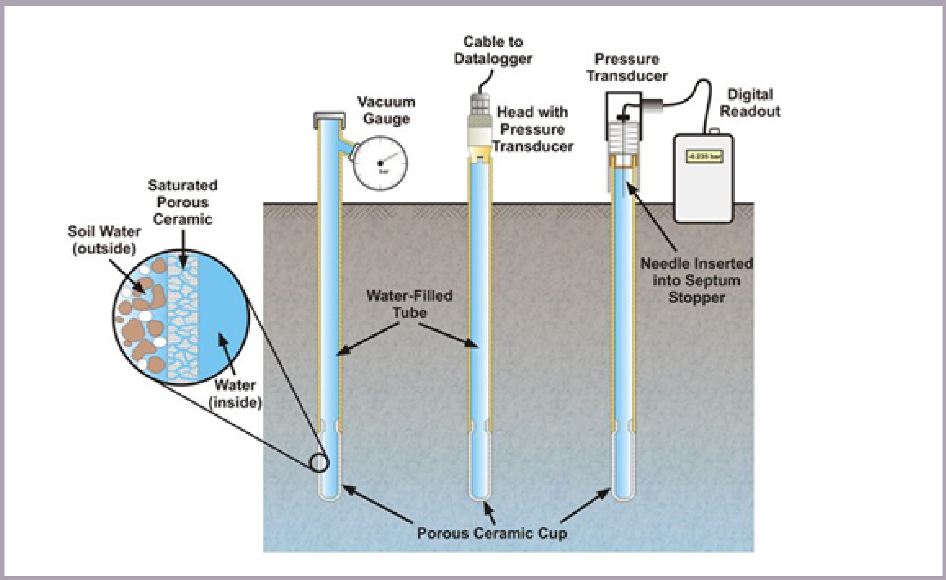


**Figure 4:** Tensiometers with vacuum gauges and electronic pressure transducers. Source: Tuller and Islam (2005)

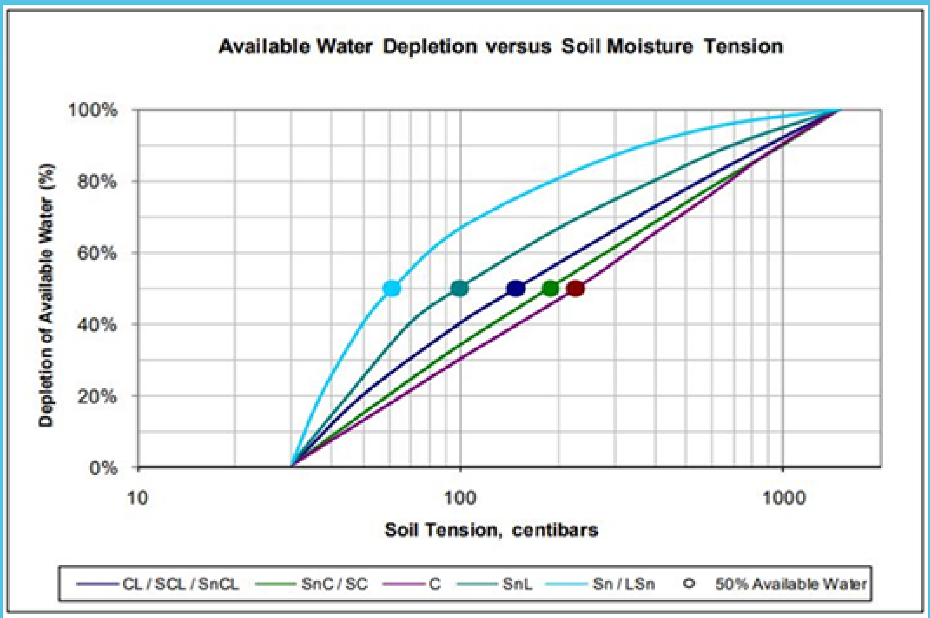


**Figure 5:** Soil tension for a range of soil textures at 50% of available water

## Resistance Devices - Gypsum and Granular Matrix Blocks (GMB)

Gypsum and granular matrix blocks are electrical resistance-based sensors made of gypsum and other material **(Figure 6)**. The blocks are buried in the soil to the depth at which water content is to be measured. Multiple blocks are used to monitor different depths and locations. A modified ohmmeter is used to read the resistance in the block on a numerical scale, which generally reads from 0 to 100. Newer gypsum blocks come with information which convert resistance readings to soil tension estimates, however, a calibration is required, specific to each soil for interpreting water content from resistance readings. Hanson et al (2002) reported more responsiveness of the granular block compared to tensiometers, but a similarly poor hydraulic contact limits their use in sandy soils.

***Gypsum blocks have the following advantages:***

1. Comparatively inexpensive, allowing for multiple depth and location monitoring compared to other units such as tensiometers.
2. They have a long lifespan (upwards of three to five years).
3. Can be set up for automated continuous readings by connecting to data loggers.
4. Can be installed with minimal soil profile disturbance.

***Disadvantages include:***

1. Gypsum blocks have decreased responsiveness at high levels of moisture and soil salinity.
2. A dissolving soil surface contact affects the accuracy of measurements over time.
3. Gypsum blocks can have slower response times than granular blocks.
4. Granular matrix blocks are two to three times more expensive than gypsum blocks.

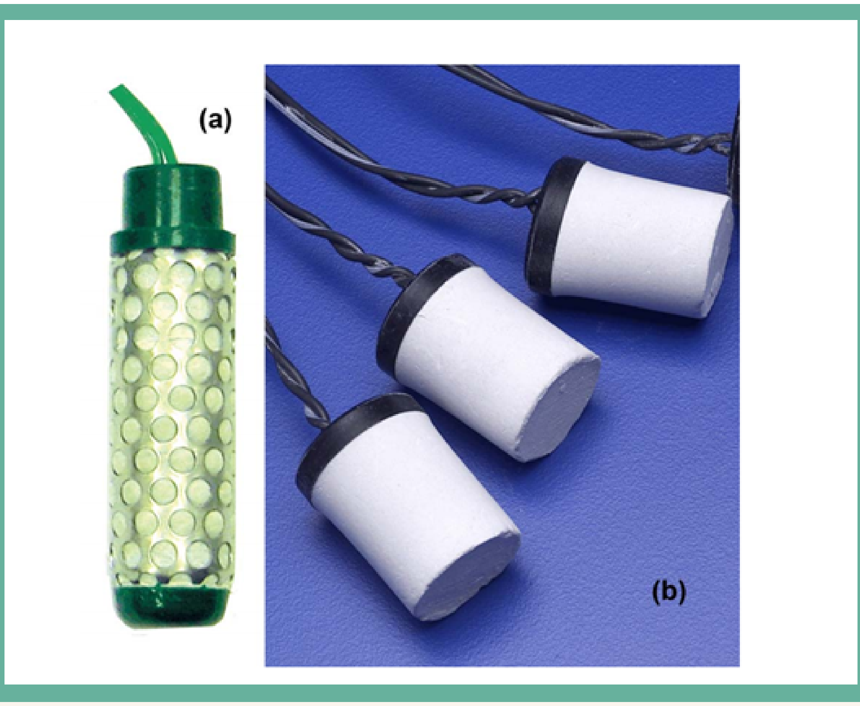


**Figure 6:** Commercially Available Electrical Resistance Sensors: (a) 253-L Watermark Soil Matric Potential Block (Irrometer Company, Inc.), and (b) Gypsum Blocks (Delmhorst Instrument Co.).
Source: Or et al. (2006)

## TDR Sensors and Probes

All materials have a property that can be measured called the “dielectric constant," which is related to how molecules behave in an electric field. The dielectric constant is a measure of the ability of the substance to store electrical energy. The most common electromagnetic sensors which can measure dielectric constant are capacitance sensors/frequency domain reflectometry (FDR) sensor and time domain reflectometry (TDR) sensors. The sensors indirectly measure volumetric water content based on the dielectric and electric properties of the soil medium (soil bulk permittivity or soil dielectric constant). Since soil particles, water, and air, all have different dielectric constants, their ability to store or dissipate electrical energy is different. This is how it can be correlated to soil water content. These sensors can be portable or stationary. They are effective over a range of soil textures and provide real time values.

TDR sensors consist of two or three parallel rods inserted into the soil acting as waveguides. When a defined voltage pulse is sent to the sensor it travels along the waveguide. When this pulse reaches the end of the waveguide it reflects. This reflection is measured by the oscilloscope connected to the senor. As the soil water increases, the dielectric constant of the soil increases. Consequently, the travel time of the pulse decreases and thus, the soil moisture content can be estimated using the calibration equation.


**Figure 7:** TDR probe with meter

The units can be used as mobile or permanently installed systems and offer rapid results to improve the decision-making aspect of irrigators. However, they are relatively expensive to obtain even though there are "cost-friendly" options.

## The Feel Method

Although subjective, the "feel method" remains a fairly reliable method of determining soil moisture. The method involves handling the soil sample then comparing the feel to predetermined moisture units. The moisture content status is determined by shaping the soil into a ball and then making a ribbon between the thumb and forefinger. One can then estimate the moisture content by comparing the observable results to a chart or sheet with keyed in characteristics to expected moisture estimates. The technique requires some experience but can be effective where the barrel approach or replenishing available water holding capacity is practiced. **Figure 8** below demonstrates the appearance of clay, clay loam soils at various moisture contents and available water depletions, whilst **Table 1** describes the expected physical feature of various soil texture during fell determination of available soil moisture.

## Plant Based Scheduling

The physiological traits of plants can be used to provide information on the moisture status of the plant and help the irrigator determine the irrigation timing that is best for the plant. Plant-based methods for irrigation scheduling include those based on direct or indirect measurement of plant water status and those based on plant physiological responses to drought (Jones, 2004). It also categorizes plant-based sensors into contact and non-contact, distinguishing between individual plant sensing where the devise is mounted on the plant and proximal or remote sensing at canopy scale. Plant traits such as stem shrinkage, leaf water potential, sap flow and canopy temperature are important parameters to help determine the irrigation schedule. Of these parameters, canopy temperature and leaf water potential are the primary methods of determining irrigation timing.

## Leaf Water Potential (LWP)

Leaf water potential (LWP) is the negative pressure or tension found in the plant leaves. As soil water potential decreases it causes a reduction in leaf water potential. This triggers a restriction in cell expansion and stomatal closure in an effort to transpire less and retain more water. In well-watered plants, the LWP is higher than that of plants experiencing water stress (which have a negative pressure potential value). To measure this pressure or tension, a pressure chamber is employed. In simple terms, a leaf is detached from a plant and placed in a chamber with its petiole (or stem) sticking out. This leaf is then subjected to gaseous nitrogen which increases the pressure of the chamber, When the pressure of the chamber is as positive in value as the leaf and petiole are negative, this equilibrium pressure is recorded as the leaf water potential.

***Available WaterCapacity***
***1.6-2.4 inches/foot***

**Percent Available:** Currently available soil moisture as a percent of available water capacity.

**In/ft. Depleted:** Inches of water currently needed to refill a foot of soil to field capacity.

**0-25 percent available**
**2.4-1.2 in/ft. depleted**

Dry, soil aggregations separate easily, clods are hard to crumble with applied pressure. (Not pictured)

**25-50 percent available**
**1.8-0.8 in/ft. depleted**

Slightly moist, forms a weak ball, very few soil aggregations break away, no water stains, clods flatten with applied pressure.

**50 - 75 percent available**
**1.2-0.4 in./ft. depleted**

Moist, forms a smooth ball with defined finger marks, light soil/water staining on fingers, ribbons between thumb and forefinger.

**75-100 percent available**
**0.6-0.0 in./ft. depleted**

Wet, forms a ball, uneven medium to heavy soil/water coating on fingers, ribbons easily between thumb and forefinger.

**100 percent available**
**0.0 in./ft. depleted (field capacity)**

Wet, forms a soft ball, free water appears on soil surface after squeezing or shaking, thick soil/water coating on fingers, slick and sticky. (Not pictured)

**Figure 8:** Appearance of clay, clay loam, and silt clay loam soils at various soil moisture conditions. Source: USDA-NRCS (1998)

**Table 1:** Guidelines for Estimating Soil Moisture Conditions. Source: USDA-NRCS (1998)

| | Coarse Texture- Fine Sand and Loamy Fine Sand | Moderately Coarse Texture Sandy Loam and Fine Sandy Loam | Medium Texture - Sandy Clay Loam, Loam, and Silt Loam | Fine Texture- Clay, Clay Loam, or Silty Clay Loam |
|---|---|---|---|---|
| | Available Water Capacity (Inches/Foot) | | | |
| | 0.6-1.2 | 1.3-1.7 | 1.5-2.1 | 1.6-2.4 |
| **Available Soil Moisturre Percent** | Soil Moisture Deficit (SMD) in inches per foot when the feel and appearance of the soil are as described. | | | |
| **0-25** | Dry, loose, will hold together if not disturbed, loose sand grains on fingers with applied pressure.<br>SMD 1.2-0.5 | Dry, forms a very weak ball, aggregated soil grains break away easily from ball.<br>SMD 1.7 -1.0 | Dry. Soil aggregations break away easily. no moisture staining on fingers, clods crumble with applied pressure.<br>SMD 2.1-1.1 | Dry, soil aggregations easily separate, clods are hard to crumble with applied pressure<br>SMD 2.4-1.2 |
| **25-50** | Slightly moist, forms a very weak ball with well-defined finger marks, light coating of loose and aggregated sand grains remain on fingers.<br>SMD O.9-0.3 | Slightly moist, forms a weak ball with defined finger marks, darkened color, no water staining on fingers, grains break away.<br>SMD 1.3-0.7 | Slightly moist, forms a weak ball with rough surfaces, no water staining on fingers, few aggregated soil grains break away.<br>SMD1.6-0.8 | Slightly moist, forms a weak ball, very few soil aggregations break away, no water stains, clods flatten with applied pressure<br>SMD 1.8-0.8 |
| **50-75** | Moist, forms a weak ball with loose and aggregated sand grains on fingers, darkened color, moderate water staining on fingers, will not ribbon.<br>SMD O.6-0.2 | Moist, forms a ball with defined finger marks. very light soil/water staining on fingers. darkened color, will not slick.<br>SMD O.9-0.3 | Moist, forms a ball, very light water staining on fingers, darkened color, pliable, forms a weak ribbon between thumb and forefinger.<br>SMD 1.1- 0.4 | Moist. forms a smooth ball with defined finger marks, light soil/water staining on fingers, ribbons between thumb and forefinger.<br>SMD I.2-0.4 |
| **75-100** | Wet, forms a weak ball, loose and aggregated sand grains remain on fingers, darkened color, heavy water staining on fingers, will not ribbon.<br>SMD O.3-0.0 | Wet, forms a ball with wet outline left on hand, light to medium water staining on fingers, makes a weak ribbon between thumb and forefinger.<br>SMD O.4-0.0 | Wet, forms a ball with well defined finger marks, light to heavy soil/water coating on fingers, ribbons between , thumb and forefinger.<br>SMD O.5 -0.0 | Wet, forms a ball, uneven medium to heavy soil/water coating on fingers, ribbons easily between thumb and forefinger.<br>SMD O.6-0.0 |
| **Field Capacity (100 %)** | Wet, forms a weak ball, moderate to heavy soil/ water coating on fingers, wet outline of soft ball remains on hand.<br>SMD 0.0 | Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking,medium to heavy soil/water coating on fingers.<br>SMD 0.0 | Wet, forms a soft ball, free water appears briefly on soil surface after squeezing or shaking, medium to heavy soil/water coating on fingers.<br>SMD 0.0 | Wet, forms a soft ball, free water appears on soil surface after squeezing or shaking, thick soil/water coating on fingers, slick and sticky.<br>SMD 0.0 |

### Canopy Temperature

Plants transpire to cool themselves during the day and remain cooler than ambient air temperatures. The soil moisture influences the ability of the plant to transpire and cool itself. When the soil moisture is high, cooling readily takes place, when it is low, cooling takes place less readily. This can be measured using infrared thermometer sensors that measure the temperature of the plant canopy.

**Advantages**

1. Portable multifunctional handheld IR sensors are now available on the market meaning that taking canopy temperature is now easier than ever.
2. Units are low cost, low maintenance and easy to install.
3. Can connect to a data logger for continuous monitoring.

**Drawbacks**

1. The plant must have its full canopy before these sensors can be used accurately.
2. Need to be combined with other indices to develop reasonable conclusions about crop water stress.

# Lessons Learnt

1. Irrigation scheduling significantly improves WUE.
2. Irrigation scheduling is influenced by soil type, crop type, climatic factors and land management.
3. The “ideal irrigation depth” can be calculated using: Dc – Dp = ETc – P – I + R + DP.
4. Irrigation scheduling can be based on soil, climate or plant-based approaches. However, these approaches are either reflective of water content or potential.
5. Modern sensors and real time water relations monitoring has positively impacted irrigation scheduling, improving WUE.

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# MODULE 5

## Crop Husbandry and Water Use Efficiency

### Goal

This module will sensitize readers to elements of crop cultivation affecting water use efficiency. Climate-smart crop management strategies synergistic with sustainable recovery, use and storage of water are discussed. An understanding of the mechanisms and process influencing management decisions is an important control point.

### Learning Objectives

- Understanding soil fertility management as a key factor in improving water use efficiency.
- Identify cultivation practices correlated with efficient water use.
- Describe soil and water conservation measures at the farm level.
- Produce and use compost as a soil quality enhancer and water regulator.

# Introduction

Crop management is essential for optimizing agricultural output and profit, particularly under water stress conditions. Climate change has exacerbated the spatial variability and obstructed conventional management approach. Minimizing water security challenges is high on the list in a changing climate. Bridging the gap and adapting to climate change impacts, while increasing resilience through farm level sustainable management are important game changers. Optimizing crop husbandry, starting from land preparation to harvest and storage, can contribute to ensuring water availability and efficient use. Optimization is challenging because crop cultivation is dynamic, responsive to environmental factors, over which there is not total control.

This implies that a mechanistic decision-making process is necessary in determining the best course of action within specific system conditions. These temporal, spatial and environmental variables that exist in crop production highlight the need to understand how agronomic practices can yield greater water storage, quality and use. Gregory et al. (2000) noted that under rainfed conditions only a small fraction of the total water available for crop production is transpired and water use efficiency (WUE) is low. The assumption that for high evaporative demands, significant losses of water occur via surface evaporation and changes in crop management practice to reduce surface evaporation, may be useful towards improving WUE. Consequently, an integration of best management practices to enhance water use by crops becomes a crucial tool for farmers to stay competitive and ensure food security.

## Elements of Crop Cultivation Affecting Water Use Efficiency

***Soil Tillage***

Soil tillage involves the physical and mechanical manipulation of the soil in preparation for agricultural activities such as seed germination, seedling establishment and root development. Conventional and conservation tillage are the two main categories of tillage systems **(Figure 1)**. Throughout the region, conventional tillage is heavily used by farmers as it is traditional and suited to soil diversity. However, overtime the method negatively alters soil structure causing poor water storage and supply. Conversely, conservation tillage is referred to as a more sustainable and climate resilient approach, which improves carbon sequestration, soil quality and moisture as it reduces the physical disturbances of the soil before cultivation.

The system maintains organic residues, stabilizes aggregates and lessens compaction, which are all essential for water movement and storage in the soil. Despite the overall benefits offered by conservation tillage, the Caribbean's high variability in topography, soil type and rainfall make it difficult to manage land and water using zero tillage. Therefore, to conserve our soils and improve water use, minimum tillage must be considered as the method is used to prepare lands for cultivation while minimizing the negative effects arising from physical disturbances. Hatfield et al. (2001) suggested that it is possible to increase WUE by 25 to 40% through soil management practices that involve tillage.

Any form of conservational tillage will leave some residue on the soil surface, which directly impacts evaporation and facilitates increased water availability to crops. While the results will differ across climates and crops, reducing surface evaporation can only have a positive effect on soil water availability **(Figure 2)**.

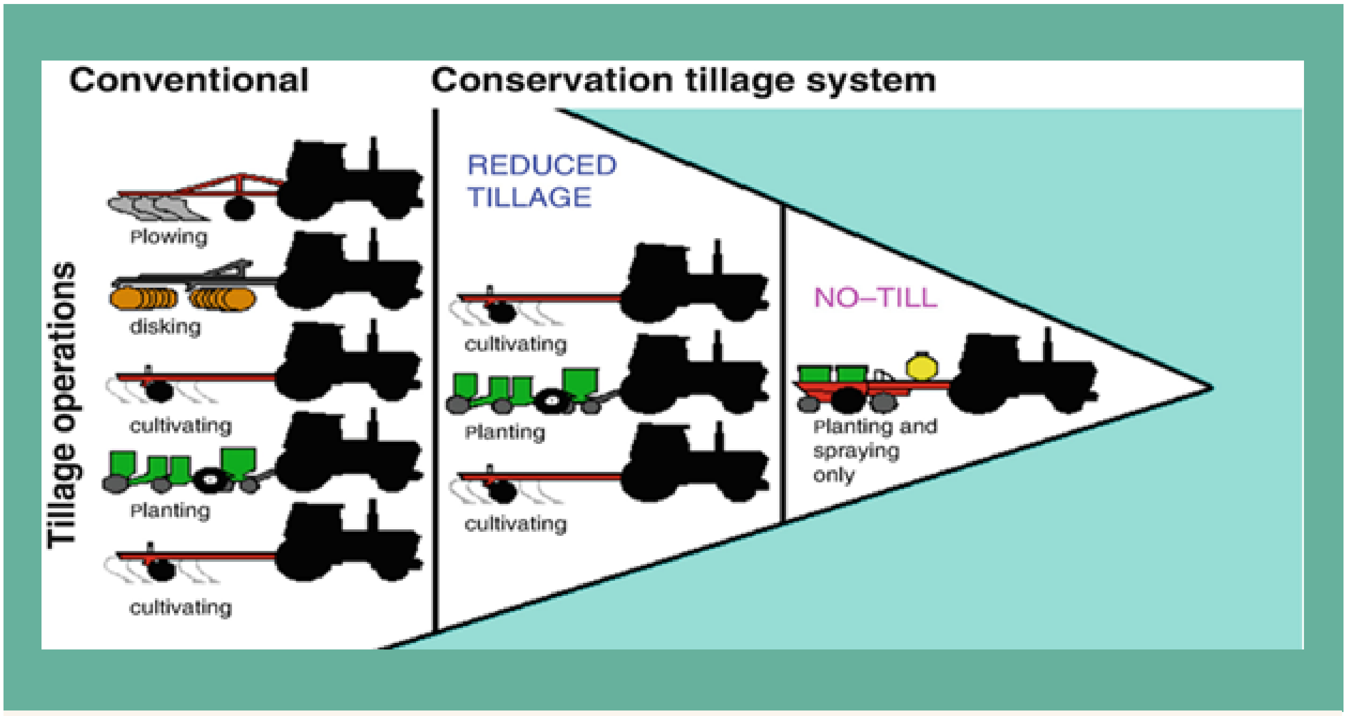



**Figure 1:** Comparison of tillage operations between tillage systems.
Source: Khan (2019)

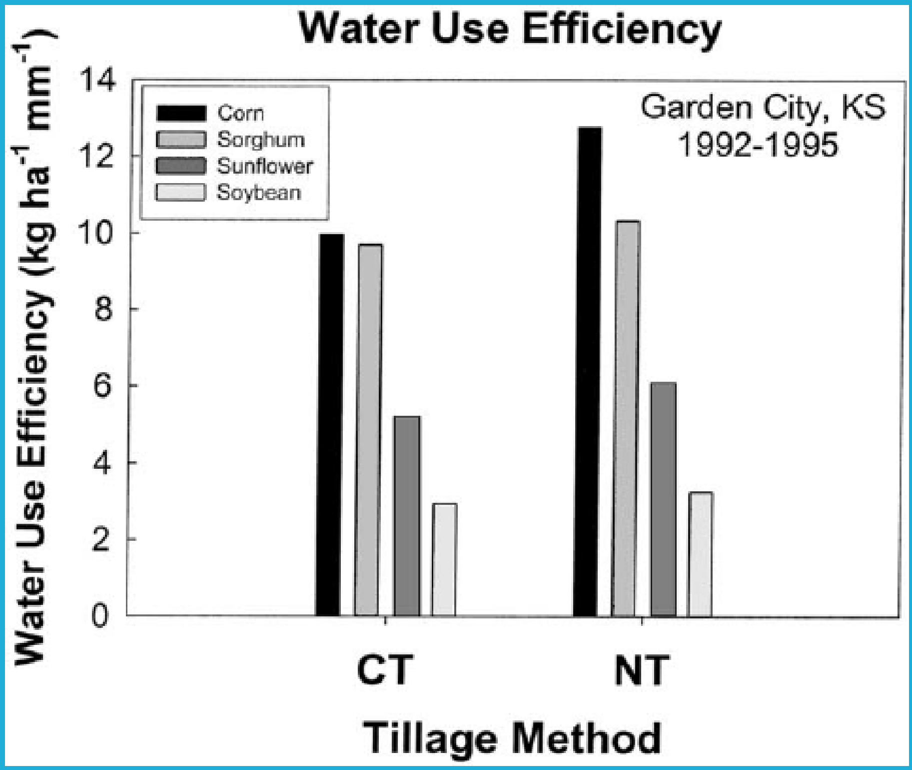



**Figure 2:** Tillage influence on WUE across different crop species for conventional (CT) versus no-till (NT) systems. Source: Nielson et al (2005)

## Major factors affecting soil moisture and plant growth arising from conventional tillage:

### Compaction

Compaction occurs when soil particles are pressed together, resulting in a decrease in size of the pores between them. Compaction occurs due to physical stresses (e.g. regular movement of tractors, humans and animals over the same area of land for prolonged periods) and changes pore space distribution leading to reduced soil water storage, infiltration and drainage and plant availability. King et al (2020) highlighted compaction as a restriction to root development which manifests in drying soils, when mechanical impedance (MI) inflates photosynthates required to extend root tips, leading to short, thick, and shallow roots. A similar stress is also imposed on roots during wet periods, where compacted soils remain waterlogged and devoid of air spaces. The role of soil organic matter in alleviating these manifested stresses are probably more significant than its role in supplying water and nutrients **(Figure 3)**.

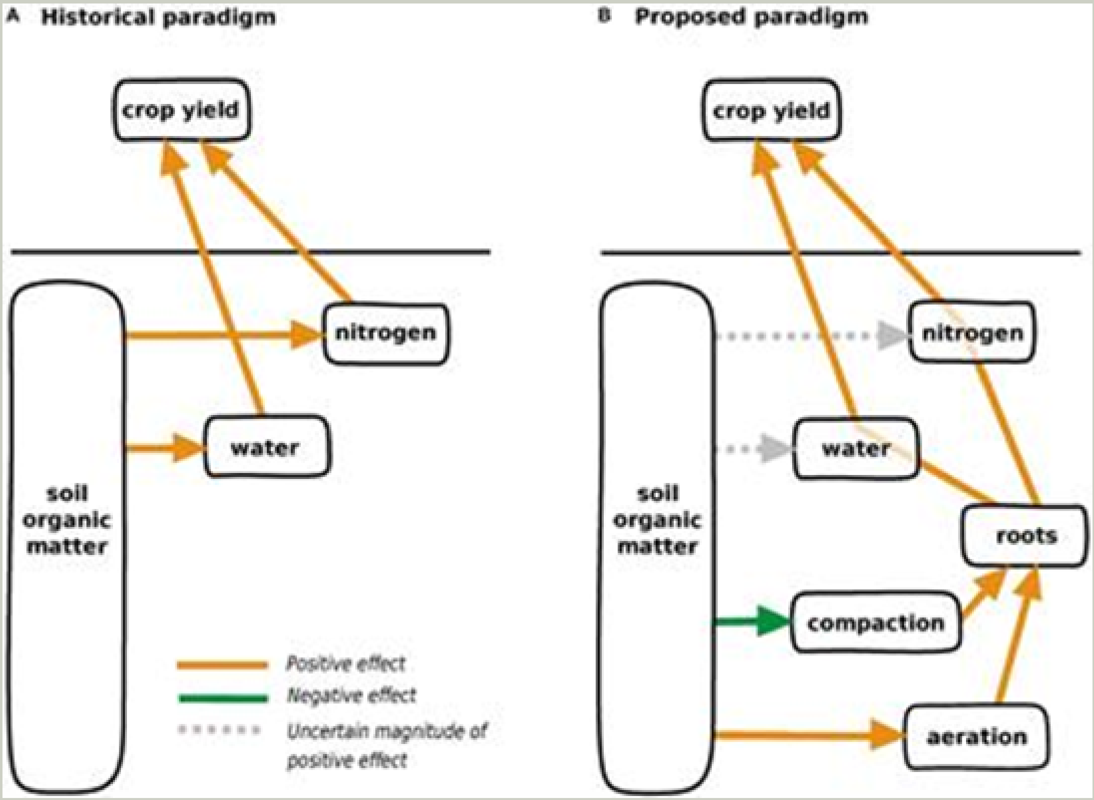



**Figure 3:** Conceptual models representing (A) historically acknowledged and (B) newly proposed mechanisms linking management-induced increases in soil organic matter with crop yield. Source: King et al. (2020)

### Soil aggregate breakdown

Aggregates are made up of soil particles (sand, silt & clay) that are bound to each other by cohesive forces (cations) and organic matter. Aggregate stability refers to the ability of the bounded particles to resist disintegration by disruptive forces such as tillage, water and wind erosion. Stable aggregates are essential in maintaining soil structure and allow for better pore space distribution, which encourages greater infiltration of water through the soil profile. Conversely, unstable aggregates (disintegrated soil particles) can result in soil crusting, which restricts air and water movement within the soil profile and lead to an increased runoff on the soil surface.

**Figure 4.** Comparison of stable and unstable soil aggregates and their effect on water permeability. Source: Cornell University Cooperative Extension

### Residue removal

Organic residues protect the soil from wind and water erosion and improves soil structure by preventing sealing and crusting. Organic residues are removed when intensive or conventional tillage is practiced. The removal of residues disrupts the soil organic matter content, soil nutrient pool and reduces the soil water holding capacity and available water capacity.

**Box 1:** Benefits of conservation tillage on water use and plant growth

**Why should I use conservation tillage as a tool to increase water use efficiency and plant growth?**

- ✓ Reduces soil compaction
- ✓ Reduces aggregate breakdown
- ✓ Reduces surface run-off
- ✓ Reduces nutrient loss and transformations
- ✓ Maintains residues and organic matter in the soil

IMPROVED

**SOIL STRUCTURE**

**WHC & INFILTRATION**

**FERTILITY**

### Stable organic matter and mulch addition

Stability refers to the rate of organic matter degradation, and organic materials are considered stable when decomposition has slowed. Unstable organic materials generally have lower water holding capacity and when applied to soils, will continue to decompose reducing the total organic matter for enriching soil quality. Low-cost technologies such as composting and vermicomposting can be engaged to process organic materials into a stable, safe and mature end-product with increased water holding capacity (WHC) and soil benefits. This increased WHC of stable organic matter arises due to the cohesive forces and the many micro, meso and macro-pores which helps it to hold up to 90% of its weight in water.

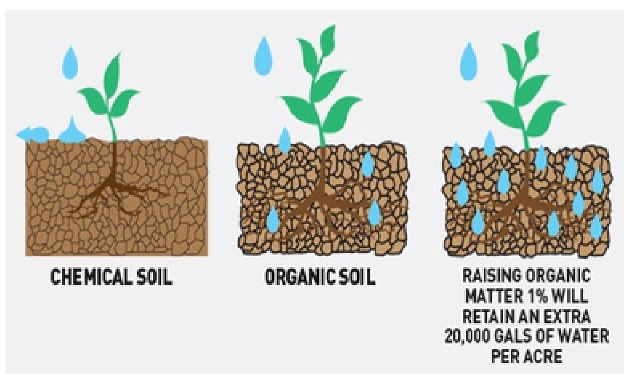
The incorporation of stable organic matter especially in coarse textured soils aid in water recovery, storage and release to meet the needs of the growing crops. Abd El-Mageed et al. (2018) reported similar yields under 15% deficit irrigation with the incorporation of 30 t ha-1 organic compost and 10 t ha-1 mulch. Compost and other stabilized organic matter (e.g. biochar) present large surface areas that work to improve soil aggregation and available water capacity. As mentioned earlier their direct effect on compaction and aeration, facilitate root development contributing to a greater soil water access.

**Box 2:** Characteristics of stable organic matter

**Stable organic amendments (compost & vermicompost) have the following characteristics:**

- ✓ **Good water holding capacity**
- ✓ Reduced pathogen load
- ✓ Reduced viable weed seeds
- ✓ Homogeneous end-product
- ✓ Dirt-like appearance
- ✓ Beneficial micro-organisms
- ✓ Increased available nutrients

**Source:** Serant, 2019



**Mulch** is a material or mix of materials used to cover the soil surface. Mulches can be incorporated into IPM strategies and may be organic or inorganic in origin. Mulch helps to retain soil moisture by reducing the direct impact of the sun on soil temperatures and soil moisture evaporation. Irrespective of mulch origin, they offer the following benefits:

- Retention of soil moisture
- Reduced nutrient leaching since applied soil water is managed
- Modulate root and soil temperatures
- Reduced weed growth
- Reduced soil erosion
- Physical aesthetics
- Grass clippings

**Steps to apply or use mulch:**

1. Ensure that a pre-weeding exercise is carried out on the land before the mulch application.
2. Apply a thin layer of organic mulch, approximately 1 – 2 inches, to facilitate seedling emergence if direct seeding is being utilized.
3. Apply another 1 – 2 inches of organic mulch, especially in coarse-textured soils, to reduce future weed emergence and water loss via evaporation.
4. If direct seeding is not utilized, then an application of 2 – 4 inches of organic mulch may be considered given the properties of the soil and existing shade conditions.
5. If plastic mulch is being used, ensure that edges of the plastic mulch are secured. (N.B. White plastic mulches maintain cooler soil temperatures relative to black plastic mulches).

**Crop selection, crop arrangement and planting density**

Certain crops have strategic physiological and morphological advantages that make them more adaptable to short-term abiotic stress conditions such as drought and waterlogging. These physiological responses and morphological characteristics are continuously being improved through biotechnology and molecular plant genetics. The selection of these environmentally adaptable crops and cultivars might not be high yielding or have the greatest market preference, but they offer an environmental competitive advantage over crops and cultivars that are sensitive to water-induced stresses.

Furthermore, selection of a crop based on its natural advantages (e.g. shallow vs. deep root crops), compatibility in cropping systems, planting density and spacing, creates an ideal opportunity to manipulate crop husbandry practices to increase productivity under unfavourable environmental conditions. Varieties that flourish under increase planting densities are more efficient in water use, as canopy cover will reduce water loss through surface evaporation **(Figure 5)**.


**Figure 5:** High density planting to improve WUE. Source: Testa et al. (2016)

## Crop groupings and their relationship with water

**Leafy vegetables (e.g. cabbage, lettuce, pakchoi)**

- They are usually planted when the soil is near field capacity.
- They have shallow roots and can access surface water more efficiently.
- The more water is available, the greater the leaf expansion of vegetables.
- They are sensitive to waterlogging and drought conditions.

**Root, tubers and bulbs (e.g. carrot, sweet potato, onion)**

- Adequate water is required for translocation of carbohydrates from the leaf to the root, tuber or bulb.
- They are sensitive to water stress during storage organ (tuber or bulb) development.
- Water stress induces small and poor flavoured tubers or bulbs.
- Drastic fluctuations in water supply result in split roots and tubers.

**Fruiting vegetables (e.g. melon, pumpkin, pepper, tomatoes, peas)**

- Fruiting vegetables are sensitive to water-induced stresses at flower and fruit development.
- Fluctuation in water supply leads to abortion of flowers, fruit cracking and increases the possibility of post-harvest losses.
- Water stress impedes the movement of immobile nutrients such as magnesium (Mg) and calcium (Ca) from the soil-root zone to the emerging shoots resulting in conditions such as blossom-end rot.
- They have deeper roots and can access water at deeper soil depths more efficiently.

### Crop Rotation

Crop rotation is a farming system where different crops are grown sequentially on the same area of land. The method allows for staggered and efficient use of resources as various crops have different agronomic needs. Rotating different crops controls water availability which is an essential resource for plant growth. The method breaks the monoculture cropping cycle to introduce crops that utilize less water and provides canopy cover. Additionally, this break in the cropping cycle to introduce crops with different root systems, canopy architecture and water demand allow for increased infiltration, greater aggregate formation, reduced run off and soil moisture evaporation. These beneficial responses that arise from rotating strategic crops, improve water relations in the soil and ultimately increases yield. A further indirect benefit derived from crop rotation is reduced soil erosion and improved soil structure.

Crop rotation allows the farmer to select the rotating sequence of crops that enhances soil structure and quality. The method alters plant spacing, introduces cover crops and provide for the alternation between deep and shallow root plants from one cropping cycle to the next. Cover crops and crops that have smaller space demand, reduce the exposure of the soil to evaporation and erosion caused by intensive wind speed and heavy rainfall. Furthermore, rotating with crops that have different root systems help in holding soil particles at various depths together and allow plants to access different depths of soil water.

### Intercropping

Intercropping is a method of farming (cropping system) where two or more crops are simultaneously grown in a strategic pattern on the same area of land **(Plate 1).** Crops with different morphological characteristics and nutrient demands (e.g. corn and sweet potatoes) are usually grown together. The method facilitates reduced inter-row evaporation, allowing for more water to be available to crops grown within rows. It also reduces water use competition, as crops with different rooting systems are generally planted together increasing access to water at different soil depths. The method offers the following additional benefits:

- Crops planted between the rows (e.g. sweet potato) can take advantage of the micro-climate created from the other crop's canopy (e.g. corn).
- Allows for the planting of multiple crops which usually have different nutrient demands.
- Optimized productivity.

**Plate 1** (description). Source: Lithourgiolis et al. (2011)

**Fertilizer Management**

Fertilizers, in conjunction with water, are important for maintaining crop growth and enhancing productivity. Inadequate soil and crop fertility restrict root growth, canopy and leaf area extension, which ultimately affects water use efficiency. The presence of improved biomass and canopy cover reduces soil evaporation, and vigorous root growth allows for improved extraction efficiency of soil water. Importantly, potassium (via its osmotic function) and nitrogen (as a result of the internal regulation of hormones and xylem pH) are important for efficient and optimal regulation and control of CO2 uptake and water loss through the stomata (Yara, n.d.).

Proper nutrition also ensures maximum yield per unit available water. Moreover, climatic conditions which regulate water availability affect nutrient dynamics in the soil and the uptake of nutrients by the plant. Soil water stress can reduce the amount of nutrients plants are able to access as many of their required nutrients are obtained through water-mediated mechanisms, such as mass flow and ion diffusion in the soil solution. Therefore, the interaction of water and nutrient use efficiency to improve crop yields can be successfully managed by using the following **4Rs**.

## Right Fertilizer Source

Supply **plant-available nutrients** that can meet the crop needs.

- Plants utilize available forms of nutrients and do not have immediate access to organic forms.

Apply fertilizers that **suit** the existing **chemical** and **physical properties** of the soil.

- Most nutrients are unavailable for uptake by the plants when the pH of the soil is very acidic or alkaline. Therefore, over-fertilizing occurs, which can cause severe environmental and water stresses.
- Understanding lime requirement allows for pH management of the field, which makes more nutrients accessible to plants, reducing over-fertilization.
- Understand which fertilizer type best suits your environmental and growing conditions (granular, pelleted, soluble and liquid fertilizer).
- Flooded soils lead to leaching and/or runoff of mobile nutrients such as nitrogen (N), especially when the N source contains no rate-controlling additives.

Understand **blend compatibility** and interactions between sources and fertility.

- Combinations may attract moisture, induce chemical reactions with other components in the fertilizer and limit the uniformity of application.

Recognize the **sensitivity of crops to associated elements** in fertilizer blends.

- Fertilizers containing nutrients with accompanying ions should be managed as they may be beneficial, neutral or detrimental to certain crops (e.g. Potassium Chloride KCl).

## Right Fertilizer Rate

Assess soil and **plant nutrient status** to determine the fertilizer application rate.

- Carry out laboratory testing of samples or utilize simple technologies such as portable soil test kits, chlorophyll meters and leaf colour charts to maintain appropriate fertilizer rates and prevent over-fertilization.

Assess **plant nutrient demand** and **plant nutrient budget**.

- Monitor season to season variability as climatic conditions affect nutrient availability, use, and demand.
- Understand crop nutrient needs at the various growth stages (establishment, vegetative growth, reproductive stage and maturity).
- Evaluate the input of nutrients from your cropping systems relative to productivity (output).

Understand the effects of **fertilizer rates on plant toxicity**.

- Over applying fertilizers can lead to root and foliar burn, which has a negative effect on how the plant interacts with soil water **(Figure 6)**.

## Right Fertilizer Timing

Assess **soil nutrient supply dynamics and timing of crop uptake.**

- Monitor mineralization of organic residues and amendment to ensure that crop need is not affected by mineralization rates.
- Synchronize nutrient application with crop growth and physiological requirements.

Assess **nutrient release** and availability from various fertilizers.

- Examine release rates which are controlled by additives and treatments to commercial fertilizers such as encapsulated protective coatings **(Figure 7)**.
- Monitor weather and soil moisture conditions which affect fertilizer release rates.

Evaluate the influence of **timing on nutrient loss due to weather conditions**.

- Plants uptake nutrients better under certain climatic conditions.

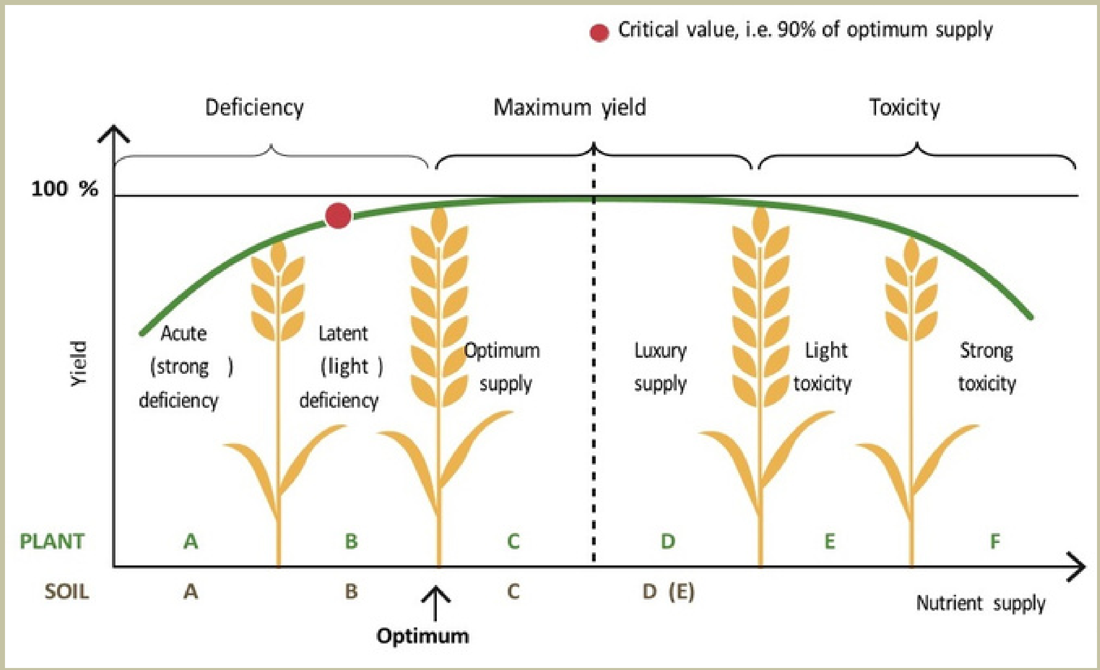



**Figure 6:** Illustration of nutrient fertilizer range on crop yield. Source: Reetz Jr, et al. (2015)

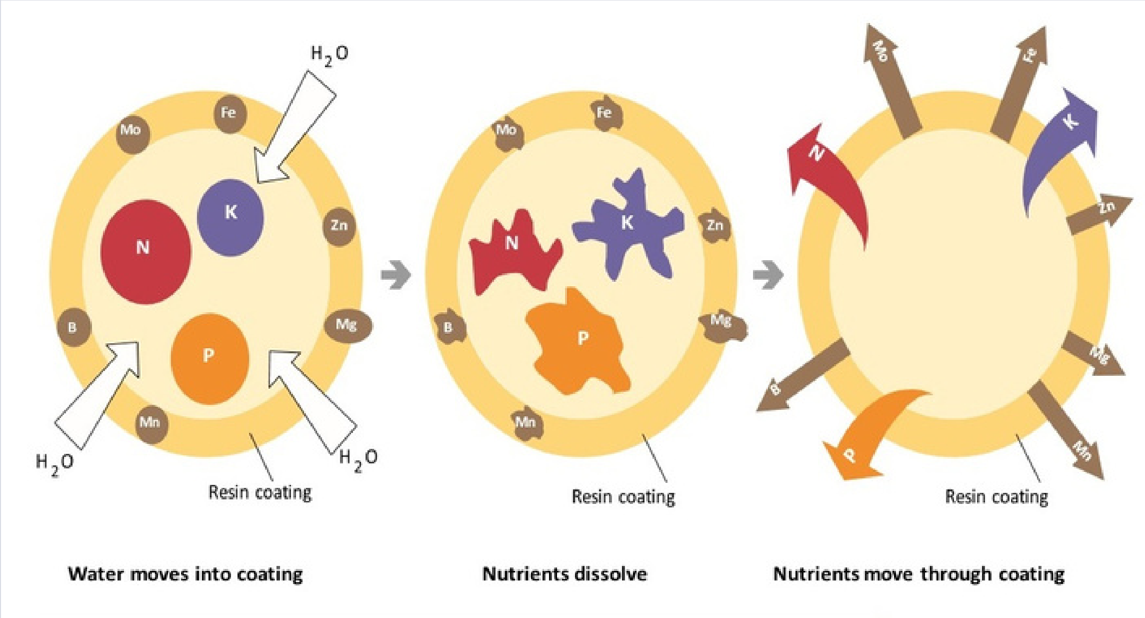



**Figure 7:** Controlled nutrient release fertilizer. Source: Reetz Jret al. (2015)

## Right Fertilizer Placement

Understand **root-soil fertilizer placement dynamics**.

- Ensure that roots can intercept and absorb an adequate amount of nutrients through various placement systems (e.g. fertigation, surface and deeper banding application) **(Figure 8)**.

Assess the **compatibility** of fertilizer **placement technique and tillage system**.

- Conservation tillage requires placement techniques that can position growing roots with fertilizers because mechanical agitation of the soil is limited.

Manage **spatial variability** on the field and limit potential loss of nutrients due to placement.

- Understand how variability in crops and soil texture can affect fertilizer placement techniques (e.g. sandy textured soils tend to be more porous and have low cohesive forces leading to increased leaching of mobile nutrients such as N).

## Drip Fertigation

Drip fertigation is the application of water-soluble fertilizers through a drip irrigation system directly to the plant root zone. The fertilizer application method offers the following benefits: Enhanced water use and uniform nutrient distribution. Efficient plant use of the soluble nutrients as it is applied directly to the active root zone. Increased management of fertilizer application time and amount. Greater ability to apply nutrients during unfavourable environmental conditions.

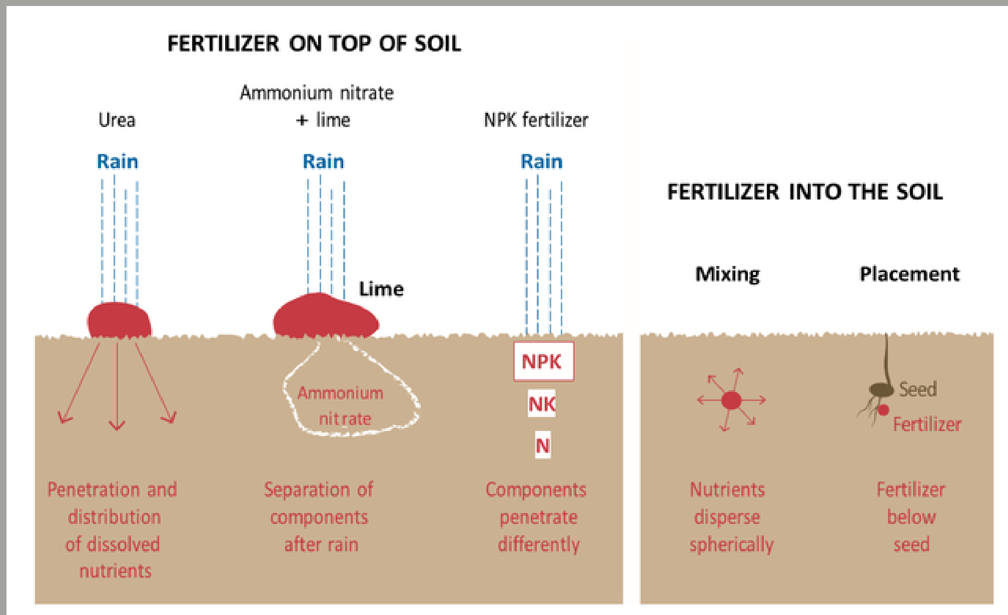
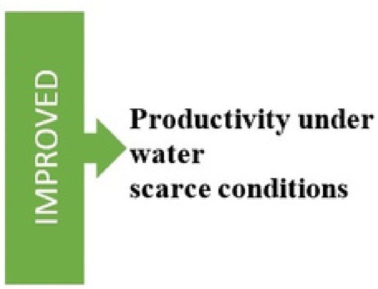



**Figure 8:** Fertiliser placement options. Source: Reetz Jr et al. (2015)

**Box 3:** Benefits of fertilizer management on water use efficiency

**Why does right fertilizer source, rate, timing and placement affect water use efficiency?**

- ✓ Reduces mineral salt accumulation in soils
- ✓ Reduces salt toxicity in plants
- ✓ Reduces plant osmotic stresses
- ✓ Reduces potential nutrient loss due to environmental factors



## Antitranspirants

Antitranspirants are a mixture of metabolic inhibiting compounds that are usually applied via spraying of plant leaves. These compounds aim to create adequate plant-water balance, and their efficacy depends on several plant factors such as stomatal distribution, new foliar growth and phytotoxicity. However, caution should be taken when using antitranspirants to reduce transpiration losses as it has been documented to also reduce photosynthetic rates due to stomatal closing and blocking mechanisms. The following are the four main ways antitranspirants work:

- Stomatal closing: induces the closing of stomata which reduces water loss from the plant due to evapotranspiration. These may also affect CO2 uptake and photosynthetic rates.
- Film forming: thin and transparent films cover the leaf surface forming a physical barrier which reduces water vapour loss.
- Reflecting: increases reflection of light and reduces the absorption of solar energy to improve leaf temperatures and ultimately transpiration rates.
- Growth retardant: manipulates growth hormones to reduce shoot growth (leads to reduced evapotranspiration) and increase root growth (able to efficiently mine for more water in the soil).

## Biostimulants

Biostimulants include micro-organisms and diverse groups of substances derived from biological origin that are used to improve plant growth, increase yields, decrease disease incidence and reduce abiotic induced stresses. Biostimulants usually contain or modify plant growth regulators and plant protective compounds. The following are examples of biostimulants that are being used to improve plant health and productivity by eliciting defence and plant growth responses:

- Seaweed extracts
- Humic acid formulations
- Plant growth promoting rhizobacteria (PGPR) formulations

Biostimulants moderation of physiological and morphological plant features increases resilience and adaptation to water stress conditions.

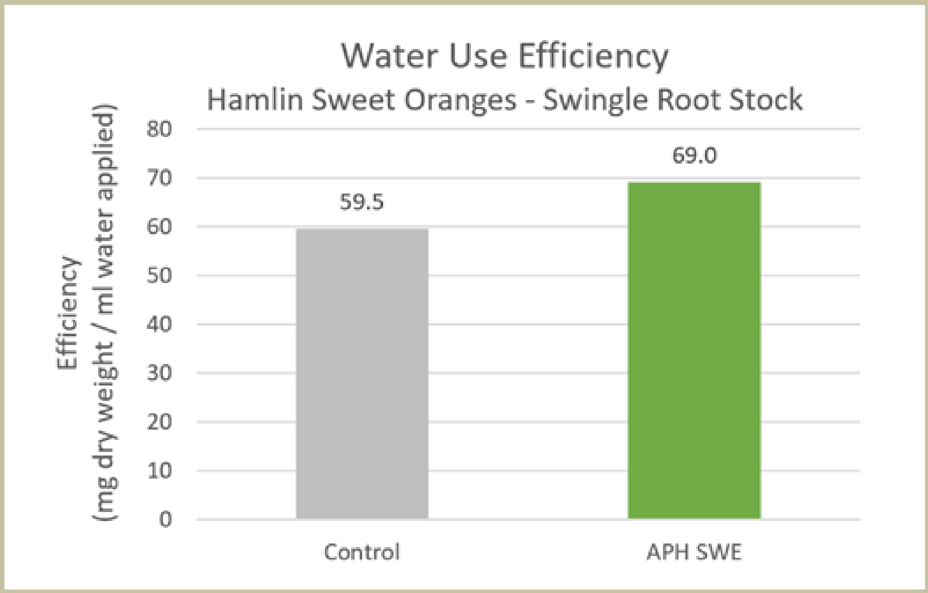



**Figure 9:** Comparison between control and seaweed extract in WUE. Source. Spann et al. (2011)

## Agroforestry

Agroforestry is the spatial arrangement and combination of trees (perennials) and crops (short term/annual) on the same area of land **(Plate 2)**. The intentional integration of trees and crops allows for environmental, economic and social benefits. The method creates conditions for farmers to adapt to climate change and diversify output (e.g. fruit trees and lumber). Agroforestry incorporates different strategic techniques such as alley cropping, silvopastures and riparian buffers. The following are some of the water and nutrient use benefits of agroforestry:

- Increase soil organic matter from leaf litter – leads to increased water holding capacity of soils.
- Provides shade from the canopy that helps reduce soil moisture evaporation and creates ideal micro-climates for crop growth.
- Reduced competition for resources if planned properly, as trees (perennials) with deep roots usually utilize different pools of nutrient and soil water relative to short term crops.
- Enhance nutrient supplies (N fixation in soils) through the incorporation of leguminous trees.

Canopy cover from trees protects the soil from the force impact of rain and wind which breaks down soil aggregates and increases surface runoff of water.

**Plate 2:** Agroforestry system. Source: Kumar et al. (2019)

# Lessons Learnt

Implementing and integrating good crop husbandry practices can increase overall crop water use efficiency, growth and yield **(Figure 10)**. Furthermore, once these good agricultural practices fit your existing field, crop and environmental conditions then the following can be expected over time:

- Improved soil quality.
- Improved storage of soil water.
- Improved water quality and reduced contamination.
- Efficient management of fertilizers and pests.
- Strategic selection of climate adaptable crops for various cropping systems and cycles.
- Efficient arrangement of crops to maximize water use and storage.
- Enhanced plant physiological response to abiotic and biotic stresses.

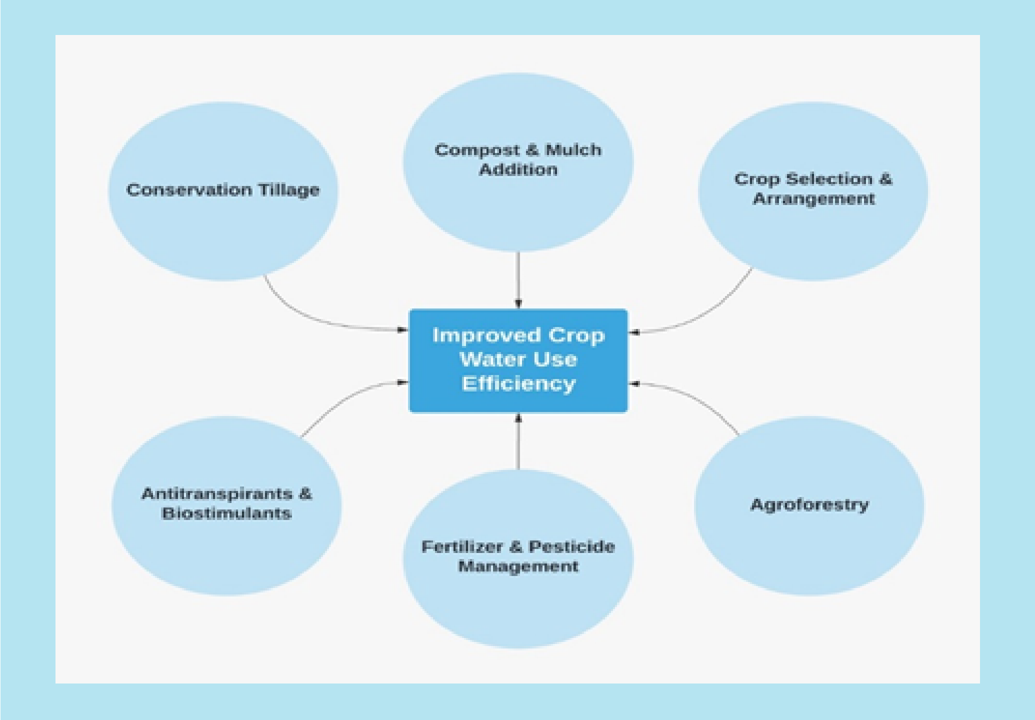



**Figure 10:** Crop management factors affecting WUE

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# MODULE 6

## Agricultural Water Management and Alternative Production Systems

### Goal

The purpose of this module is to increase awareness of traditional and alternative sources of irrigation water in SIDS. The legal and regulatory framework for water collection, distribution and use will also be highlighted with focus on the requirements to achieve improvements in productivity and water use. Assessment of irrigation water quality associated with different sources will also be covered. Finally, alternative production systems including greenhouse, and soilless cultivation will be described in relation to water use efficiency.

### Learning Objectives

- Identify alternative sources of irrigation water at local level.
- Understand the legal and regulatory framework for water management within respective countries.
- Describe key water quality parameters important to irrigation use and how to mitigate against potential pollution.
- Compare water use efficiency of intensive and extensive production systems.

# Introduction

Water management at farm level may involve storage, conveyance, application and monitoring of quantity and quality. At the district/community level, public intervention is typical with the implementation and enforcement of legal instruments concerning water resources management. All Caribbean countries possess a water regulating authority, which manages national/local storage and distribution based on existing laws. These instruments are mostly outdated and do not encourage approaches to improve WUE across management zones. Agricultural water use is not prioritized and farmers typically face shortages from surface or ground supplies during peak demand periods (dry season). Specifically, addressing agricultural water use is crucial to improving WUE.

Further efforts aimed at encouraging alternate sources of water for irrigation will bolster limited natural supplies while reducing the competition for water across sectors. Use of treated wastewater following appropriate guidelines has potential as an irrigation source for countries currently possessing such treatment plants.
At present, treated wastewater is released back into the environment, at great opportunity costs.

Alternative water sources require assessment of quality to protect against possible pollution and/or health and safety concerns. Irrigation water quality is an important factor affecting use and management of the water. Poor quality water can negatively affect the crop and contribute to soil degradation. Water quality has greater significance for intensive greenhouse/soilless systems that are 100% based on irrigation. In most instances, such systems are combined in the process of fertigation, which is highly sensitive to water quality.

Notwithstanding this, greenhouse and other controlled production systems present the greatest opportunities for improving WUE, notably associated with the significant level of control of all factors of production. Tanaskovik et al. 2011, reported that during three years of research, treatments under drip fertigation showed almost 28% more water use efficiency in comparison to the treatment with conventional application of fertilizer and drip irrigation and 87% more than the treatment with furrow irrigation and conventional application of fertilizer. In a scenario of reduced freshwater resources and increasing drivers of crop water demand, consideration to this option is warranted.

## Alternative Sources of Irrigation

### Rainwater Harvesting

In addition to optimizing water use efficiency using technologies, finding and utilizing alternative sources of water for irrigation can help increase WUE. A traditional alternative water source is rainwater harvesting. Typically, when rain falls, only a fraction remains as available soil moisture accessible to crops. Rainwater harvesting captures some of this rainfall by directing the runoff from impervious surfaces to storage areas such as surface ponds, tanks and underground aquifers. Rainwater harvesting systems may consist of the following components **(Figure 1)**. Harvested rainwater supplements surface water which is maybe inadequate to meet crop demands especially during the dry season and enhanced periods of prolonged water stress as projected under climate change scenarios.

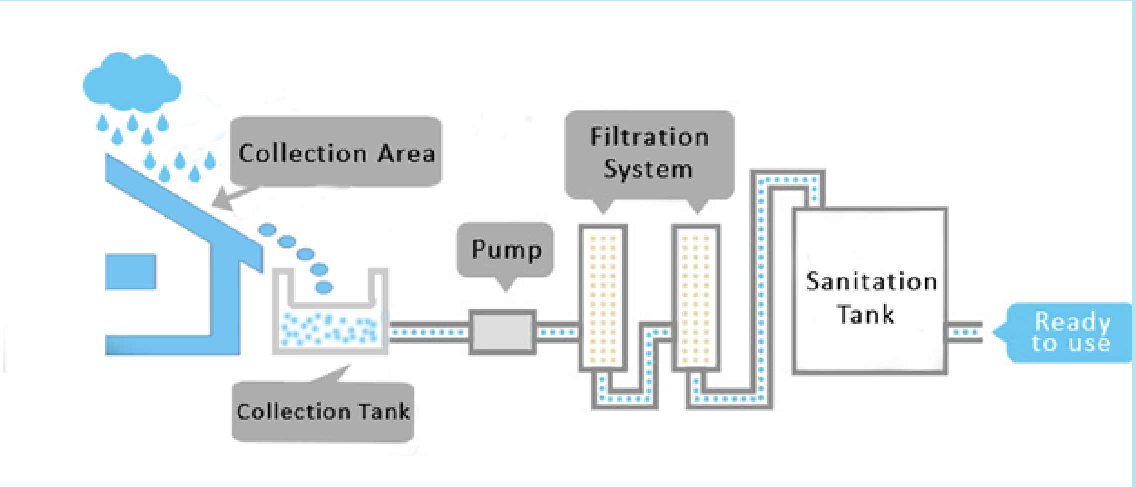


**Figure 1:** Illustration of the rainwater harvesting process.
Source: (Akruthi Enviro Systems n.d.)

**There are two major ways of harvesting rainwater:**

1. **Surface Runoff Rainwater Harvesting Method:** This type of harvesting seeks to capture rainwater flowing across the ground for irrigation and other purposes. The volume of water flowing across the ground is significantly more due to a larger surface area and events such as flood flows. Significant water losses can take place due to high ground infiltration rates and runoff. The water quality collected from this method is often quite marginal, but suitable for irrigation purposes. The Local version of this method is called “runoff ponds." Its use has improved productivity during water stress periods but the lack of other supporting information on crop water demand and ET has limited their use towards improved WUE.

2. **Roof Top Rainwater Harvesting Method:** Rainwater is captured from the roof catchments of domestic and non-domestic buildings and stored in tanks. In the Caribbean it is not uncommon to see it being collected from rooves constructed with galvanize sheets, clay tiles and slates. Special attention should be paid to the type of roof being used as a catchment, since water from asbestos roofing and catchments with metallic paint may affect the quality of water and health if consumed. These systems are mainly used to supplement portable water for household and not for irrigation. However, they offer better quality water, in lesser amounts.

**Calculating Irrigation Supply of Harvested Rainwater**

Calculating the irrigation supply of harvested rainwater can help agriculture stakeholders prepare in advance for the growing season. If calculations predict a surplus of rainwater for the season, then preparations can be made for extra storage or use of the resource. However, if a deficit is predicted, then plans can be made to obtain another source, change crop focus, or even limit the amount of planting. The irrigation operator has many options when calculations of rainwater supply are made.

**Calculate Supply** (Amount of Rainwater Collected off all or part of Roof)

Supply In gallons = Rainfall In inches X 0.623 X Catchment Square feet X Runoff Coefficient

**Calculation Input Variables:**

**Rainfall:** The estimated amount of rain for a given period.

**0.623:** one inch of rain will provide 0.6 gallons per 1 square foot of roof.

**Catchment:** Size of catchment area.

**Runoff Coefficient:** Runoff coefficient is a dimensionless factor that is used to convert the rainfall amounts to runoff. It represents the integrated effect of catchment losses and hence depends upon the nature of land surface, slope, degree of saturation, and rainfall intensity. It is also affected by the proximity to water table, degree of soil compaction, porosity of soil, vegetation, and depression storage (Goel, 2011).

## Treated Wastewater

Treated wastewater is another potential water source that can be used to supplement irrigation demands. Wastewater is any water which has been affected by anthropogenic influence. Wastewater is abundant and represents a renewable resource in the hydrological cycle. It is usually effluent from baths, sinks, kitchens, toilets and industry among other sources **(Figure 2)**. However, with existing technology, this water can be treated to meet strict health and environmental regulations and reused for irrigation purposes, reducing environmental degradation while addressing water scarcity.

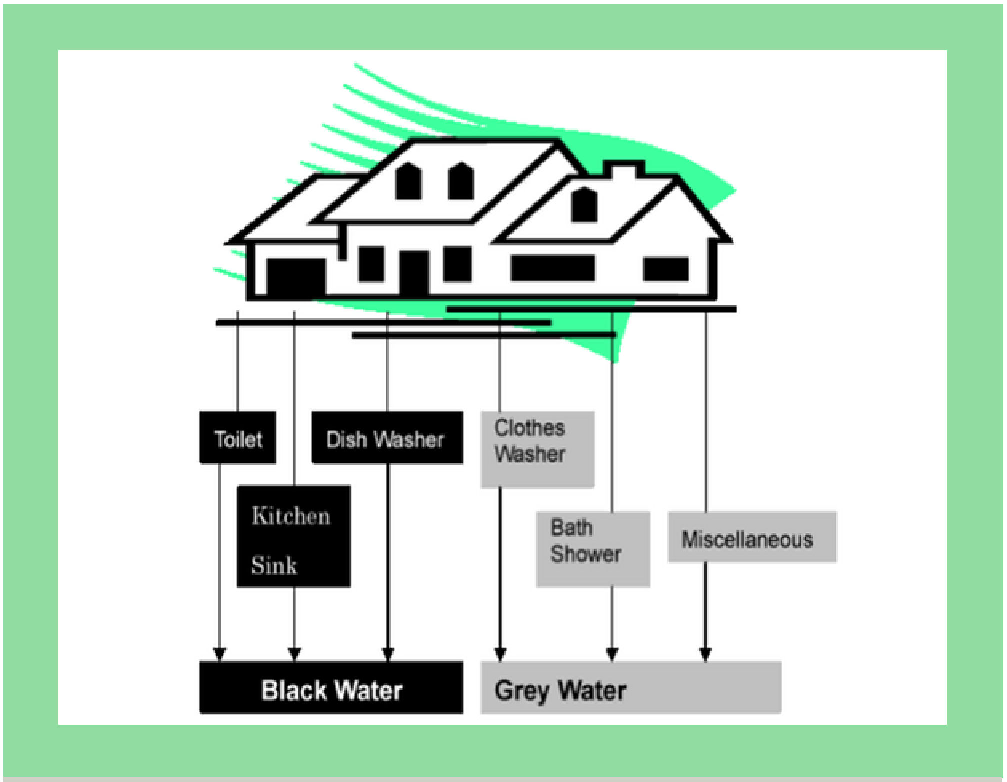


**Figure 2:** Schematic showing the sources and types of wastewater. Source (GEF Crew, 2015)

**Treated wastewater has many benefits including:**

- Helps conserve limited freshwater reserves.
- Increases crop yields as it is nutrient rich.
- Reduces pollution of water sources (rivers, natural wells etc).
- Conserves nutrients, reducing the need and cost of purchasing artificial fertilizers.
- Provides a reliable source of water to the farmer and irrigator.

However, the use of wastewater in agriculture is met with numerous concerns, not least the health and safety concerns. Secondary treated water possesses a microbiological concern (presence of pathogen) and should only be used following strict regulatory guidelines. Tertiary treated water should possess similar water quality as potable water and can be used without restrictions for crop irrigation.

## Wastewater Treatment

The aim of wastewater treatment is to recover usable water from previously contaminated effluent, making it suitable for human health firstly, and the environment. To be considered recovered or usable, treated wastewater will need to meet sensory, chemical and microbiological quality standards. Wastewater treatment plants will therefore seek to reduce chemical and biological constituents, as well as organic and suspended solids which may be of concern to public health. The different treatment stages are:

- Screening: Large (and often very visible) objects are removed from wastewater.
- Primary: Organic and inorganic solids are then removed along with other floating materials.
- Secondary: Organic residue and other suspended particles are removed through aerobic degradation.
- Tertiary and/or Advanced: Removal of heavy metals and nutrients. Microbial load is reduced through disinfection and the treated water discharged.

The process is illustrated in **Figure 3** on the following page.

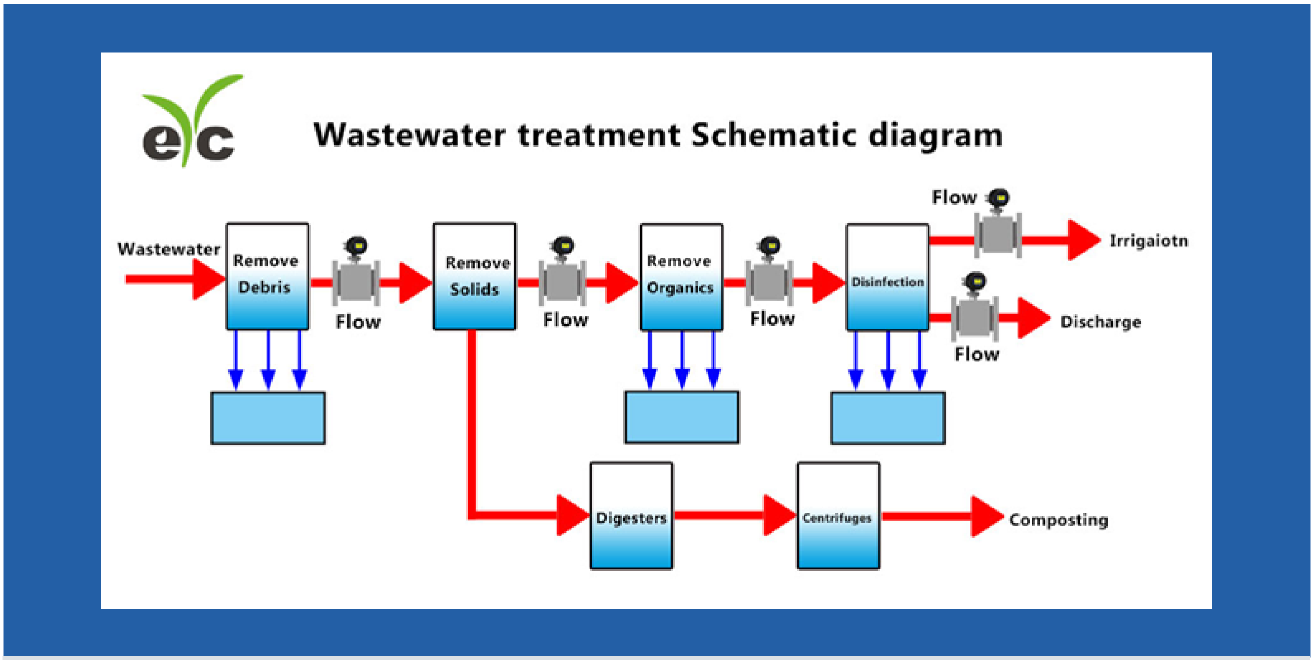


**Figure 3:** Flow Diagram of Wastewater Treatment. Source: (EYC, 2020)

## Desalination

The islands of the Caribbean are surrounded by salt water which potentially is a source of irrigation water once treated. Desalination effected through the process of reverse osmosis, removes dissolved salts from saline water to produce fresh water. The process has a high energy requirement, which has limited fresh water produced to domestic use. Other options that make use of renewable energy sources such as solar radiation, is more practical for agricultural use. Such technology as shown in **Figure 4**, can be beneficial for farming communities closer to the shoreline in Caribbean Islands.

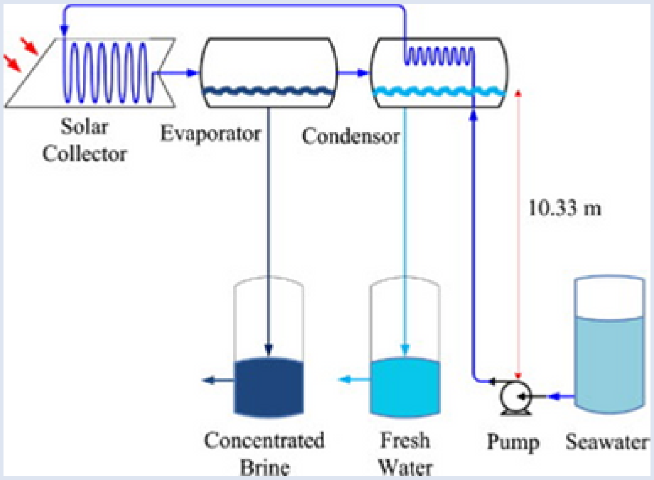


**Figure 7:** Flow Diagram of a solar assisted desalination plant. Source: (Li, et al. 2013)

## Legal and Regulatory Framework for Alternative Water Sources

Cashman, (2014) noted that no country yet has implemented any significant IWRM proposals, other than a few catchment scale demonstration projects. Nor have the key linkages between land and water management been incorporated into policies and planning. This reality remains a major constraint to sustainable development and improved livelihoods, as water is critical to economic and social growth. Water management has continued to be public sector driven and managed with service providers duplicating as resource managers.

The system is inefficient with significant duplication in some areas and absenteeism in others. While monitoring and management calls for interagency and inter-ministry coordination, harmonization of effort including resource use is poor at best. Internationally, Caribbean countries agreed to have Integrated Water Resources Management (IWRM) plans and Water Use Efficiency (WUE) plans developed and implement since 2005, in keeping with the growing understanding and trend of these concepts in sustainable water resource management and climate change. Cashman (2012) noted that only four countries have approved and adopted water sector policies inclusive of the international commitments.

Noting the absence of a policy framework at national level, sectoral management of water resources is ever more difficult. Water availability remains a primary limiting factor of production for most farmers, which if not addressed through a holistic approach, may result in unsustainable futures. Attempts at aligning current water resources management to IWRM and WUE standards should consider:

1. Legislation governing agricultural water use.
2. Wastewater reuse including irrigation supplementation and aquifer recharge.
3. Institutional coordination and harmonization of water resource management and professional capacity building.
4. Implementation of IWRM.
5. Improvements of systems of transparency and accountability.

## Irrigation Water Quality

Irrigation water quality is a very important aspect of irrigation and agricultural production as it affects plant growth, soil health, human health, and the functionality and longevity of irrigation systems. Water quality refers to the physical, chemical and biological properties of water that influences its use, which in this case is irrigation. These properties are compared to established standards to determine if the water is fit for use. There are four major criteria for assessing irrigation water quality:

- pH: acid, basic or alkaline
- Salinity: Amount of dissolved salts
- Specific ions: Sulphates, chlorides, heavy metals and trace elements
- Microbial pathogens

## pH

The pH of irrigation water is important for plant growth as pH (including alkalinity) affects the solubility and availability of nutrients in the root zone. Plants prefer slightly acidic soil pH levels of between 6.0 – 7.0 and can tolerate higher pH levels more so than lower levels if the pH is not excessive. Low pH, similar to high pH, can affect nutrient uptake by plants and may result in plant toxicity. Issues of high pH can be addressed by using acids (Phosphoric acid) and issues of low pH can be remedied by using soluble liming products (Calcium hydroxide). However, if nutrients (fertigation) are going to be added to irrigation water, further caution is needed to ensure compatibility and solubility.

## Salinity

Salinity refers to the salt content of the irrigation water. It is perhaps the most prevalent issue pertaining to irrigation water, as it can have devastating effects on plants. Most agronomic crops have low salt tolerance and begin to show reduced productivity at salinity levels approaching 2 dS m-1 **(Table 1)**. To determine whether one can use irrigation water with moderate levels of salinity, consideration should be given to crop's salt tolerance, the soil type, climatic conditions and management practices. Water reuse for irrigation purposes must have low to medium electrical conductivity (EC) (0.6 – 1.7dS m-1).

**Table 1:** Suggested Criteria for Irrigation Water Use based on Electrical Conductivity (EC)

| Classes of Water | Electrical conductivity (dS $m^{-1}$) |
|---|---|
| Class 1- Excellent | 0.25 |
| Class 2- Good | 0.25 – 0.75 |
| Class 3- Permissible | 0.76 – 2.00 |
| Class 4- Doubtful | 2.01 – 3.00 |
| Class 5- Unsuitable | 3.00 |

While it is best to use good quality water to irrigate, the quality of water from particular sources may be outside the control of the irrigator. If saline water is the only option, a leaching fraction must be included to compensate for the adverse effects of the saline water on crop and soil health. The leaching fraction (LF) is defined as the ratio of the quantity of water draining past the root zone to that infiltrated into the soil's surface. An additional amount of poor quality water is applied to drain excess salts out of the root zone **(Figure 8)**. However, care must be taken to ensure that leached soils do not contaminate ground water or pose an environmental concern at lower elevations.

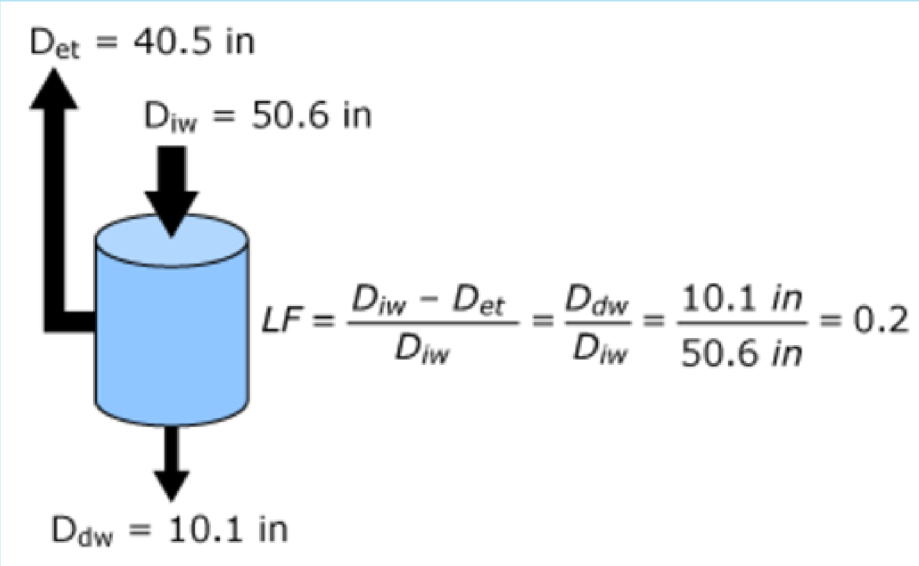


**Figure 8:** Calculation of the LF and depicting of the relationship among irrigation, ET, and root zone drainage. Source: http://www.salinitymanagement.org/

**Specific Ions**

**Trace Elements -** Trace elements such as boron and other heavy metals are generally not present in irrigation water in any high amount. However, at high levels these can be toxic to plants and remain in the soil if there is not enough leaching taking place. This is of greater concern in the use of groundwater that has interacted with geological material with increase potential for metal dissolution.

## Controlled Agricultural Systems

### Greenhouse Farming

Greenhouse farming is a form of controlled environment agriculture **(Figure 9)**. This system allows for the control of most to all the factors of production, providing increased control over water use efficiency and productivity. Greenhouse conditions affect stomatal activity which influences evapotranspiration. This can mean that less or more water can be used. However, it is expected that the water used will result in higher productivity, thus increasing WUE. It is worth noting that micro-irrigation is required to deliver water to crops. Hence, crops can still be negatively affected if water requirements are not met.

Growers therefore must consider factors such as: methods of application, irrigation application amount, water-quality and conservation, and runoff. These factors when considered point to the use of automated irrigation as a best practice in greenhouse farming since timing and quantity can be scheduled and adjusted with ease as plants grow. Many of the monitoring technologies described in **Module 4** support automated water management decision in greenhouses, leading to improved WUE.

**Figure 9:** Greenhouse production at the UWI Agricultural Innovation Park in Trinidad and Tobago.

### Shade House Farming

Similar to greenhouse farming, it's designed using wooden or steel frames covered with a netting or cloth material that provides protection from external climatic elements like excessive rainfall, sunlight and dry periods **(Figure 10)**. These shade houses can be equipped with irrigation systems aiming to maximize the water use efficiency. This system like the greenhouse system also reduces the evapotranspiration rate.

### Vertical Farming

These systems use shipping containers and warehouses to provide a controlled environment for producing food **(Figure 10)**. These crops are grown in vertically stacked layers using hydroponics or aeroponics systems. The system is fitted with electronic sensors that ensure that crops are provided with sufficient LED light, nutrients, heat and water. In this intensive system, approximately 70 – 90% of water is saved compared to extensive systems. This is because soil and evapotranspiration losses are significantly reduced and there is an opportunity for water capture, "cleaning" and reuse.

**Figure 10:** Showing shade house production in Guyana. Source: The Guyana Chronicle.

**Figure 11:** Intensive Vertical farming system. Source: Tasgal (2019)

# Lessons Learnt

1. Rainwater harvesting, desalinated water and treated/reclaimed can be accessed for agricultural use in Caribbean SIDS.
2. There are opportunities for Caribbean SIDS to improve WUE in agriculture through the development of policies and legislation to support it.
3. Irrigation water quality is of utmost importance when considering alternative sources for agriculture. It impacts the environment, human health and the agricultural production systems.
4. Intensive systems of agriculture allow for more control over WUE and is an area that can be tapped to increase WUE in SIDS.

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**Caribbean WaterNet (Cap-Net UNDP)**
The mission of Caribbean WaterNet is to promote sustainable Integrated Water Resources Management (IWRM) in Small Island Developing States (SIDS) of the Caribbean: "Ensuring a future by learning in the present." Caribbean WaterNet focuses on building institutional and technical capacity of Caribbean SIDS as it relates to IWRM by increasing resilience of vulnerable populations across the region. It develops and administers training programmes, workshops, awareness initiatives and outreach concepts tailored to suit the Caribbean context.

**Website:** www.caribbeanwaternet.org | www.cap-net.org

**Faculty of Food and Agriculture, The University of the West Indies (UWI), St. Augustine**
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