CHAPTER 5

Water efficiency in agriculture

Water efficiency of irrigation can be improved by making the right decisions regarding:

- Crop selection
- Irrigation scheduling
- Irrigation methods
- Source of water.

Globally, agriculture is the largest user of water[1] and also uses 85% of the water withdrawn in the MENA region. Additionally, water use in agriculture is often highly inefficient with only a fraction of the water diverted for agriculture effectively used for plant growth, with the rest drained or lost via evapotranspiration.

With population growth and rising affluence, the need for food and thus agricultural water for irrigation is increasing. At the same time the quantity of water with a sufficient quality is declining. There is also an increasing demand to shift more of the water used in agriculture to higher-value urban and industrial uses. Thus, producing more with less is the only option.

Water efficiency in agriculture has been extensively researched for many years. Universally applicable solutions are however difficult to come by, particularly due to different contexts and high specificity of agricultural practices. But efficiency gains are often possible through suitable crop selection, proper irrigation scheduling, effective irrigation techniques, and using alternative sources of water for irrigation. It should be noted that increasing water efficiency often provides benefits that go far beyond reduced water use.

[1] Vital Water Graphics. An Overview of the State of the World's Fresh and Marine Waters - 2nd Edition - 2008

Improving Irrigation practices can:

- Reduce water and pumping costs
- Reduce costs for fertilizers and other agricultural chemicals
- Maintain a higher soil quality
- Increase crop yields – by as much as 100%.

IMPROVING WATER EFFICIENCY IN IRRIGATION

Irrigation is necessary when plants cannot satisfy all their water needs through natural precipitation – this practice is also called deficit irrigation. Therefore, an ideal irrigation effort aims to cover the deficit between a crop's optimal water needs and what it can take up through natural means. Because arid, semi-arid, and desert climatic conditions prevail in the Arab region, irrigation is indispensible.

Climatic conditions, soil type and structure, plant type, and the irrigation techniques applied are among the main factors that influence the efficiency and effectiveness of irrigation practices. For a given location and climatic and soil conditions, the efficiency of water irrigation practices can be improved by making the right decisions regarding:

- Crop type
- Irrigation scheduling
- Irrigation method
- Soil enhancement measures
- Source of water

CROP WATER NEEDS

Crops differ both in terms of their daily water needs and the duration of their total growing period. Consequently, **crop type** is a chief factor influencing irrigation water needs. Crops with high daily needs and a long total growing season require much more water than those with relatively lower daily needs and shorter growing seasons. Therefore, 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.

In Tables 5.1, 5.2, and 5.3, values of typical water needs, average length of growing season, and the total water demand for different crops are given.

Water requirement as compared to ordinary grass				
30% less	**10% less**	**Same**	**10% more**	**30% more**
Citrus	Cucumber	Carrots	Barley	Paddy rice
Olives	Radishes	Crucifers (Cabbage, Cauliflower, Broccoli, etc.)	Beans	Sugarcane
Grapes	Squash		Maize	Banana
			Flax	Tobacco
			Small grains	Nuts and fruit trees with cover crops
		Lettuce	Cotton	
		Mellons	Tomato	
		Onions	Eggplant	
		Peanuts	Lentils	
		Peppers	Millet	
		Spinach	Oats	
		Tea	Peas	
		Grass	Potatoes	
		Cacao	Safflower	
		Coffee	Sorghum	
		Clean cultivated nuts & fruit trees	Soybeans	
			Sugarbeet	
			Sunflower	

Table 5.1: Water needs of field crops in peak period as compared to standard grass[2]

Crop	Total growing period (days)	Crop	Total growing period (days)
Alfalfa	100 – 365	Millet	105 – 140
Banana	300 – 365	Onion green	70 – 95
Barley/Oats/Wheat	120 – 150	Onion dry	150 – 210
Bean green	75 – 90	Peanut	130 – 140
Bean dry	95 – 110	Pea	90 – 100
Cabbage	120 – 140	Pepper	120 – 210
Carrot	100 – 150	Potato	105 – 145
Citrus	240 – 365	Radish	35 – 45
Cotton	180 – 195	Rice	90 – 150
Cucumber	105 – 130	Sorghum	120 – 130
Eggplant	130 – 140	Soybean	135 – 150
Flax	150 – 220	Spinach	60 – 100
Grain/small	150 – 165	Squash	95 – 120
Lentil	150 – 170	Sugarbeet	160 – 230
Lettuce	75 – 140	Sugarcane	270 – 365
Maize sweet	80 – 110	Sunflower	125 – 130
Maize grain	125 – 180	Tobacco	130 – 160
Mellon	120 – 160	Tomato	135 – 180

Table 5.2: Indicative values of the total growing period for different crops[3]

[2] FAO, 1986. Irrigation Water Management: Irrigation Water needs.
[3] Ibid.

Crop	Crop water need (mm/total growing period)
Alfalfa	800 – 1600
Banana	1200 – 2200
Barley/Oats/Wheat	450 – 650
Bean	300 – 500
Cabbage	350 – 500
Citrus	900 – 1200
Cotton	700 – 1300
Maize	500 – 800
Mellon	400 – 600
Onion	350 – 550
Peanut	500 – 700
Pea	350 – 500
Pepper	600 – 900
Potato	500 – 700
Rice (paddy)	450 – 700
Sorghum/Millet	450 – 650
Soybean	450 – 700
Sugarbeet	550 – 750
Sugarcane	1500 – 2500
Sunflower	600 – 1000
Tomato	400 – 800

Table 5.3: Approximate values of seasonal crop water needs[4]

IRRIGATION SCHEDULING

Irrigation scheduling helps eliminate or reduce instances where too little or too much water is applied to crops. Scheduling is performed by all growers in one way or another. However, proper irrigation scheduling involves fine-tuning the time and amount of water applied to crops based on the water content in the crop root zone, the amount of water consumed by the crop since it was last irrigated, and crop development stage. Direct measurement of soil moisture content is among the most useful methods for irrigation scheduling. The extent to which farmers can utilize advanced irrigation depends on their access to water and labor. The economics, and in particular the critical impact of water availability on the yield, also play a role on the uptake of advanced irrigation scheduling.

Crops need different amounts of water at different stages of their growth cycle. In addition, local climatic and soil conditions influence the availability of water to crops. It should be kept in mind that excessive water provision can also be counterproductive as crops cannot utilize excess water and may be stressed from reduced oxygen levels of saturated soil.

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[4] Ibid.

This practice will also waste not only water but also energy and pumping costs. Consequently, it is essential to plan for irrigation properly and match the amount of water provided to a crop's water needs – both for yield optimization and for water efficiency. With proper irrigation scheduling, soil reservoir is managed such that optimum amount of water is available when the plants need it. Good irrigation scheduling requires knowledge of:

- Crop water demand at different growth cycles
- Moisture content of the soil and soil water capacity
- Weather conditions.

During the early season planting stage, the water requirement is usually about 50% less than what is required at the mid-season stage, when the crop has fully developed and reached its peak water need. The late season demand, on the other hand, is as high as the peak demand for crops harvested fresh, and can be as much as 75% less for those plants harvested dry. It is essential for growers to be attentive to this irrigation schedule and for the irrigation system to be adaptable to such changing demands.

Although overall water needs of different crops can be approximated using the typical values given in **Tables 5.1**, **5.2**, and **5.3** above, determination of these values at different growth stages is more complicated because water needs can show significant variations based on local climatic and soil conditions and crop variety. It is therefore important to consult competent authorities – e.g. Agricultural Ministries or local Irrigation Departments – to obtain relevant information.

Monitoring of **soil moisture content** provides a good assessment of the crop's water needs. A wide range of methods offering varying accuracy levels is available for monitoring soil moisture, each having its respective strengths and shortcomings. Some of the common methods are summarized in **Table 5.4**.

Method	Advantages	Disadvantages
Feel and appearance at different depths of the crop root zone	Very simple and requires no cost	Has low accuracy (but can be useful if visual guidance by competent authorities is provided)
Gravimetric methods	• Inexpensive and accurate • Works well for all soil types and moisture levels	Takes a long time to obtain results
Gypsum blocks	• Simple and inexpensive • Accurate when the conditions are right	• Requires individual calibration • Not accurate in very wet or saline soil • Readings are affected by soil temperature and fertilizer content • New blocks needed every year
Granular matrix sensors	• More accurate • Offers more stable calibration • Possibility for automated plotting of readings over time	More costly
Tensiometers	• Reusable • No need for calibration	• Does not work well in course sand and in some clay soils • Fails to read at higher tensions of drier soils • Requires regular maintenance
Capacitance or frequency domain sensors	• Provides immediate readings • Can be installed permanently or be used as mobile modules	• Salinity and soil texture affect readings • Needs calibration prior to use • Air pockets near probes or access tube walls give errors
Neutron probe	• Provides very accurate data • Quick and reliable if used by trained operators serving multiple farmers	• Requires calibration • Has low level radiation safety issues • Requires trained operator • Costly

Table 5.4: Overview of approaches for monitoring soil moisture[5]

Soil capacity, which is the ability of the soil to hold water between irrigation or precipitation events, is another important factor. Determinants of soil capacity include soil depth, ratios of different soil particles making up the soil, soil porosity, and soil water tension.[6] These factors influence the amount of water available to the plants. Because soil properties change

[5] Summarised from: Texas Water Development Board. Agricultural Water Conservation Practices.

[6] As different crops have different root depths, it is important to monitor the soil capacity at different depths for different crops.

at various depths, it is important to know the soil capacity throughout the plant root zone. It should also be noted that during irrigation, or precipitation, water only reaches a zone at a lower depth once the preceding zone has become fully saturated. Soil capacity surveys are usually difficult to perform by individual farmers, but can be performed by competent authorities and the information can be made available for different regions.

The prevailing **climatic conditions**, such as average ambient temperature, intensity of solar radiation, humidity, and wind-speed also affect both the moisture retained in the soil and the speed by which plants lose water through transpiration. The highest crop water needs are found in areas that are hot, sunny, dry, and windy. Thus, climatic conditions also need to be taken into consideration for proper irrigation scheduling.

Accurate monitoring of water used in irrigation is an essential part of irrigation scheduling and helps reach optimal performance, saving water while enhancing yields. Accurate readings can be obtained through different direct measurement methods available for pipes and closed conduits (propeller meters; orifice, venturi, or differential pressure meters; magnetic flux meters; ultrasonic meters) and for open channels (weirs and flumes; stage discharge rating tables; area/point velocity measurements; ultrasonic methods). Indirectly measuring irrigation water use can also provide sufficiently accurate approximations at lower costs. Common methods used include:

- Measurement of energy used by irrigation pumps
- End-pressure measurements in sprinkler irrigation
- Elevation differences in irrigation reservoirs or tanks
- Measurement of irrigation time and size of irrigation delivery system.

IRRIGATION METHODS

Once the quantitative and temporal characteristics of optimal water demand have been determined, a method that can make such water available in the most effective way should be selected. There are three main irrigation methods, namely:

- Surface (or gravity) irrigation
- Sprinkler irrigation
- Drip irrigation.

These methods, and their respective advantages and disadvantages are summarized.

Surface irrigation

Surface irrigation involves the application of water by gravity flow to the surface of the field. Surface irrigation can have different forms. In basin irrigation, the whole field is flooded with water. Alternatively, furrow or border irrigation can be used where water can be fed into small channels or strips of land. Surface irrigation is the easiest and least costly method, but is usually highly inefficient – only less than 10% of the water is taken up by the plant. Unfortunately, this is also the widely most used method in the Arab region.

Sprinkler irrigation

Sprinkler irrigation systems imitate natural rainfall. Water is pumped through pipes and then sprayed onto the crops through rotating sprinkler heads. These systems are more efficient than surface irrigation, however, they are more costly to install and operate because of the need for pressurized water. Conventional sprinkler systems spray the water into the air, losing considerable amounts to evaporation. Low energy precision application (LEPA) offers a more efficient alternative. In this system the water is delivered to the crops from drop tubes that extend from the sprinkler's arm. When applied together with appropriate water-saving farming techniques, LEPA can achieve efficiencies as high as 95%. Since this method operates at low pressure, it also saves as much as 20 to 50% in energy costs compared with conventional systems.

Different sprinkler irrigation systems – conventional (left) and low energy precision (right) systems.

Drip irrigation

Drip irrigation delivers water through the use of pressurized pipes and drippers that run close to the plants and that can be placed on the soil surface or below ground. This method is highly efficient because only the immediate root zone of each plant is wetted. This system also allows precise application of water-soluble fertilizers and other agricultural chemicals. Drip irrigation is reported to help achieve yield gains of up to 100%, water savings of up to 40-80%, and associated fertilizer, pesticide, and labor savings over conventional irrigation systems.[7] Drip irrigation systems can have different levels of sophistication and costs. Drip irrigation systems that are operated by solar-driven pumps are a particularly promising alternative for the MENA region. Figure 5.1 shows a layout of a drip irrigation system.

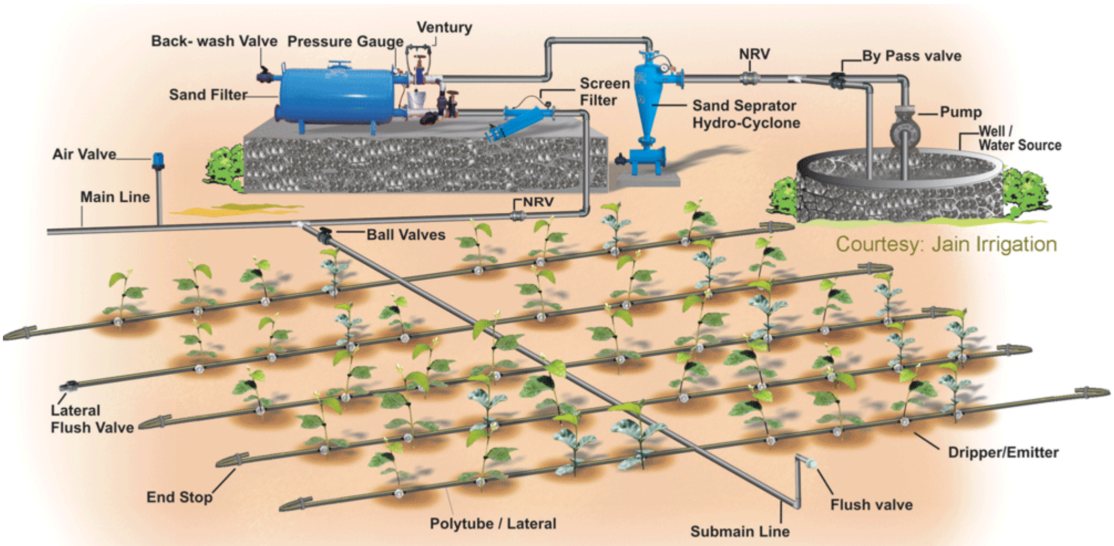

Figure 5.1: Drip Irrigation System (Wikimedia – Courtesy of Jain Irrigation)

The variations in soil moisture content usually achieved with different irrigation methods are depicted in Figure 5.2.

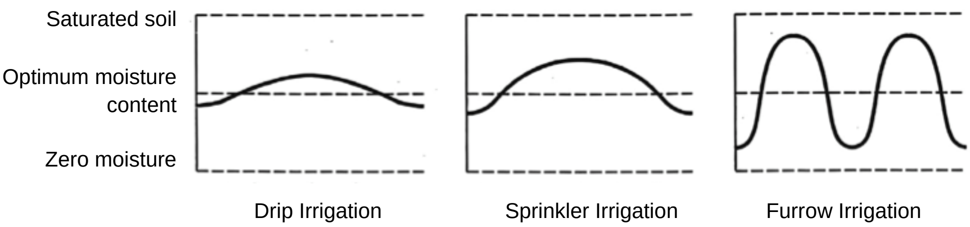

Figure 5.2: Comparision of different irrigation systems[8]

[7] Burney, et al. (2009). Solar-powered drip irrigation enhances food security in the Sudano–Sahel.
[8] Texas Water Development Board: Agricultural Water Conservation Practices.

With the exception of Saudi Arabia and the United Arab Emirates (UAE), surface irrigation is predominantly used in more than 90% of irrigated agricultural land in the MENA region.[9]

SOIL ENHANCEMENT MEASURES

In addition to the inherent efficiencies of different irrigation methods, a number of additional soil enhancement approaches can be considered to improve the efficiency of irrigation practices.

Proper field leveling, in order to allow the water to travel in an optimum speed, is an approach that assists uniform distribution of water and reduces runoff, particularly in surface and sprinkler irrigation. **Furrow diking,** which allows the capture of irrigation or precipitation water in small earthen dams within furrows, is another approach that can reduce runoff and increase the effectiveness of irrigation.

Further water savings can be achieved through **residue management** and **conservation tillage**, where the amount, orientation, and distribution of crop and plant residue on the soil surface are managed. These practices improve the ability of the soil to hold moisture, reduces water run-off from the field, and reduces surface evaporation. Because conservation tillage can cause disturbances in furrow irrigation systems, they are better suited for fields using sprinkler or drip irrigation.

Further efficiency gains are possible through appropriate measures in **water distribution** systems. Where water is delivered to fields by canals, for example, lining of the canal surface – by compacted clay or concrete – can drastically reduce water seepage. Covering the canals or putting them underground can further decrease evaporation losses.

ALTERNATIVE WATER SOURCES

Further efficiency gains at the local or regional levels, and even at the farm level, can be achieved through the use of alternative sources of water for irrigation. Two major approaches dominate.

Rainwater harvesting is an increasingly popular approach in those parts of the world where short periods of heavy precipitation are often followed by long stretches of dry

[9] AQUASTAT Survey 2008. Irrigation in the Middle East Region in Figures.

periods. In these locations, impermeable surfaces covering sufficiently large areas are created to reduce the infiltration of rainfall into the soil. By controlling the run-off of the harvested rain, water is diverted to tanks, underground aquifers, or dedicated surface ponds (though this is the least costly alternative, it results in excessive water loss via evaporation), from where water can be extracted and used for irrigation. Rainwater harvesting is successfully used in parts of India co-habited by multiple small-scale farmers.

Utilizing treated wastewater is another approach that can provide a feasible alternative source for irrigation water. With the use of modern technology, domestic wastewater can be treated to meet strict health and environmental guidelines, allowing safe use in irrigation. Conventionally, however, use of treated wastewater in irrigation practices has only been possible in farms located in close proximity to cities or towns that are large enough to operate an effective wastewater treatment system. Treated wastewater is already used in irrigation in Jordan and Tunisia and in landscaping in member countries of the Gulf Cooperation Council. With advancements in wastewater treatment technologies, use of treated wastewater on a smaller scale and in a distributed mode is becoming feasible.

Other innovations, such as micro-scale solar desalination units that can convert brackish water to low salinity water suitable for irrigation, are developments that hold a promise for the future.