GUIDELINES FOR RECLAIMED WATER IRRIGATION IN THE JORDAN VALLEY

- Practical Recommendations for Farmers and Extension Workers -

gtz

Reclaimed Water Project
Jordan Valley Authority (JVA)
Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)

Table of Contents

List of Tables

List of Figures

Abbreviations

AE	Application Efficiency
Ca	Calcium
CEC	Cation Exchange Capacity
CFA	California Fertilizer Association
CWR	Crop Water Requirement
DA	Development Area
DU	Distribution Uniformity
du	Dunum
EC_e	Electrical Conductivity for soil extract (dS/m)
ET_c	Crop Evapotranspiration
ET_0	Potential Evapotranspiration
FC	Field Capacity
FFTC	Food and Fertilizer Technology Centre
FU	Farm Unit
FWR	Field Water Requirement
h	Hour
JV	Jordan Valley
JVA	Jordan Valley Authority
IE	Irrigation Efficiency
IFA	International Fertilizer Industry Association
K	Potassium
KAC	King Abdullah Canal
KTR	King Talal Reservoir
K_2O	Potassium Oxide
kg	Kilogram
l	Liter
m	Meter
MAD	Maximum Allowable Depletion
mm	Millimeter
Mg	Magnesium
mg	Milligram
N	Nitrogen
NCARTT	National Center for Agricultural Research and Technology Transfer
NH_4^+	Ammonium
NO_3^-	Nitrate
P	Phosphorus
pH	Index of acidity
ppm	Parts per million
PWP	Permanent Wilting Point
RAWC	Readily Available Water Content
R_e	Effective Rooting Depth
RH	Relative Humidity
RWP	Reclaimed Water Project
SO_4^{2-}	Sulphate
t	Ton
TAWC	Total Available Water Content
USDA	United State Department of Agriculture
WP	Wetting Percentage

1 Background

The Reclaimed Water Project (RWP) has been jointly implemented by the Jordan Valley Authority (JVA) and German Technical Cooperation (GTZ) since 2003. One major purpose of the project is to develop agronomic guidelines for the use of reclaimed water (RW) for irrigation in the Jordan Valley (JV).

RW supplied to the central and southern part of the JV is effluent from the wastewater treatment plant (WWTP) at As Samra. On its course to the JV it is diluted by surface run-off water from adjacent catchments areas of Wadi Duleil, Wadi Zarqa and the King Talal Reservoir (KTR), where it is stored temporarily. Although diluted, RW contains nutrients that are beneficial to crops and soils. On the other hand it contains - to some extent - salts, heavy metals and microbial contaminants which, in cases of high concentrations, could have adverse effects on crops and soils, for farmers, consumers and the environment. Accordingly, the following guidelines have been compiled to make best possible use of the positive properties of RW and to avoid negative impacts. They have to be seen in combination with the other outputs delivered by RWP, including the Irrigation Water Quality Guidelines and the Monitoring System for Fresh Fruit and Vegetables.

These guidelines are the result of activities carried out during three cropping seasons in the JV. In the seasons 2003/2004 and 2004/2005, the RWP field staff monitored main crops on about 70 fields on more than 20 farms in the central and southern JV in order to collect data on the agricultural practices of experienced and successful farmers who have applied RW for the past 20 years. The focus was on irrigation and fertigation methods, as well as plant varieties, planting time, tillage and yields. Data were evaluated and analysed and first results, conclusions and recommendations were obtained. The recommendations were introduced to farmers during field days and to agricultural engineers during workshops and training courses. Because the recommendations were often different from traditional practices, the farmers themselves suggested that they should "examine" the findings and recommendations on their fields and compare them with their usual methods. Accordingly, 15 demonstration plots were designed and implemented, three of them in the 2004/2005 season and 12 during the 2005/2006 season.

The results and corresponding recommendations from the monitoring program are documented in the report 'Analysis of Irrigation and Fertigation Practices using Reclaimed Water in the Jordan Valley' (GTZ, 2006). Added to these first findings were the results of the demonstration plots, which confirmed the recommended practices, the feed-back from farmers and agricultural engineers, as well as experiences and results from desk-based research. The main criterion for screening the literature and internet was practical applicability, not theory or abstract modelling.

Furthermore, the guidelines have also been introduced to and discussed with Jordanian scientists, agricultural specialists and experienced farmers and their observations and recommendations have been thankfully considered and integrated. A list of specialists, scientists and farmers which contributed to the guidelines and attended the final workshop is attached in the Annex.

The guidelines are not meant to be prescriptions or recipes. The cultivating of crops is influenced by numerous factors; accordingly the guidelines provide general principles, basic concepts, ranges, averages and rules of thumb. As these general principles can be applied to most vegetables in the JV, there are no specific chapters on particular crops.

The approach to the elaboration of the guidelines so far suggests that more work still needs to be done, including research and experiments on representative sites in the JV. This is the task and responsibility of the national agricultural research institutions. Some prior needs, open questions and proposals for such trials can be found in GTZ, 2006.

Summarizing the described approach, the authors of the following guidelines would venture to say that they are highly relevant for farmers in the JV in general, and in particular for those who use RW for irrigation. They are easily understood and illustrated by practical examples and calculations. For broad dissemination and better understanding, they will be introduced during field days for farmers, in meetings with water user groups as well as during training workshops for agricultural extension officers.

2 Aspects under Consideration

2.1 Reclaimed Irrigation Water

In more than 90% of the JV, the moisture from rainfall and shallow groundwater is insufficient to sustain non-irrigated agriculture. This creates a demand for irrigation with other water sources, including groundwater from deeper aquifers and springs, brackish water and RW from WWTP.

Wastewater Reuse Terminology: Wastewater reclamation involves the treatment or processing of wastewater to make it reusable, and wastewater reuse or water reuse is the beneficial use of the treated water. Reclamation and reuse of water frequently require water conveyance facilities for delivering the RW and may require intermittent storage of the RW prior to its reuse. (….) Indirect use includes mixing and dilution by discharge into an impoundment, receiving water or groundwater aquifer prior to reuse. (Asano, 1998). RW used in the central and southern JV comes from the country's largest WWTP, As Samra, which treats the domestic water of the capital Amman and the city of Zarqa. On its course to the JV it is diluted by surface run-off water from adjacent catchments areas of Wadi Duleil, Wadi Zarqa and the KTR, where it is stored temporarily. Therefore, RW in the JV can also be addressed as RW for indirect use.

Mixing point

RW contains special impurities that derive from domestic and industrial uses of the original freshwater. These can be classified as salts, nutrients, micro-organisms and solids (see chapter 7.1 Filtration). Table 1 gives an overview of the main impurities.

Table 1: Main impurities in RW

Salts Name and Symbol		Salts /Nutrients Name and Symbol		Nutrients Name and Symbol		Micro-organisms	Solids
Chloride	Cl^-	Sulfate	SO_4^{2-}	Nitrate	NO_3^-	Bacteria	Suspended solid s
Carbonate	CO_3^{2-}	Potassium	K^+	Ammonium	NH_4^+	Viruses	Organic matter
Bicarbonate	HCO_3^-	Calcium	Ca^{2+}	Phosphate	PO_4^{3-}	Helminths	Fat, oil, grease
Sodium	Na^+	Magnesium	Mg^{2+}	Zinc	Zn	Protozoa	
Trace elements		Boron	B	Iron	Fe		
		Carbon	C	Manganese	Mn		

RW contains salts from human activity such as industrial disposal, household disposal and the use of fertilizers. Accumulated salts decrease the fertility and stability of the soil. The quantity and composition of different salts determine important chemical characteristics of RW: (1) Index of acidity (pH), (2) hardness, (3) alkalinity, (4) sodicity and (5) toxicity. Table 2 shows the range of salinity of the irrigation water in the central and southern JV. The salinity expressed as deciSiemens/m (dS/m) is relatively high for KTR and southern King Abdullah Channel (KAC-south).

Table 2: Water quality of KAC-north, KTR and KAC-south

Source	EC-range (dS/m)
KAC-north	1.0 - 1.2
KTR	2.0 - 2.8
KAC-south	1.5 - 2.5

Source: (JVA lab) 2005

The management of salts in brackish water irrigation is discussed extensively in "Guidelines for Brackish Water Irrigation in the Jordan Valley", published by the Brackish Water Project of GTZ and JVA. In the above mentioned report it is suggested that for practical reasons the threshold for brackish irrigation water in the JV is considered to be 3 dS/m. The considered RW sources are below this value.

2.1.2 Nutrient Content of RW

RW contains considerable amounts of plant macro-nutrients: nitrogen (N), phosphorous (P) and potassium (K) and can be considered as a low-strength multi-nutrient fertilizer. The concentration of the nutrients fluctuates according to the degree of wastewater treatment, the seasons and the degree of dilution with rainwater.

Nitrogen: The total N concentration in RW is generally between 10 to 60 mg/l. In the JV, the majority of N in the RW is in the form of NH_4^+-N and to a lesser extent in the form of organic-N and NO_3 -N.

Phosphorus: P is present in RW in the form of (1) organic bound phosphate and (2) phosphate from soaps and detergent residues. The concentration of phosphate in RW is variable but, according to Ryden and Pratt (1980), in most cases is below 30 mg/l.

Potassium: K is present in RW in the form of the dissolved K-cation, K^+. The concentration in RW is in general 30 to 60 mg/l.

Table 2 shows nutrient contents in RW used in the central and south JV according to samples analysed by the JVA laboratory. The total current monetary value of the macro nutrients NPK in RW released into the JV is estimated to be around 2.34 million Jordanian Dinar (JD) of which 23% is N, 20% P and 57% K (GTZ, 2006).

Other plant nutrients available in RW are secondary nutrients such as calcium (Ca), magnesium (Mg) and sulphur (S) and micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum

(Mo), chlorine (Cl) and boron (B). The level of these nutrients varies widely throughout the year.

When RW is used for irrigation, primary and secondary nutrients are applied to soils. This nutrient application can supply part of the nutrients required by the crop. On the other hand, the application of nutrients with RW can cause nutritional imbalances in the soil solution and in the crop and has the potential to reduce crop yield and quality.

2.1.3 Micro-Organisms in RW

As mentioned in Table 1, RW contains micro-organisms, which could probably be harmful to human health. Shuval et al. (1986) distinguished three main groups of pathogenic agents with different risks for contamination and health impacts: (1) a high risk occurs with the presence of parasites; (2) a medium risk is provided by enteric bacteria and (3) a low risk occurs in the case of enteric viruses. The difference in survival time of helminth eggs, nematodes and bacteria in the treated wastewater determines the level of risk for contamination.

Transmission of pathogens and population groups at risk:

Pathogens in RW can be transmitted to the general public and to agricultural workers through various transmission vectors. In the case of RW irrigation, different population groups in Jordan are exposed to different levels of risks.

1. The highest level of risk occurs in the group of irrigators, including farmers, farm workers and their families, which work directly with RW. Potential vectors of disease transmission are the exposure to RW while operating and maintaining the system, the accidental ingestion of small quantities of water via the hands during eating or smoking and the consumption of contaminated crops.
2. A smaller risk occurs in the group of crop consumers. The potential vector for disease transmission is the consumption of uncooked or unprocessed crops that have been contaminated with RW. The risk level of this group is dependent on the soundness of the RW irrigation guidelines, the effectiveness of monitoring and enforcement by the authorities and the procedures for post-harvest handling of crops.
3. A small risk occurs with the general public living in the area of the irrigation system. Potential vectors are direct skin contact with RW from open canals and leaking pipes or potential ingestion during swimming and bathing in RW.

A small risk, but with a large-scale impact once it occurs, is the contamination of drinking water sources by either pipe cross-connections or groundwater pollution. As the majority of the conveyance system consists of closed pipes (except KAC), this risk is small in the JV. However, in cases of leakage and under-pressure in the drinking water conveyance system, water from the RW conveyance structures can be siphoned into drinking water pipelines.

Cases of disease transmission have been reported among both consumers and farm workers as a result of using *untreated wastewater to irrigate edible crops*. Shuval et al. (1984) showed that an outbreak of worm diseases (*Ascaris*) in the 1950's among the Jerusalem area population was closely related to the practice of using untreated wastewater for irrigation. These results are supported by two studies from Darmstadt, Germany (Krey, 1949; Baumhogger, 1949). Results from India (Sehgal and Mahajan, 1991) also indicate that sewage workers working barefoot had much higher infection rates compared to those wearing shoes (25.1 % vs. 7.7% respectively).

However, in case indirect use of RW is practised, *no evidence of contamination* exists, as found in a study by Shuval et al. (1986). It is important to acknowledge that no evidence of contamination exists in situations where drip irrigation is practised together with indirect used RW and plastic mulch. The use of surface irrigation and flooding irrigation techniques does pose a higher threat to safety and occupational health as it leads to direct contact between farm workers and RW and to splashing on crops and clogging of soil pores. Sprinkler irrigation with RW may promote the aerosol transmission of viruses. Therefore it is preferable that drip irrigation in combination with plastic mulch should be used for RW irrigation while surface irrigation methods such as flooding, basin and furrow irrigation as well as sprinkler irrigation with RW should be discouraged.

2.2 Protection of Farm Workers - Occupational Safety

The greatest probability of infection when working with RW comes from *the direct ingestion of the RW* or *physical contact*. Diseases can also be transmitted by handling or consumption of contaminated crops. Crop contamination can occur via the splashing of wastewater on the crop surface or via the transmission of pathogens through soil, stem and plant tissue to the interior of the crop, although the latter only occurs as the result of very high concentrations of pathogens in the RW.

2.2.1 Guidelines for Occupational Health and RW Irrigation

There are three main ways that diseases can enter the body when working with RW

- disease can be transmitted through hand-to-mouth transmission during drinking, eating and smoking while working with RW; wiping the face with dirty hands can also cause contamination
- by skin contact through cuts, scratches or small wounds
- by breathing them in via small drops of water and water mist; some rare organisms enter through the eyes, nose or mouth.

Farmers should take the following precautions

- it is highly recommended to prefer drip irrigation over surface or sprinkler irrigation
- all farmers should have a standard Polio-Diphtheria-Tetanus vaccination
- all farmers should wear boots and gloves, they should not work barefoot
- they should not touch their face, or smoke, drink or eat during and after working with RW until they wash their hands and face with soap and water
- all exposed wounds, however small, should be cleaned and covered with a sterile dressing
- if clothes get wet with RW, they should be changed immediately after working.

Farmers should contact their doctor in case of

- persistent stomach aches, diarrhoea and bad digestion
- symptoms of worm infection, such as itching skin, especially around the bottom, or worm traces in excreta
- a flu-like fever, especially if it comes with severe headaches and skin infections
- chest problems, especially if they come with asthma or lung inflammation
- regular checkup at least once yearly .

2.2.2 Protection of Crop Consumers

Using RW for irrigation might also expose consumers of agricultural produce to certain health risks. Such risks can be avoided or minimized by the following measures

- using drip irrigation and plastic mulch
- pesticides should not be diluted or mixed with RW
- heating, cooking and thoroughly cleaning of crops prior to consumption
- avoiding contact between crops and RW after harvesting
- processing of crops
- a strict state monitoring system for crops irrigated with RW.

2.2.3 Crop Classifications

There are four different classifications of crops that can be irrigated with RW. In case of the quality of RW in the JV, only crops with a very low (Table 3) and low probability (Table 4) for contamination should be irrigated. However, to date it is common practice to irrigate vegetables that are eaten fresh with RW in the central and southern JV. (Table 5). Without approving of this practice, some strategies are provided to mitigate the possibility of contamination for fresh eaten produce.

Table 3 lists crops with a very low risk for contamination upon consumption and use. These crops can be irrigated without major risks in the JV.

Table 3: Irrigated crops with a very low risk for consumer contamination with RW

Crops that are processed or treated with high temperature before consumption	Crops that are not for human consumption or used as animal fodder	Vegetables that are cooked
Olive Wheat	Barley Corn/Maize Alfalfa Berseem	Pumpkin Potato Eggplant Artichokes Corn
KEEP 1 WEEK BETWEEN THE LAST IRRIGATION AND THE HARVEST.		

Table 4 lists crops with a low risk for contamination upon consumption and use. These crops can be irrigated without major risks in the JV.

Table 4: Irrigated crops with a low risk for consumer contamination with RW

Crops with an inedible shell	Crops that are grown for their seeds	Tree and shrub crops	Crops that are bound on trellis
Citrus Cactusfruit Avocado Pomegranate Mango Watermelon Melon	Watermelon Melon Peas	Date palm Fruits fallen on the ground should not be marketed	Grapes Grapes touching the ground should not be marketed
KEEP 2 WEEKS BETWEEN THE LAST IRRIGATION AND THE HARVEST.			

Table 5 lists crops with a medium and high risk for contamination upon consumption and use. These crops should not be irrigated with RW in the JV.

Table 5: Irrigated crops with a medium to high risk for consumer contamination with RW.

Crops that are eaten fresh, grown just above the ground (MEDIUM RISK)		Crops that are eaten fresh, grown on and in the ground (HIGH RISK)	
Tomato Zucchini Cucumber	Pepper Beans	Lettuce Cabbage Carrot	Radish Onion

If farmers want to irrigate crops mentioned in Table 5 in spite of the guidelines, the following precautions should be applied:

- plastic mulch should be laid between the irrigation emitters and the crop
- the irrigation system should be checked regularly for spraying or broken emitters and pipe leaks
- produce that has fallen on the ground or the black mulch should not be marketed
- produce hanging on the ground should not be marketed
- irrigation should be stopped two weeks before harvesting if possible.

It is worth mentioning, that RWP initiated a state monitoring program for vegetables irrigated with reclaimed water in the Jordan Valley in cooperation with the Ministry of Health, Ministry of Agriculture, Jordan Food and Drug Administration, and National Center for Agricultural Research. Samples of vegetables are taken randomly on farms in the Jordan Valley and on whole sale markets and are analyzed for nitrate, heavy metals (cadmium and lead) and microbial contaminants (Salmonella and E. coli). So far no contaminations have been detected. It is envisaged to make the results of this monitoring program available to farmers and consumers in the near future.


Fruit Sampling


Water Sampling

3 Methodology

3.1 On-Farm Data Collection

The guidelines outlined in this report are based on an intensive farm monitoring program conducted by the RWP team between 2003 and 2006 on about 70 fields of more than 20 farm units (FU) in the development areas (DA) 29, 22, 23, 24, 25, 26, 27 and 28, as shown in Figure 1.

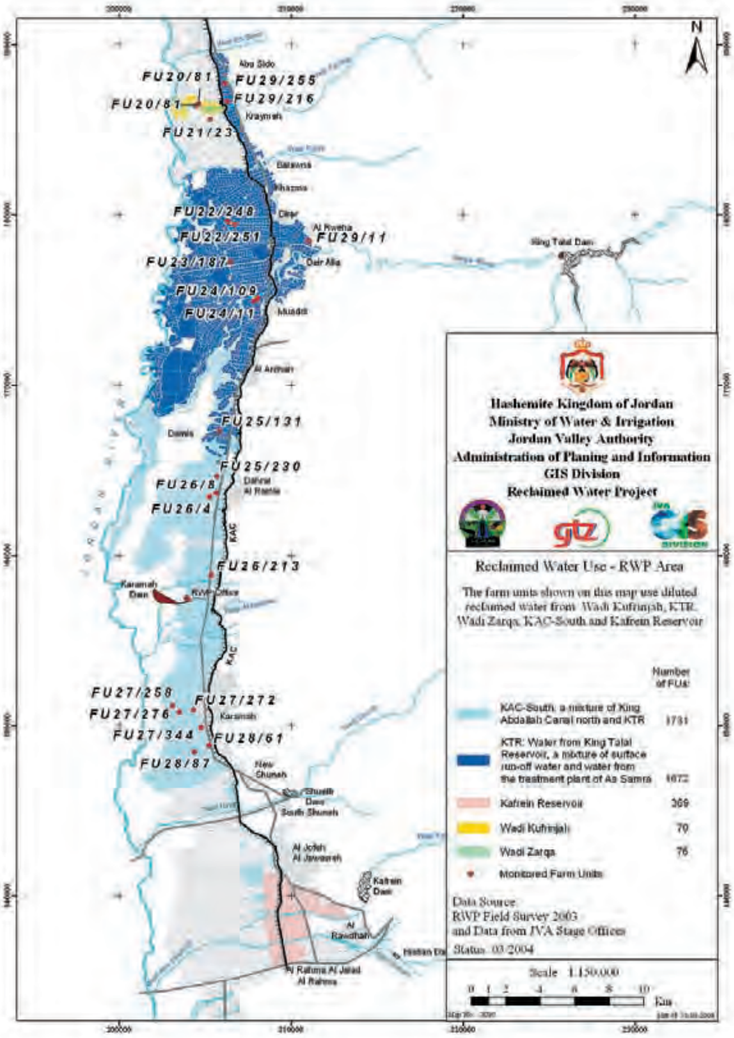

Figure 1: Map of monitored FU and DA

The crops monitored were tomato, eggplant, cucumber, sweet pepper, squash, okra, and date palm. Monitoring of potatoes, onion and lettuce was also started but had to be abandoned due to unfavorable weather conditions, pests and diseases. The analyses comprised cultural practices (timing, depth and type of tillage), growing seasons and crop stages (transplanting and planting, timing, plant density and planting depth), irrigation (timing, pump discharge, irrigated area and irrigation duration) and fertigation scheduling (timing, manure type application, fertilizer type application and amounts) and harvesting (timing and yield amount).

The fields were irrigated with RW from one of the following sources: KTR, KAC-south, and water from the WWTP at Kufrinja.

The monitoring of on-field management practices was supplemented by soil and water quality data and compared with crop water and fertilizer requirements obtained from international literature and from the internet. The following factors were taken into account

- recommendations from the report "Practical Recommendations for Nutrient Management under Irrigation with Reclaimed Water"
- soil test and soil test interpretation
- irrigation application and efficiencies
- nutrients and organic matter applied with RW
- nutrient contribution from manure
- nutrient application with fertilizers
- plant nutrient uptake for each crop stage
- influence of soil texture and pH with regard to behavior of important nutrients
- other relevant agricultural practices
- yield and yield quality
- principles of RW irrigation.

The data gathered during the monitoring process were compiled in a relational data bank that served as a reference for the field analysis. Each field was analyzed individually with crop growth- and spread sheet models concerning the performance of irrigation and fertigation.

3.2 Demonstration Sites

After the introduction of the first findings and recommendation during field days for farmers and workshops for agricultural engineers held in April 2004, some farmers suggested verifying these recommendations on their own fields. The idea behind these demonstration fields was to compare the project's recommendations regarding irrigation and fertigation with the conventional practices of the farmers. A total of 15 demonstration sites were implemented in direct cooperation with farmers. In each demonstration site, the farmer was given a complete fertigation program and asked to apply it in two or three plastic houses and to compare the results with his usual method. The same approach was implemented in open fields.

Checking tensiomter

The results of selected demonstration sites are presented in Annex 11.2. They show that farmers can save up to 60% of their fertilization costs, when applying the projects' recommendations. The following general conclusions can be drawn from the monitoring program and the demonstration fields

- farmers in the central and south JV apply excessive amounts of P and K
- farmers do not consider either nutrient in the irrigation water or in the soils
- reclaimed irrigation water and soils in the central and southern JV can provide crops with more than 50% of their nutrient requirements
- farmers tend to apply compound fertilizers and believe that straight or single fertilizers are not as effective as compound fertilizers
- straight fertilizers are as good as compound fertilizers and, in addition, they are considerably cheaper
- farmers should consider manure not only as a soil conditioner but as a valuable source of nutrients if it is applied according to good agricultural practice (no time lag between delivery and application, immediate incorporation after application).

Based on the analyses of single fields, findings on demonstrations plots, literature screening, internet search and desk-based research, simplified but detailed methods for calculating irrigation and fertigation requirements for different crops will be discussed in the following chapters.

4 Water Requirements under Drip Irrigation

The prevailing irrigation method in the JV is drip irrigation, which is applied on around 80% of the farm units. Because of this, and because drip irrigation has several particular features that are not yet widely considered among farmers in the JV, the guidelines will focus on field water requirements (FWR) under drip irrigation.

Mulching - Drip Irrigation

There are two essential approaches in determining irrigation requirements

- water budget calculation, which is estimating the amount of water the crop requires based on weather conditions, crop growth stages and soil conditions
- measuring the soil moisture content using tensiometers, which are useful instruments that can assist in irrigation management.

Here the first approach will be discussed, because the application of tensiometers in the JV is supported by other projects, namely Kafa'a and MREA, and good material about their use is available from these projects.

4.1 Crop Water Requirements (CWR)

Water requirements of crops are estimated by using the modified FAO Penman-Monteith (PM) method. The potential evapotranspiration (ET_0) provides a standard to which evapotranspiration at different periods of the year or in other countries can be compared and evapotranspiration of other crops can be related. ET_0 includes the unproductive evaporation of liquid or solid water from soil and plant surfaces plus productive transpiration of water through tissue (without differentiating between plant and accompanying flora), and is expressed as millimetre. (Burman et al. 1983). ET_0 is based on the amount of water loss from a field with a complete cover of an actively growing grass crop. It is only influenced by climatic parameters and expresses the evaporative power of the atmosphere at a specific location and time of year and does not consider crop characteristics and soil factors. However, crop type and its development stage should be considered when assessing ET_0 of different crops. Differences in resistance to transpiration, crop height, crop reflection, and rooting characteristics, among others, result in different evapotranspiration levels for crops grown under the same environmental conditions. To establish the effect of crops on ET_0, the crop coefficient K_c approach for calculating the crop evapotranspiration ET_c under standard conditions as described by Allen et al. (1998) is used. The standard conditions refer to crops grown in large fields under excellent agronomic and soil water conditions. As the crop develops, leaf area index, ground cover, crop height and other characteristics change with time. Due to differences in evapotranspiration during various growing stages, the K_c will vary over the growing period. The growing period can be divided into four different growing stages, the initial stage (K_{c1}), crop development stage (K_{c2}), mid-season stage (K_{c3}) and late season stage (K_{c4}).

RWP is aware of the problems when calculating CWR based on potential evapotranspiration (ET_0). There are many factors involved including the influence of mulching and adjusting K_c values. Nevertheless, the purpose of these guidelines is not to present precise figures but to explain this subject and to consider these variables in a comprehensible way for growers and extensions workers. Calculating ET_0 provides the crop requirement but it does not include irrigation scheduling, i.e. frequency of irrigation, which is based on soil water holding characteristics and other factors. Neglecting them can lead to deep percolation on one hand and a possible problem of water shortage for plants on the other hand. Relevant factors are discussed in the following chapters.

Table 6 displays historical daily averaged ET_0 values per month for different regions in Jordan. In the following calculations and examples the ET_0 for Deir Alla or Karamah are used. These stations are located in the central and southern JV.

Table 6: Average daily ET_0 values for different regions in Jordan.

	Deir Alla	Karamah	Ghor Al-Safi	Mafraq	Shoubak	Irbid
	Penman-Monteith, averages of more than					
Month	40 years	14 years	22 years	23 years	23 years	23 years
January	2.5	1.4	1.7	1.5	1.5	1.7
February	2.8	1.9	2.1	2.1	2.0	2.2
March	3.8	3.0	3.3	3.1	2.0	3.1
April	5.6	4.5	4.6	4.8	4.2	4.7
May	6.9	5.7	5.6	6.5	5.3	6.3
June	7.3	6.6	6.3	7.4	6.0	7.5
July	7.3	6.6	6.2	7.5	6.2	7.6
August	6.7	6.2	5.8	6.8	5.6	6.8
September	5.5	4.9	4.8	5.3	4.4	5.5
October	4.7	3.3	3.2	3.6	3.3	3.8
November	4.0	1.9	2.1	2.3	2.3	2.7
December	2.7	1.3	1.3	1.5	1.6	1.8

Source: based on CROPWAT and historical data (Jordan Climatological Handbook, 2003)

When ET_0 is used to calculate FWR the following factors should be considered

- crop growth stages, which can be divided into a) crop coefficient (K_c) approach and b) ground coverage approach
- plastic mulch
- irrigation system: a) irrigation efficiency (IE) b) application efficiency (AE) c) distribution uniformity (DU)

- leaching requirement
- different conditions under greenhouses.

4.2 Crop Growth Stages

4.2.1 Crop Coefficient (K_c) Approach

The common way accounting for growth stages when calculating CWR (ET_c) is to apply a crop coefficient for defined crop growth stages (Equation 1) These factors are available in the literature. The coefficients for the main crops cultivated in JV and the duration of the stages in days as observed and estimated by RWP field staff are summarized in Table 7. The shortcoming of using K_c coefficients found in literature are (1) these coefficients are calculated for specific weather conditions (relative humidity (RH) 45% and wind speed (2 m/s),therefore higher or lower values of these two parameters will affect K_c coefficients, (2) using tabulated K_c coefficients should take into consideration that K_c coefficients for development and late stages are not constant and changing daily with growth progress, therefore if this consideration is not taken into account it can lead to estimating higher ET_c for the development stage and lower ET_c for the late stage, (3) calculating ET_c based on K_c coefficients assumes standard conditions and does not account for pest and disease occurrence or some common practices such as removal of leaves that definitely affect K_c. The conclusion from the above mentioned shortcomings is that tabulated K_c coefficients cannot be taken for granted.

$$ET_c = ET_0 \times K_c \qquad \text{Equation 1}$$

Table 7: K_c values and growth stage durations for the main crops cultivated in the project area

Crop	K_{c1}	K_{c2}	K_{c3}	K_{c4}	Total
Sweet corn	0.6	0.9	1.2	1.1	
Days	20	30	30	20	100
Eggplant	0.6	0.85	1.1	0.9	
Days	30	40	40	100	210
Potato	0.40	0.90	1.20	0.75	
Days	30	30	30	30	120
Squash	0.60	0.80	1.00	0.80	
Days	10	20	20	35	85
Tomato	0.60	0.93	1.25	0.65	
Days	30	40	100	40	210
Cucumber	0.60	0.87	1.15	0.75	
Days	30	35	90	40	195
Onion	0.70	0.87	1.05	0.75	
Days	20	35	110	45	210
Sweet pepper	0.60	0.87	1.15	0.90	
Days	30	40	110	30	210

Source: FAO, 1992 and GTZ, 2003

It has to be noted that K_c values do not change from one day to the other, (like in Figure 2, eggplant, left side, K_c of 0 on day 29, followed by K_c of 0.6 on day 30) or do stay on the same level for a certain stage (i. e. 40 days with a K_c of 0.85), but change dynamically as in Figure 2, eggplant (right side). If farmers adjust coefficients according to these circumstances they pay their tribute to the daily/weekly changing crop conditions and will be on the safe side whilst calculating irrigation requirements.

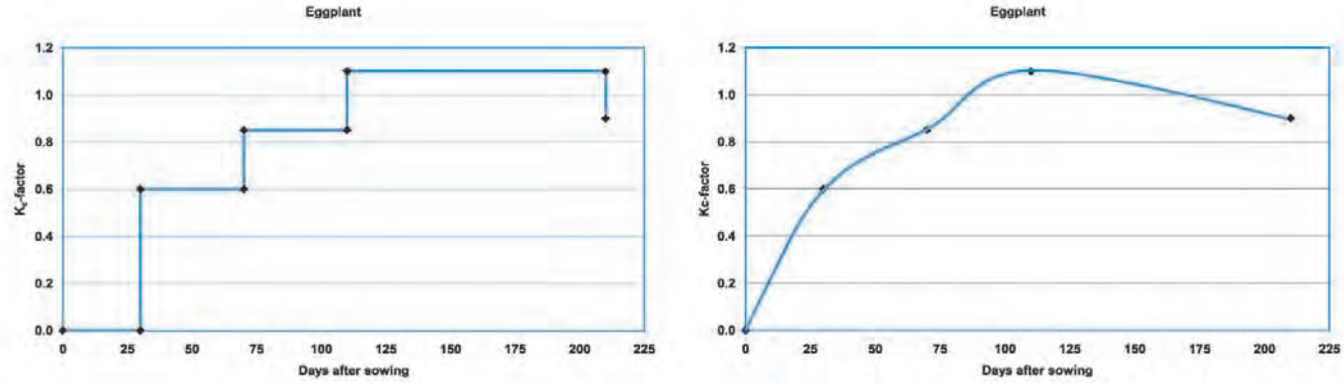

Figure 2: K_c-coefficients for eggplant, expressed in a static (left side) and dynamic (right side) way.

4.2.2 Ground Coverage Approach

An alternative and more practice-oriented method for farmers is to estimate the foliage of the cultivated crop covering the ground instead of using K_c coefficients. CWR are mainly determined by the crop's age, size, height, leaf size and insertion. Thus it is possible to deduce the requirements by estimating the percentage of the field surface covered by the crop. The percentage of the field surface covered by the crop is estimated by assessing the width of the strip under the crop canopy in comparison to the planting distance between the rows; e.g. plants at the time of planting cover less than 25% of the ground surface while at harvesting time nearly all ground surface is covered. Once the percentage of surface covered by foliage is estimated this percentage is increased by 10 - 20% (factor 1.2 in equation 5) to account for higher water loss of the cultivated crop compared with the reference evapotranspiration of grass (Hartz, 2000). Generally ground cover percentage ranges from 0.1 to 1. If the ground cover is less than 0.1, consider it 0.1 because evapotranspiration includes both transpiration and evaporation, therefore even if ground cover is less than 0.1 most of the water will be lost from the soil in the form of evaporation. The rate of ground cover increase depends on the rate of growth rate, weather conditions, soil fertility and other management practices. However it can be said that increase ranges from 5 - 10% weekly until full maturity for open field cultivation and 10 - 15% for greenhouse cultivation. Although this approach seems easy to apply because it does not require K_c in computing ET_c, it does need some experience and practice by farmers and extension workers to avoid over or under estimation of the crop coverage in percent.

Low ground coverage High ground coverage

Table 8 provides a comparison of CWR for both approaches for sweet corn and squash, showing that the differences are minor. The 'ground coverage approach' was also applied for calculating CWR on the demo sites and has proved to be applicable in practice.

Table 8: Comparison between CWR using K_c approach and ground coverage approach

Crop	Sweet corn	Squash
Planting Date	1/11/05	1/11/05
Crop life (days)	100	85
FWR using K_c approach (mm)	345	254
FWR using ground coverage approach (mm)	327	251

4.3 Field Water Requirements

The amount of water, which needs to be added in form of irrigation is usually higher than the CWR due to losses of different kinds. The below mentioned factors will explain the difference between CWR and the amount of water finally irrigated, here called field water requirements (FWR).

4.3.1 Plastic Mulch

Plastic mulch substantially reduces the evaporation of water from the soil surface, especially under drip irrigation systems. Crop coefficient (K_c) values should be decreased by an average of 10 - 30% due to the 50 - 80% reduction in soil evaporation. Battikhi and Hill (1986) reported 25 - 30% reduction in K_c for watermelon planted under plastic mulch. Safadi (1991) reported 15 - 20% reduction in K_c for cucumber and 5 - 15% reduction for squash. Since most farmers in JV use black plastic mulch it is recommended to reduce K_c value by an average of 15 - 20% (factor 0.8 in equation 4).

4.3.2 Irrigation Efficiency

Most drip irrigation systems cannot provide equal amounts of water to all areas of the field due to irregular distribution uniformity. To ensure that even the driest section of the field receives adequate water, the crop water requirement calculated from ET_0 and crop canopy coverage need to be increased by 15 - 30%. This increase is due to poor distribution uniformity.

Application Efficiency (AE)

AE can be defined as

$$AE\ (\%) = \frac{\text{Amount of water stored in crop root zone} \times 100}{\text{Amount of water delivered to the farm}} \qquad \text{Equation 2}$$

The difference between the two quantities in the above equation is due to

- surface runoff
- deep percolation
- evaporation losses.

Under drip irrigation the major loss is the deep percolation. According to the above definition, RWP estimates the application efficiency for drip irrigation systems in the Jordan Valley to about 75 - 85%. As the application efficiency is difficult to measure the best way to account for it is to check the distribution uniformity.

Distribution Uniformity (DU)

DU relates to the evenness of water application to plants throughout the field. DU is an indication of whether all plants receive the same amount of water. It is not an efficiency term; an irrigation application may be very uniform (high DU) but if the duration is excessive, there may be deep percolation and run-off resulting in low irrigation efficiency.

The principle of DU is explained in Figure 3 (Burt et al., 1998). In this figure, it is assumed that the moisture content is sufficient for plant uptake and the soil moisture requirement depicts the depth of the root zone of the plant. Obviously, if the depth of water infiltrated is greater than the soil moisture requirement, there is deep percolation. If there is less water than the soil can hold and the plants need, there is under-irrigation. In addition, where fertilizers are applied with the water, the distribution of the fertilizers cannot be better than the distribution of the irrigation water and the nutrients are leached more rapidly with increasing deep percolation.

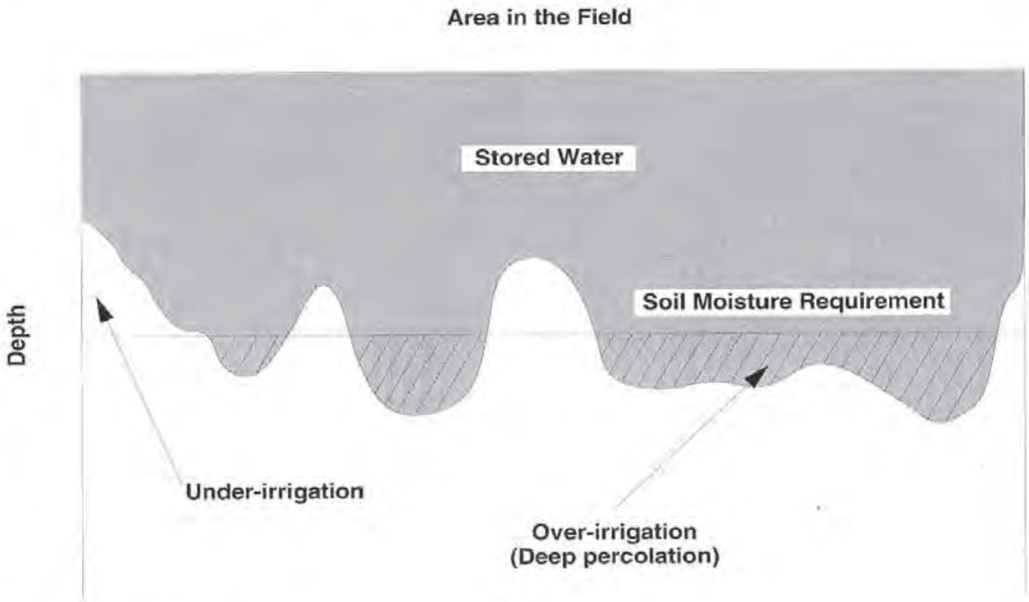

Figure 3: Concept of DU

Distribution uniformity can be defined as

$$DU = \frac{\text{average flow rate of low quarter emitters}}{\text{average flow rate of all emitters}} \qquad \textbf{Equation 3}$$

An applicable method for evaluating the DU of an irrigation system is as follows (see Figure 4)

1. Select 12 (or more) emitters from different parts of an irrigated plot as shown in Figure 4.
2. Place graduated containers under the selected emitters.
3. Measure water content of each container after one minute.
4. Calculate the average of the lowest quarter of the collected water in the graduated containers.
5. Calculate the average of all water collected in the containers.
6. Compute the DU according to equation 3.

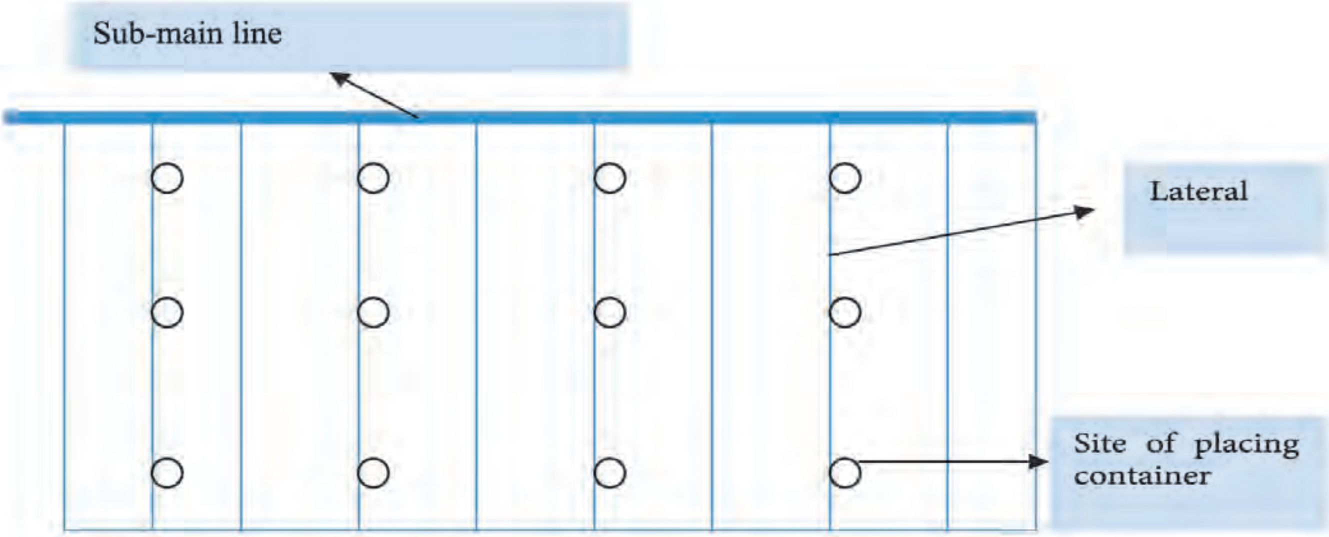

Figure 4: Assessing DU in drip irrigation systems

A high irrigation efficiency (IE) with minimal under-irrigation can only be obtained if the DU is also high. Therefore, conducting a field evaluation of the DU of the irrigation systems must be one of the first steps in improving on-farm IE. DU tests conducted by RWP on monitored farms and on demonstration plots revealed that it is on average 0.75 (factor 1.33 in Equation 4). Similar result was given by Kafa'a, a USAID supported project (USAID, 2005).

4.3.3 Leaching Requirement

Leaching requirement must be another consideration in calculating FWR. If salinity of irrigation water is higher than 1.5 dS/m, and the plant is salt sensitive, a fraction of the applied water should be added to leach out salts from the root zone during each irrigation event. (Burt et al., 1999). Calculation of leaching requirements for different crops revealed that CWR should be increased by an average of 10% to leach salts out of the root zone (factor 1.1 in equation 4). Yet one can consider that accounting for irrigation efficiency is enough and there is no need to account for leaching requirements if leaching requirements are less than 10%. EC_{iw} for RW in the central and southern JV ranges between 1.5 - 2.8 dS/m. Besides the main irrigation water sources, namely KTR and KAC, many brackish water sources, including wells, springs and drains with even higher salinity values than KTR and KAC, are used by farmers for irrigation. In these cases leaching requirements are higher and can be calculated as shown in the 'Guidelines for Brackish Water Irrigation in the JV (GTZ, 2003).

Taking all factors discussed so far the following equation can be used to estimate the actual amount of water needed to meet FWR:

FWR (mm) = ET_0 (mm) x ground cover (%) (which is CWR)

x 1.2 (factor for higher transpiration of different crops than the reference crop)*

x 0.8 (factor for mulching)

x 1.33 (system inefficiency factor)

x 1.1 (factor for leaching requirements) **Equation 4**

*(adjusted from Hartz, 2000)

or simplified:

$$FWR\ (mm) = ET_0 \times ground\ cover\ (\%) \times 1.4 \quad (for\ open\ field)$$ **Equation 5**

4.4 Greenhouse Conditions

Growing conditions in plastic houses differ from that in open field; wind speed and solar radiation are lower, whereas temperature and RH are higher. ET_0 under plastic houses is less than in open field, with the main factors reducing ET_0 being wind speed and solar radiation. Wind speed is negligible inside plastic houses. The net amount of radiation (R_n) differs in plastic houses compared to open fields, depending on type, age and transparency of plastic sheets. In addition to these factors dust and water condensation on the plastic covers and plastic house structure can reduce light transmission drastically. Only 35% to 70% of light measured outside the greenhouse typically reaches the greenhouse crop (Faust, 2002). Kaspersma (2001) assumes radiation in plastic houses to be 50% less than solar radiation measured in the open field. Mazahrih et al. (2001 and 2004) suggest that only 40% of open field ET_0 should be considered in a plastic house. Other studies (Fernandandez et al.,2000 and Banco et al., 2003) indicate that K_c values are higher under plastic house conditions, because crops grow faster and lusher. The increase in K_c values range from 15 - 20% (1.15 in equations 6). This increase is justified because cultivated varieties inside plastic houses are characterized by its indeterminate growth (unlimted vertical growth). As a rule of thumb the RWP team estimates ET_0 under plastic house conditions to be 50% of open field ET_0 for the northern part of the project area (factor 0.5 in Equation 6) and 60% of the open field ET_0 for the southern part of the project area (factor 0.6 in Equation 8). Accordingly FWR under plastic houses conditions can be estimated as follows

$$FWR = ET_0 \times \text{ ground cover}(\%) \times 1.4 \times 1.15 \times 0.5 \quad \text{for greenhouses (central JV: DAs 29, 22, 23, 24, 25)}$$

Equation 6

or simplified

$$FWR = ET_0 \times \text{ground cover } (\%) \times 0.8$$

Equation 7

$$FWR = ET_0 \times \text{ground cover}(\%) \times 1.4 \times 1.1 \times 0.6 \quad \text{for greenhouses (southern JV: DAs 26, 27, 28)}$$

Equation 8

or simplified

$$FWR = ET_0 \times \text{ground cover } (\%) \times 0.97$$

Equation 9

Greenhouse

5 Pre-Irrigation Requirements

Pre-irrigation is a good practice because it leaches salts below the root zone, thus giving young plants a good start for healthy root growth. If salt concentration in the root zone is high, plants will suffer and may die. Therefore farmers should ensure that soil salinity levels do not have any negative effects on plant growth. From an agronomic point of view it is sufficient to leach the first 20 - 30 cm of the soil at the beginning of planting. Leaching salts out of deeper layers would require large quantities of water that might not be available. Some farmers in the JV apply too much water as pre-irrigation; others use insufficient quantities to leach salts out of the root zone.

Following rule of thumb is given to leach salts from any given soil type to a target value of about 2 dS/m in the top 30 cm. Required precondition is that soil is already saturated up to field capacity (FC) in the desired depth at the start of leaching, this amount can be seen in Table 9, second column.
15 mm of water moving through the soil will leach 50% of the salts (i.e. $EC_e = 4$), 30 mm of water moving through the soil will leach about 80% of the salts (i.e. $EC_e = 10$) and 60 mm of water moving through the soil will leach about 90% , i.e. $EC_e = 20$, (CFA,1995).

Pre-Irrigation

Example for clay loam with EC_e = 10 dS/m: to saturate to FC, 95 mm have to be applied. To leach salts, a further 30 mm (= total of 125 mm) have to be applied. EC_e will then decrease from 10 dS/m to 2 dS/m.

The amount required for pre-irrigation is a function of four major parameters

- salts content (EC_e), which originates from mineral weathering, inorganic fertilizers, soil amendments (e.g., gypsum, and manures) and irrigation water
- soil texture
- soil depth
- crop.

Accordingly, it is difficult to give general figures for farms in the JV. To simplify the subject, the following quantities for the different soil types and different EC_e values are recommended to obtain a soil salinity of about 2 dS/m (Table 9).

Table 9: Approximate pre-irrigation requirements to leach salts in the upper 0.3 m for different soil types at three levels of soil salinity

Soil Type	Water content at FC (mm) in 0.3 m depth	Pre-irrigation (mm) $EC_e = 4$	Pre-irrigation (mm) $EC_e = 10$	Pre-irrigation (mm) $EC_e = 20$
Sand	27	42	57	87
Loamy sand	38	53	68	98
Sandy loam	62	77	92	122
Loam	81	96	111	141
Silt loam	99	114	129	159
Sandy Clay loam	77	92	107	137
Clay Loam	95	110	125	155
Silt Clay loam	110	125	140	170
Sandy Clay	102	117	132	162
Silt clay	116	131	146	176
Clay	119	134	149	179

Source: adjusted from CFA,1995

Table 9 shows the large differences in pre-irrigation requirements of different soil types and different soil salinities ranging from about 40 to 180 mm. Therefore, RWP recommends pre-irrigating according to soil type and soil salinity using Table 9 as an orientation. If the available water is insufficient to pre-irrigate the farm for leaching purposes, it is recommended to apply half of the quantities given in Table 9. These are enough to leach salts in the upper 15 cm of soil and this will give the plants a good start. An example how to calculate the duration of the pre-irrigation is given in Annex11.3.

It is essential before starting pre-irrigation to find out the soil salinity level, either by sending a sample to the laboratory or by conducting 1:1 test in the field (see Guidelines for Brackish Water Irrigation, GTZ 2003).

6 Irrigation Depth and Scheduling

Irrigation scheduling usually means deciding two things

- how much water to apply
- when to start an irrigation application.

Irrigation scheduling is based on a water budget of the soil moisture depletion. The soil water depletion balance is accomplished by keeping an account of daily or weekly ET_c, effective precipitation, root zone depth and net irrigation application values. Scheduling requires an understanding of physical soil-water properties and, most important, the water holding capacity of the soil (Figure 5). Calculating water holding capacity enables farmers to estimate the net- and gross amount of water that can be added to the soil. Inaccuracies in estimating water holding capacity of the soil can lead to leaching (deep percolation) or desiccation.

Factors affecting irrigation scheduling are

- FWR
- system efficiency and leaching requirement which is needed to calculate gross amounts
- water holding capacity of the soil affecting net irrigation amounts (Table 10)
- precipitation.

6.1 Net Irrigation Depth

If irrigation frequency is not adjusted correctly to suit the water holding characteristics of the soil, substantial amounts of applied irrigation water can leach below the root zone, or in the other case, plants may suffer water stress. The concept behind determining net amount is to know the maximum amount of water that can be stored in the soil and used by crops without inducing any stress on the plant. Figure 5 shows the total available water content (TAWC) as the difference between permanent wilting point (PWP) and FC for different soils. Plants are not able to use this TAWC, because they will suffer stress before depleting it. Therefore the concept of the readily available water content (RAWC) is introduced and as a rough estimate is around half the TAWC. The RAWC is the amount of water needed (net amount) to raise water content in the soil to FC after considering a maximum allowable depletion (MAD) for the cultivated crop (0.49 for most vegetable crops according to Allen et al. (1998) and the effective rooting depth (R_e). Table 10 shows the approximate calculated net irrigation depths for different soil types at four rooting depths and for different spacing of laterals (1 and 1.8 m).

Drip irrigation usually wets only a portion of the field. The percentage of wetted area compared with the entire cropped area depends on the volume and rate of discharge for each emitter, the spacing between emitters and the type of the soil. The area wetted at each emitter is usually quite small at the soil surface and expands with depth (bulb shape). Under drip irrigation the wetting percentage can reach as high as 100% in narrow spacing and heavy textured soils and as low as 30% or even less in wide spacing and very light textured soils.

$$\text{Net irrigation depth (mm)} = (\text{FC (Vol\%)} - \text{PWP (Vol\%)}) * \text{MAD} * R_e\,(\text{m}) * \text{WP} \qquad \textbf{Equation 10}$$

where

MAD: this value varies depending on crop sensitivity and on ET, where at low ET this value can go up to 0.6 and at high ET goes down to 0.37, with an average of 0.49 (FAO, 1998)

R_e: effective rooting depth (m)

WP: wetting percentage under drip irrigation (20% - 100% depending on plant spacing, emitter spacing, number of emission points per plant and lateral water movement in different soil types).

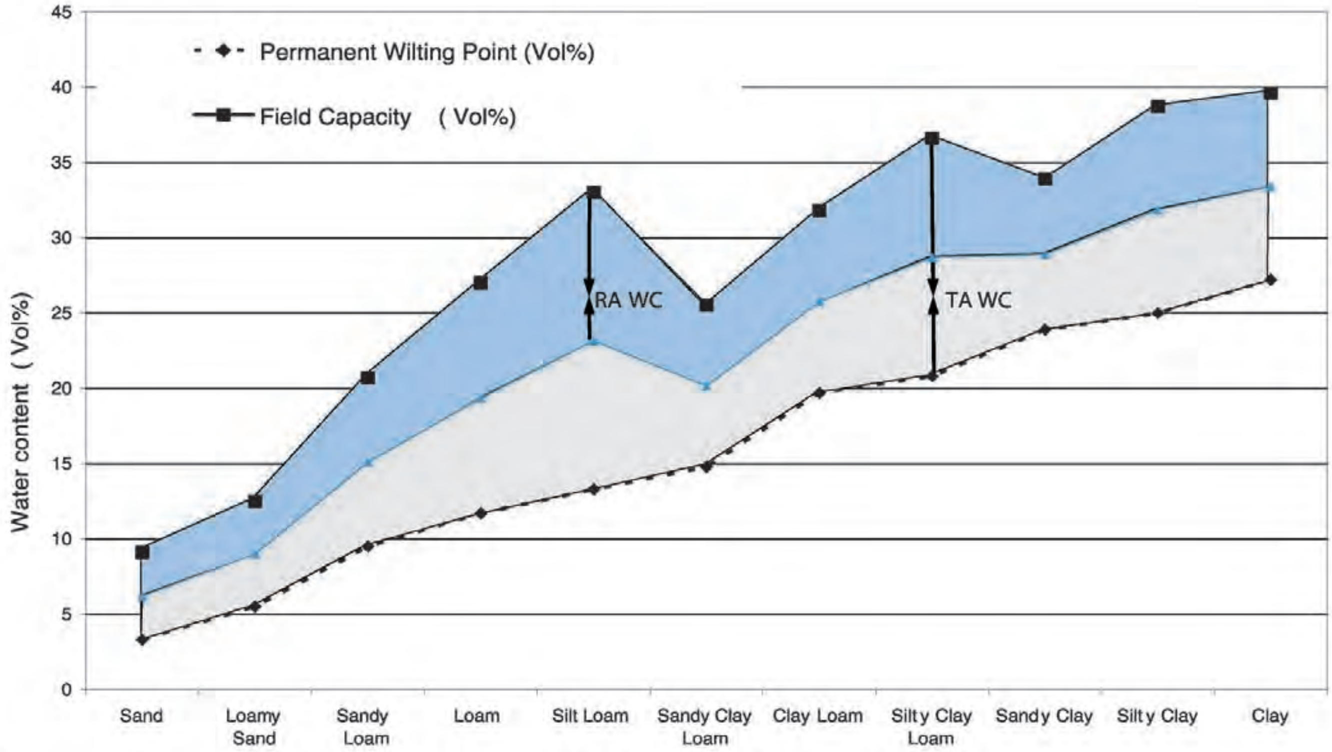

Figure 5: Impact of soil texture on TAWC and RAWC (after Rawls et al., 1982).

6.2 Gross Irrigation Depth

This is the maximum amount of water that should be applied to the soil during each irrigation, taking into account the amounts needed to compensate for AE and leaching requirement.

$$\text{Gross water depth (mm)} = \frac{\text{Net water depth (mm)}}{\text{AE \% x (1 - LF)}}$$ **Equation 11**

where

LF: leaching fraction (%)

If the AE is 75% and LF 0.1, then gross water depth = Net irrigation depth * 1.48 **Equation 12**

Table 10: Approximate net irrigation depths for different soil types at different root depths 0.15, 0.3, 0.5 and 0.7m for most vegetable crops, calculated with a MAD of 0.49.

Soil Type	Net irrigation depth (mm)	Net irrigation depth (mm)	Net irrigation depth (mm)	Net irrigation depth (mm)
Rooting depth	**0.15 m**	**0.30 m**	**0.5 m**	**0.7 m**
Sand	0.9 - 1.7	1.9 - 3.4	3.2 - 5.7	4.4 - 8
Loamy sand	1.1 - 2.1	2.3 - 4.1	3.8 - 6.9	5.3 - 9.6
Sandy loam	2.7 - 4.9	5.5 - 9.9	9.1 - 16.5	12.8 - 23
Loam	5.6 - 10.1	11.2 - 20.2	18.7 - 33.7	26.8 - 47.2
Silt loam	8.8 - 14.5	17.7 - 29	29.5 - 48.3	41.3 - 67.2
Sandy Clay loam	7.9 - 5.2	10.5 - 15.7	17.5 - 26.2	24.5 - 36.7
Clay Loam	6.4 - 8.9	12.8 - 17.8	21.4 - 29.6	30 - 41.5
Silt Clay loam	9 - 11.9	18.1 - 23.2	30.1 - 38.7	42.2 - 54.2
Sandy Clay	6.1 - 7.4	12.3 - 14.7	20.4 - 24.5	28.6 - 34.3
Silt clay	8.4 - 10.1	16.8 - 20.1	28 - 33.6	39.2 - 47
Clay	7.6 - 9.1	15.2 - 18.2	25.3 - 30.4	35.4 - 42.5

Lower values for wide rows spacing (1.8 m) and higher values for narrow rows spacing (1 m)
Source: adjusted from Rawls et al. (1982).

6.3 Precipitation

In the central JV the annual average of precipitation is less than 150 mm. In open fields many farmers carry out an excellent practice, which is to irrigate just immediately after a rain. They have learned this from experience as, after a light rain, salts accumulate along the fringes of the wetted surface and leach into the zone of intensive root activity thus severely injuring plants. To minimize this hazard the drip system should be operated during and after a rain. Because of the previous mentioned practice, and because of low annual average of precipitation in the central JV, rain does not contribute significantly to irrigation; therefore it is not considered in the irrigation scheduling. However, in wet years rain contributes to leaching salts and helps to prevent salinity build up.

6.4 Irrigation Frequency

It is important to mention that the frequency of irrigation is not fixed; on the contrary, it changes according to net irrigation amount and ET_c. For the sake of simplicity and for most vegetable crops, farmers and extension workers should consider four major net irrigation depths during one growing season: the first at a root zone depth of 0.15 m for the early stage (seedling stage, 2 - 3 weeks after planting), the second at 0.3 m for the early flowering stage, the third at 0.5 m for fruit bulking stage and the fourth at 0.7 m for the late stage (some crops only). The reason for considering four net irrigation depths is that roots, especially for annual crops, deepen with time thus affecting net irrigation amount. Applying precise scheduling requires experienced irrigation know-how which is complex work for both farmers and extension workers. What RWP recommends is an easy approach as follows.

6.4.1 Weekly Irrigation

If the value of the weekly FWR is less than the gross irrigation depth for that specific age of plant (value from Table 10, multiplied by 1.48), this means that there will be no deep percolation (water loss) and in this case the farmer can apply the whole amount of FWR for that week (preferably at one irrigation) or as he desires and in this case

applied water = FWR (daily) * number of days between irrigations.

6.4.2 Daily/Repeated Irrigation

If the value of weekly FWR is higher than the gross irrigation depth, this means that the soil reservoir will not hold this amount if the entire quantity is applied at once, and the surplus will deep percolate. In this case, the farmer should check the daily FWR and if it is less than the gross irrigation depth, he can irrigate daily and apply the daily FWR or as he desires. However, the applied quantity during each irrigation should not exceed gross irrigation depth. If the value of daily FWR is still higher than the gross irrigation depth, which might happen in case of hot weather, on sandy soil and at the early growth stage, he should irrigate twice a day. With the first irrigation he should apply the gross irrigation depth and with the second the difference between FWR and gross irrigation depth according to the following formula

second irrigation = daily FWR - gross irrigation depth

If the value of weekly FWR is equal to gross depth, the farmer might apply this amount at one time without being at risk of deep percolation. In case he desires to split it into a number of amounts then he should apply the previous formula

applied water = FWR (daily) * number of days between irrigations

When shifting from one rooting depth to another, water should be applied to refill the root zone depth of the new stage (value from Table 10).

6.5 Irrigation Duration

So far, irrigation requirements in terms of mm/day or mm/week have been discussed. Depending on emitter flow rate, distance between emitters and operating pressure, the number of irrigation hours can be calculated. A reasonable estimate of flow rate can be calculated from the timed capture of the flow from individual emitters in different parts of the field. The best time to do so is at an early stage of the crop because it is easier to access irrigation pipes at that time (Hartz, 2000). It is very important to mention that emitter flow rate should be measured in the field because it depends on the system pressure, therefore it is not uncommon to have emitters designed to give 4 l/h but giving not more than 2 l/h under field conditions.

6.5.1 Application Rate

To calculate application rate apply the following equation

$$\text{Application rate (mm/h)} = \frac{\text{Emitter flow rate (l/h)}}{\text{Emitter spacing (m)} \times \text{row spacing (m)}} \qquad \text{Equation 13}$$

6.5.2 Running Time

Running time can be calculated as follows

$$\text{Running time (h)} = \frac{\text{Depth (mm)}}{\text{Application rate (mm/h)}} \qquad \text{Equation 14}$$

6.5.3 Application Rate versus Infiltration Rate

Some farmers do not pay attention to the application rate of their irrigations systems. This can create problems when the infiltration rate of the soil is very low, as it is the case with heavy textured soils.

Table 11 gives the basic infiltration rates for different soil types. It is highly recommended for the farmer to compare the application rate of his irrigation system with the infiltration rate of his soil. If the application rate of his equipment is higher than the soil infiltration rate, water is lost through run off between rows; this run-off water is missing in meeting the FWR and might increase the chances of fungal diseases, especially in plastic houses during winter months.

Table 11: Infiltration rates for different soil types.

Soil Type	Infiltration rate (mm/h)
Sand	25
Loamy sand	16
Sandy loam	13
Loam	11
Silt loam	10
Sandy Clay loam	9
Clay Loam	8
Silt Clay loam	8
Sandy Clay	8
Silt clay	6
Clay	4

Source: Western Fertilizer Handbook, 1995 & 2002

6.6 Examples for Calculation of FWR, Gross Irrigation Depth, Application Rate and Running Time

Following are three *examples* applying the previous equations for cases as provided in Table 12. The FWR for the months of September, December and March are calculated.

Table 12: Three crops under different cultivation methods, acreage and water application rates.

Crop	Eggplant	Pepper	Cucumber
Date of planting	20/7/2005	30/8/2005	15/10/2005
Region	Karamah	Deir Alla	Deir Alla
Month	September	December	March
Coverage %	50	90	100
Cultivation	open field	open field	plastic house
Emitter flow rate (l/h)	2.6	6	3.2
Emitter spacing (m)	0.4	0.3	0.3
Rows spacing (m)	1.8	1	1
Area (m^2)	1,000	1,000	450
Soil type	Loam	Silt clay	Sandy loam
Root depth (m)	0.5	0.5	0.5

Table 6 shows that average ET_0 for September at Karamah is 4.9 mm/day, ET_0 for December at Deir Alla is 2.7 mm/day and 3.8 mm/day for March.

FRW:

Based on the simplified equation 5 (open field cultivation) FWR for eggplant and pepper are

$FWR_{(eggplant)}$ = 4.9 (mm ET_0/day) * 0.5 (% coverage) * 1.4 (factor from equation 5)

= 3.4 (mm/day) * 7 (days) = 23.8 mm weekly

$FWR_{(pepper)}$ = 2.7 (mm ET_0/day) * 0.9 (% coverage) *1.4 (factor from equation 5)

= 3.35 (mm/day) *7 (days) = 23.5 mm weekly

Based on equation 7 (plastic house cultivation, central JV) FWR for cucumber is

$FWR_{(cucumber)}$ = 3.8 (mm ET_0/day) * 1 (% coverage) * 0.8 (factor from equation 7, plastic house)

= 3.04 (mm/day) *7 (days) = 21.3 mm weekly

Gross Irrigation Depth

The eggplant in the example is cultivated on loam soil (Table 12); for an assumed root depth of 50 cm the net irrigation depth ranges from 18.7 to 33.7 mm. In the example the spacing is wide (1.8 m); accordingly the net depth is 19 mm.

Gross irrigation depth (mm)

= net irrigation depth (mm)* 1.48 (factor from leaching requirement (0.1) and system efficiency (75%)

= 19 mm * 1.48 = 28 mm

Because FWR (23.8 mm) is less than gross irrigation depth (28 mm) the farmer has the choice to apply the entire amount at one time or as follows:

Daily FWR * number of days between irrigations.

For the pepper example, rooting depth is 0.5 m, row spacing is 1 m; for silt clay the net irrigation depth is 33.6 mm.

Gross irrigation depth (mm) = 33.6mm * 1.48 = 49.7 mm

Because FWR (23.5 mm) is less than gross depth (49.7 mm) the farmer has the choice to apply the entire amount at one time or as follows:

Daily FWR * number of days between irrigations.

For the cucumber example, rooting depth is 0.5 m, row spacing is 1m, and accordingly the net irrigation depth in sandy loam is 16.5 mm.

Gross water depth (mm) = 16.5 mm * 1.48 = 24.4 mm

Because FWR (21.3 mm) is less than gross water depth (24.4 mm) the farmer has the choice to apply the entire amount at one time or as follows

Daily FWR * number of days between irrigations.

Application Rate

Based on equation 13, following application rates can be calculated:

Application rate for eggplant = 2.6 l/h (emitter flow rate) / (1.8m (row spacing) * 0.4m (emitter spacing) = 3.6 mm/h

Application rate for pepper = 6 l/h / (1m * 0.3m) = 20 mm/h

Application rate for cucumber = 3.2 l/h / (1m * 0.3m) = 10.7 mm/h.

Running Time

Running time can be calculated according equation 14:

Running time for eggplant if the farmer applies it all at once = 23.8 mm/3.6 (mm/h) = 6.6 h = 6 h 37 min

Running time for pepper if the farmer applies it all at once = 23.45 mm/20 (mm/h) = 1.17 h = 1 h 10 min

Running time for cucumber if the farmer applies it all at once = 21.3 mm /10.7 (mm/h) = 2 h

7 Maintenance of the Irrigation System

Farmers using RW should consider its possible effects on the irrigation system. RW can contain suspended solids, biological agents and high concentrations of Ca and Mg. All these impurities can cause partial or even full clogging of emitters. Even partial clogging reduces the efficiency of the system and DU.

Causes of clogging

Physical

- soil particles such as sand and silt
- organic matter
- trash, weed seeds, rags etc.

Chemical

- precipitation of salts like Ca-carbonate, Ca-sulphate, Mg-carbonate.

Biological

- algae and bacteria
- bacterial precipitation of sulphur, iron and manganese.

Fertigation

High concentrations of Ca and Mg in the presence of bicarbonate lead to the formation of insoluble solids. Less than 0.2 parts per million (ppm) of iron and manganese concentrations is sufficient to provide favourable conditions for bacterial growth (Burt et al., 1998). The iron bacterial growth looks reddish, whereas the manganese bacterial growth is black in colour. Iron and manganese in the presence of sulphides can form insoluble black precipitants.

7.1 Filtration

Drip irrigation systems require proper filtration systems to prevent clogging of emitters as well as to ensure even water distribution for all parts of the field. A good filtering system should include

- water pools (reservoirs) that store irrigation water and can act as settling basins for sand and silt serving as pre-treatment measures for drip systems; the disadvantages are that they allow the growth of organic matter and bacteria and allow significant water evaporation
- sand filters to remove large suspended solids; these filters use several layers of sand and gravel of different sizes through which the water percolates. They are effective in filtering out particles in the range of 200 to 25 micron (1 micron equals 0.001 mm), therefore they are suitable for removing heavy loads of very fine sands and organic impurities like algae. The efficiency of these filters depends on the media utilized and to a certain degree on the depth of the filter bed, the flow rate of water and the pressure. Table 13 provides different sizes of commonly used material as media in these filters. These filters are cleaned through back flushing. They are usually followed by a screen or disc filter as a safety measure to prevent sand going into the system during the cleaning process. They are available to remove particulate matter in the range of 25 to 100 micron
- disc filter to remove the very small suspended particles; the element of this type of filter is composed of many plastic discs with grooves, which are very tightly spaced.

Table 13: Types and sizes of media used in sand filters (FAO, 1996)

Material	Mean size (microns)	Particle size removed (microns)
Crushed granite no. 8	1840	> 160
Crushed granite no. 11	952	> 80
Silica no. 16	806	> 60
Silica no. 20	524	> 40
Silica no. 30	335	> 20

It is very important that filters are kept clean and back flushed regularly so that the pressure drop between the inlet and the outlet does not exceed the designated limits, usually less than 0.7 bar (Sarraf, 1999).

7.2 Chemical Treatment for Chemical Causes of Clogging

Precipitation of minerals can be due to changes in the pH and/or temperature. Efficient filtration systems will not prevent emitter clogging resulting from chemical precipitation. Therefore, different measures should be taken to minimize this problem. Table 14 depicts measures to overcome chemical precipitations.

Table 14: Measures and solutions to overcome chemical precipitation

Problem	Problem occurs when	Solution
Ca precipitations	$HCO_3^- \geq 2$ meq/l and pH >7.5	– acid injection (hydrochloric or sulfuric acids), amount needed ranges from 0.02 - 2% of the system capacity – water aeration in pools leads to settling of precipitates in the pools
Iron precipitations	Fe ≤ 0.3 ppm	– chlorination using sodium hypochloride
Phosphorous sedimentations	High use of P fertilizers combined with high Ca and Mg in the irrigation water	– avoid mixing fertilizers containing Ca, Mg and Fe with P fertilizers – acid injections – apply least half of P fertilizers as pre-planting application

7.3 Chemical Treatment for Biological Causes of Clogging

Clogging caused by bacteria takes place at high temperatures and darkness. Such conditions usually exist inside emitters and pipes during warm weather. Growth of algae is encouraged when water contains high levels of P at high temperatures, which is common in JV and supports algae growth on the surface of the water pools on farm units. These problems can be eliminated by chlorination using sodium hypochloride. Table 15 shows the typical chlorine dosages needed to overcome these problems

Table 15: Typical chlorine dosages (FAO, 1984)

Problem	Dosage
Algae	0.5 - 1 ppm continuously or 10 - 20 ppm for half an hour
Iron bacteria	1 ppm over the number of ppm of iron present in the water
Slimes	0.5 ppm

7.4 Pressure Variations

When using drip irrigation systems a major component of non-uniformity (low DU) is caused by pressure differences in the system. Therefore, farmers should regularly adjust pressure properly to ensure even water distribution. One of the cheapest methods for measuring pressure is to use a hand pressure gauge, which is available in the local market for around 7 JD. The rule of thumb is to ensure that the pressure value at the beginning and at the end of lateral (hose) lines is around 1 bar with a pressure difference of not more than 5 - 10%.