Brackish Water Project

Guidelines
for Brackish Water Irrigation in the Jordan Valley

November 2003

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

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List of Abbreviations

BW	Brackish Water
BWP	Brackish Water Project
CEC	Cation Exchange Capacity
CWR	Crop Water Requirement
d	Day
DA	Development Area
Dr	Drain
dS/m	deciSiemens per meter
du	Dunum (1000 m^2)
EC	Electrical Conductivity
EC_e	Electrical Conductivity of saturated soil paste extract
EC_{iw}	Electrical Conductivity of irrigation water
EC_{sw}	Electrical Conductivity of soil water
ET	Evapotranspiration
ET_0	Reference crop evapotranspiration
ET_c	Crop evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
f_c	Conversion factor
FU	Farm Unit
FW	Freshwater
FWR	Field Water Requirement
g/l	Gram per liter
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
IAS	Irrigation Advisory Service
IW	Irrigation Water
JVA	Jordan Valley Authority
KAC	King Abdullah Canal
k_c	Crop coefficient
kg/du	Kilogram per durum
kg/m^2	Kilogram per square meter
KTR	King Talal Reservoir
l/h	Liter per hour
l/s	Liter per second
LF	Leaching Fraction
LR	Leaching Requirement
MCM	Million Cubic Meter
meq/l	milliequivalent per liter
mm	millimeter
mM/l	milli Mol per liter
MoA	Ministry of Agriculture
mol/m^3	Mol per cubic meter
mol_c/m^3	Mol charge per cubic meter (equivalent to meq/l)
MoWI	Ministry of Water and Irrigation
NCARTT	National Center for Agricultural Research and Technology Transfer
ppm	parts per million or mg/l
RSC	Residual Sodium Carbonate
SAR	Sodium Adsorption Ratio
Sp	Spring
TDS	Total dissolved solids
TWA	Total Water Applied
We	Well

Background

THE BRACKISH WATER PROJECT (BWP) is jointly implemented by the Jordan Valley Authority (JVA) and the German Technical Cooperation (GTZ). The agricultural component of the project is focusing on the use of brackish water (BW) for irrigation in the middle and southern Jordan Valley.

After an inventory of the brackish water sources and their use in the middle and southern Jordan Valley (*GTZ, 2001* and *GTZ, 2002*), farm units irrigating with BW were pre-selected. Within the farm monitoring program of the project an assessment procedure was applied in order to identify successful farmers with long experience in BW use.

Over four years, from 2000 to 2003, the BWP field staff visited regularly more than 20 farm units (FU) in the middle and southern Jordan Valley (see Fig. 1). The agricultural and irrigation practices were intensively monitored and recorded. Interviews and discussions with farmers, estimates and measurements by the BWP field staff, e.g. of discharges and yields, resulted in detailed information compiled in a data bank. The evaluation and analysis of the data allowed the identification of local experiences and successful practices with regard to BW use in agriculture. Based on these local practices, combined with international experiences obtained through studies (*GTZ, 2001*) and continuous scientific update, the following guidelines were developed. Their purpose is to serve farmers and agricultural extension agents as a source of relevant information and appropriate know-how that can be practically applied in the field when BW is used for irrigation.

The draft of the guidelines was reviewed by and discussed with Jordanian researchers, scientists and specialists with practical experiences in this field from

- University of Jordan (UJ)
- University of Science and Technology (JUST)
- Ministry of Water and Irrigation (MoWI)
- Jordan Valley Authority (JVA)
- Water Authority of Jordan (WAJ)
- Ministry of Agriculture (MoA)
- National Center for Agricultural Research and Technology Transfer (NCARTT)
- Jordan Farmer's Union (JFU)
- Private Sector (farmers, agricultural input suppliers).

We would like to express our thanks to the colleagues involved for their valuable comments and remarks, which greatly helped to further the significance of the Guidelines for practical application and dissemination among BW users.

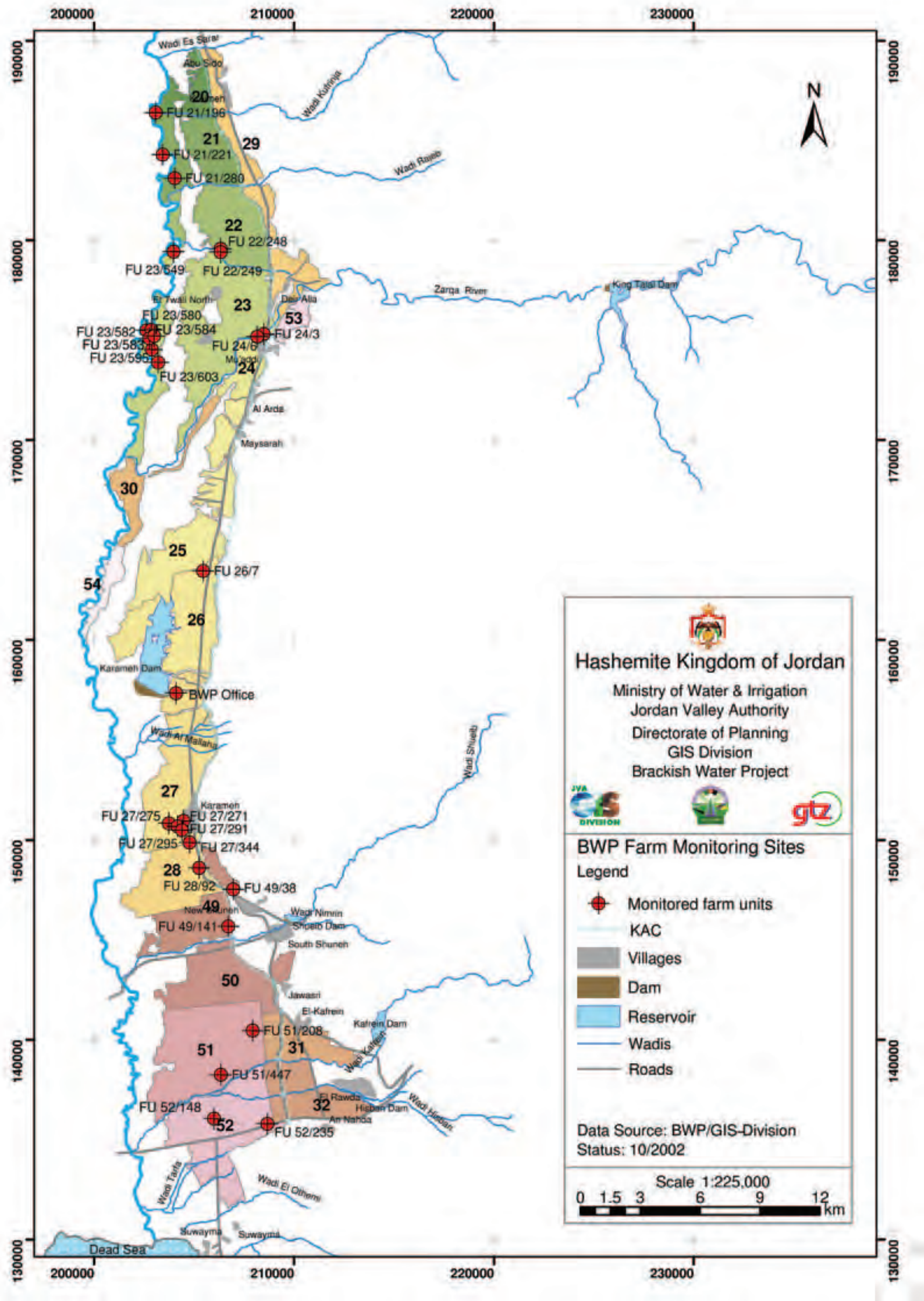


Fig. 1: Locations of monitored farm units in the middle and southern Jordan Valley

Irrigation Water Quality

IRRIGATION WATER contains salts, either originating from geological layers and the groundwater or from man-made influences like fertilizers. Salts dissolved in water separate into ions. Tab. 1 gives an overview of the main ions and their charges.

Anions (acidic)	Chemical symbol	Cations (basic)	Chemical symbol
Chloride	Cl^-	Sodium	Na^+
Sulfate	SO_4^{--}	Potassium	K^+
Carbonate	CO_3^{--}	Calcium	Ca^{++}
Bicarbonate	HCO_3^-	Magnesium	Mg^{++}
Nitrate	NO_3^-		

Tab. 1: Main ions in irrigation water

The salinity of irrigation water is determined by measuring the electrical conductivity (EC) in deciSiemens per meter [dS/m] at 25° C. The relation between the electrical conductivity of irrigation water (EC_{iw}) and another occasionally used unit, total dissolved solids (TDS), is

EC_{iw} [dS/m] x 640 = TDS [mg/l] or [ppm]

For practical reasons the threshold for brackish irrigation water in the Jordan Valley is in this context considered to be

$EC_{iw\ threshold}$ = 3 dS/m or ~ 2,000 ppm

which is also applied in the context of these guidelines.

Fig. 2: Salinity of water sources on monitored farms (FU / DA / code of water source)

The salinity of the brackish water sources of the monitored FUs (Fig. 2) reaches up to 7 dS/m depending on the origin of the water and the season of the year. In winter, during the rainy period, the salinity of the water sources normally decreases.

Fig. 3: Measurement of water salinity

Another important quality parameter is the <u>acidity</u> of the irrigation water, measured as pH with values between 0 - 14. Neutral water has a pH of 7, lower values indicate higher acidity, higher pH values mark basicity. The normal pH range of irrigation water is between 6.5 - 8.4. No water source of the monitored FUs exceeded the pH value of 8.4 during the past three years. Water with pH of 7 and above and HCO_3^- of about 100 ppm (2 meq/l) can cause $CaCO_3$ precipitation. Acidification of the water (pH between 7 and 5) helps to control the precipitation of lime and clogging of dripper tapes and emitters. This is well known by the farmers of the monitored FUs and one of the reasons why they add ammonium sulfate $(NH_4)_2SO_4$ and humic acid as fertilizers to the irrigation water.

<u>Chloride</u> (Cl^-) has no adverse effects on soils but can be toxic if taken up by the plants and accumulated in the leaves. Especially citrus and other fruit trees are susceptible to high concentrations in the irrigation water, the threshold being at 10 meq/l. With sprinkler irrigation systems there is a hazard of leaf burn when the concentration is higher than 3 meq/l (*FAO, 1985*).

In the Jordan Valley most brackish water sources have chloride contents higher than 10 meq/l, which represents a hazard for citrus and other fruit trees.
No sprinkler irrigation equipment should be used with $Cl^- > 3$ meq/l

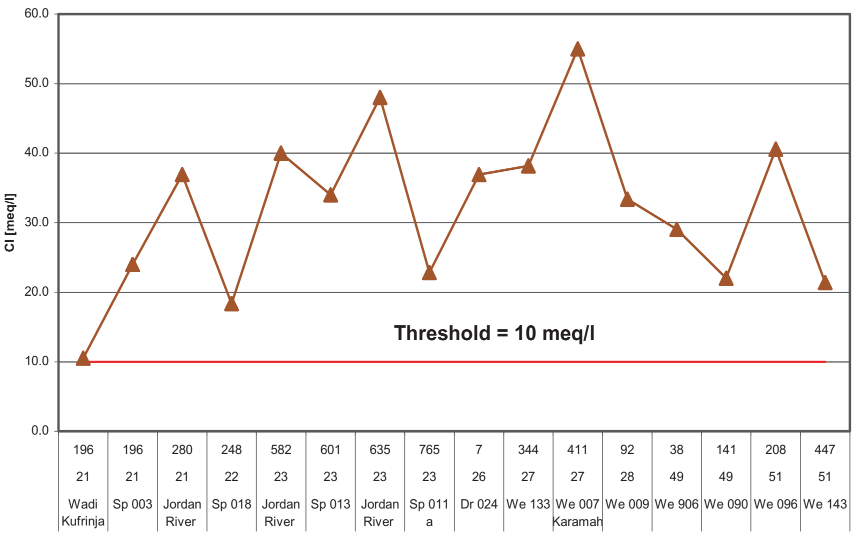


Fig. 4: Chloride content and threshold of water sources on monitored FUs

As can be seen in Fig. 4, the Cl^- content of the water sources of the monitored FUs is high and in all cases above the threshold of 10 meq/l. This is the main reason why hardly any citrus and fruit trees are grown with brackish water in the area under review. On the other hand visible leaf burn symptoms on the grown vegetables and field crops due to the relatively high chloride content have not been observed on the monitored FUs. However, chemical analysis of plant tissue is recommended if chloride toxicity is suspected.

Sulfate (SO_4^{--}) forms salts with Na^+, Ca^{++} and Mg^{++} but is not toxic to plants. The solubility and dissociation of sulfate salts in water is lower than that of chloride salts. SO_4^{--} is essential to plant growth, but at high concentrations it can damage irrigation pipes and canals. Sulfate contents of the water sources of the monitored FUs range between 1 and 50 meq/l; so far no adverse effects have been observed on the monitored FUs.

Carbonate (CO_3^{--}) and bi- or hydrogen-carbonate (HCO_3^-) in the irrigation water can precipitate Ca^{++} and Mg^{++} as carbonates and thereby increase the adverse effect of the remaining sodium (Na^+). The residual sodium carbonate (RSC) is calculated as the difference between the sum of carbonate plus bicarbonate and the sum of calcium and magnesium ions expressed in milliequivalent per liter [meq/l].

$$\mathbf{RSC = (CO_3^- + HCO_3^-) - (Ca^{++} + Mg^{++})\ [meq/l]}$$

Irrigation water with high CO_3^{--} and HCO_3^- contents can reduce soil permeability and deteriorate soil structure

Irrigation water with RSC > 2.5 meq/l is normally not suitable for irrigation. Alkaline soils will be more damaged than acid soils; for the latter, carbonate rich waters can even be an amendment. The precipitation of Ca^{++} and Mg^{++} caused by carbonate rich water increases the sodium content, reduces the permeability of heavy soils and deteriorates the structure of such soils.

For the irrigation water of the monitored soils no RSC data are available. However, results of the soil assessment study (*GTZ, 2000*) and the soil monitoring program (*GTZ, 2001*) show that the probability of any hazard caused by high RSC is low.

Nitrate (NO_3^-) is found in considerable amounts in most water sources in the Jordan Valley. The NO_3^- found in the KAC-south water mainly originates from the wastewater treatment plant of As-Samra. Other water sources such as drains, springs, and wells receive nitrate from percolating irrigation water containing fertilizer residues.

Fig. 5: King Talal Reservoir

Fig. 6 shows that the nitrate-nitrogen content of the water sources on the monitored FUs varies between about 5 to 40 ppm. Farmers using such water benefit from the nutrient content. Assuming an average content of 20 ppm and an application of about 1,000 mm per year (2 seasons), this results in an influx of about 20 kg/du/year of NO_3-N.

Nitrate-nitrogen (NO_3-N) content of most brackish water sources in the Jordan Valley is relatively high and should be considered in the fertilizer management

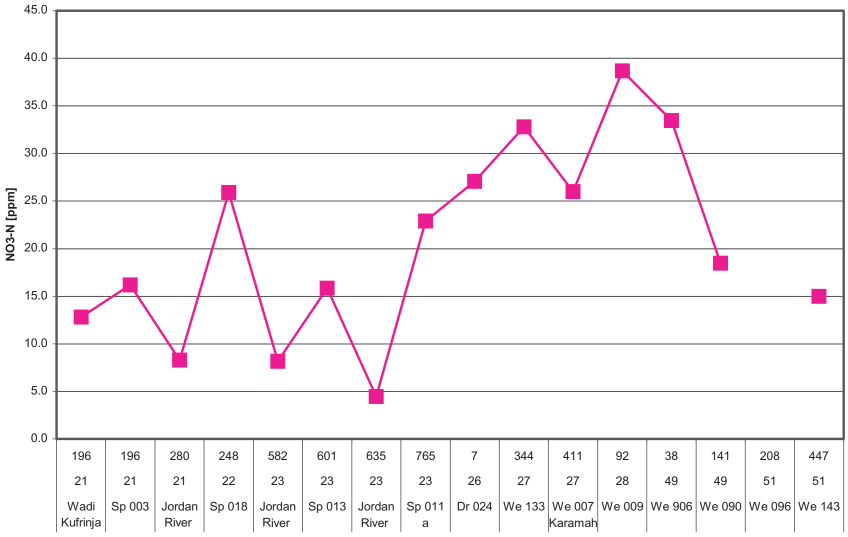


Fig. 6: Nitrate-nitrogen content of water sources on monitored FUs

High sodium (Na^+) content in irrigation water can cause severe soil problems. The cation replaces Ca^{++} and Mg^{++} ions at the negatively charged exchange complex and leads to dispersion of the soil aggregates and to the deterioration of the soil structure (see also under carbonates). This, in turn, reduces the permeability of the soil for infiltration of rainfall and irrigation water as well as exchange of air, thus causing unfavorable growing conditions for plants.

With regard to possible soil problems, the ratio between the concentration of Ca^{++} plus Mg^{++} vs. Na^+ is important. The Na^+ hazard is reduced if Ca^{++} plus Mg^{++} is high compared to Na^+. This relation is reflected in the formula of the sodium absorption ratio (SAR):

$$\mathbf{SAR} = \frac{\mathbf{Na^+}}{\sqrt{\frac{(\mathbf{Ca^{++}} + \mathbf{Mg^{++}})}{\mathbf{2}}}} \text{ [meq/l].}$$

Water with high SAR and low to moderate EC_{iw} can reduce the soil's infiltration rate. At a given SAR, infiltration decreases as water salinity decreases.

	Degree of restriction on use		
	none	moderate	severe
SAR		EC_{iw}	
0 - 3	> 0.7	0.7 - 0.2	< 0.2
3 - 6	> 1.2	1.2 - 0.3	< 0.3
6 - 12	> 1.9	1.9 - 0.5	< 0.5
12 - 20	> 2.9	2.9 - 1.3	< 1.3
20 - 40	> 5.0	5.0 - 2.9	< 2.9

Tab. 2: Effects of SAR and EC_{iw} on use restrictions *(FAO, 1985)*

With regard to the toxicity hazard of Na^+, no clear information and guidelines are found in the literature. According to *Grattan (2000)* there is a potential for Na^+ toxicity due to foliar absorption in case of sprinkler irrigation; however this is rarely found in the Jordan Valley.

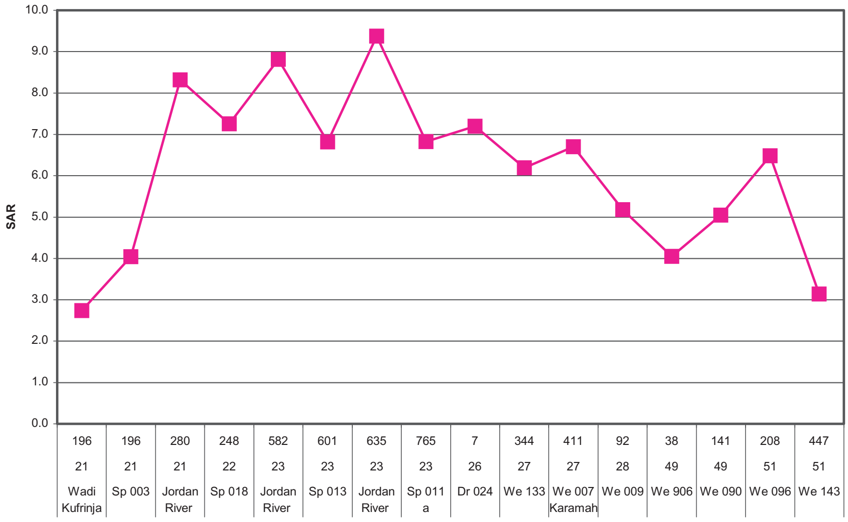


Fig. 7: Sodium absorption ratio (SAR) of water sources on monitored FUs

As can be seen in Fig. 7, the SAR of the water sources on the monitored FUs is in the range of about 3 - 9 meq/l. According to Tab. 2 no restriction is to be expected from SAR since the salinities of the brackish water sources are higher than 3 dS/m.

Magnesium (Mg^{++}) is a plant nutrient, but in high concentrations it can inhibit plant growth and reduce crop yields. In Mg^{++} dominated water ($Ca^{++}/Mg^{++} < 1$), the potential effect of sodium may be slightly increased and plant nutrition might be disturbed. In this case, according to *FAO (1985)* further evaluation is recommended.

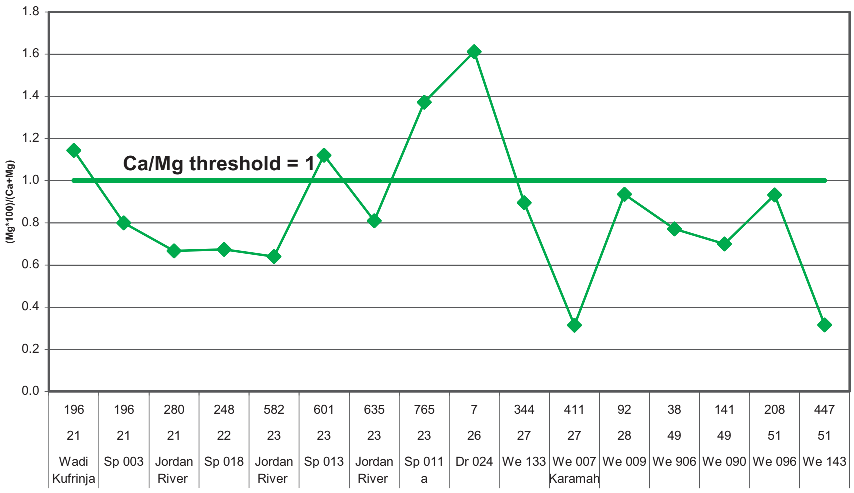


Fig. 8: Magnesium evaluation of water sources on monitored FUs

Magnesium (Mg) content of most brackish water sources is high and can cause plant nutritional disorders

For 12 out of 16 monitored water sources, the ratio Ca^{++}/Mg^{++} is < 1 as shown in Fig. 8. This indicates the possibility of magnesium related plant nutrition and plant growth problems.

Another important constituent of irrigation water is the element Boron, which is, on the one hand, an essential trace element and nutrient for plants, but on the other hand, can also be toxic if accumulated in high quantities in plant tissues. Especially in arid regions boron is regarded as a potential hazard.

Boron (B) content of brackish water sources has to be monitored regularly

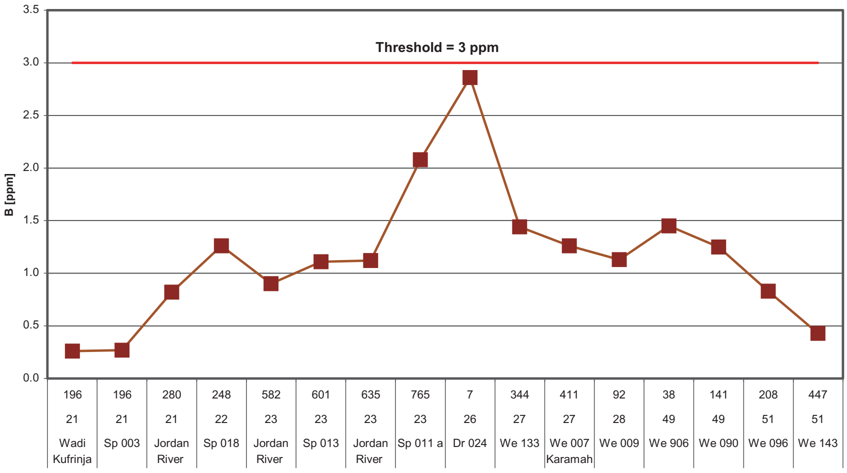


Fig. 9: Boron content of water sources on monitored FUs

According to *FAO (1985)*, severe toxicity problems will occur even for relatively tolerant plants if the concentration of B exceeds 3 ppm. Between 0.7 - 3.0 ppm, slight to moderate problems might appear.

Apparently the water sources on the monitored FUs are in the slight to moderate range, but so far no significant plant problems due to boron content have been reported or directly observed on the farms.

Crop and Field Water Requirement

CALCULATION OF crop water requirement (ET_c) is based on the reference evapotranspiration (ET_0) and a particular crop coefficient (k_c), which depends on the growth stage of the crop.

$\mathbf{ET_c = k_c \times ET_0}$

In the middle and southern Jordan Valley, the climatic data for daily evapotranspiration are measured at the Agricultural Stations of the National Center for Agricultural Research and Technology Transfer (NCARTT)[1] at Deir Allah and Karamah, and calculated according to the Penman-Monteith formula.

The monthly reference evapotranspiration rates (ET_0) between July 2000 and February 2003 at Deir Allah and Karamah Station are displayed in Fig. 11 and Fig. 12.

Fig. 10: Agro-climatological station at Karamah

The comparison of the measured values with the values calculated on a weekly basis is displayed in Fig. 13 and Fig. 14 over the period from July 2000 to February 2003 and shows little deviation.

[1] ww.ncartt.gov.jo/imis

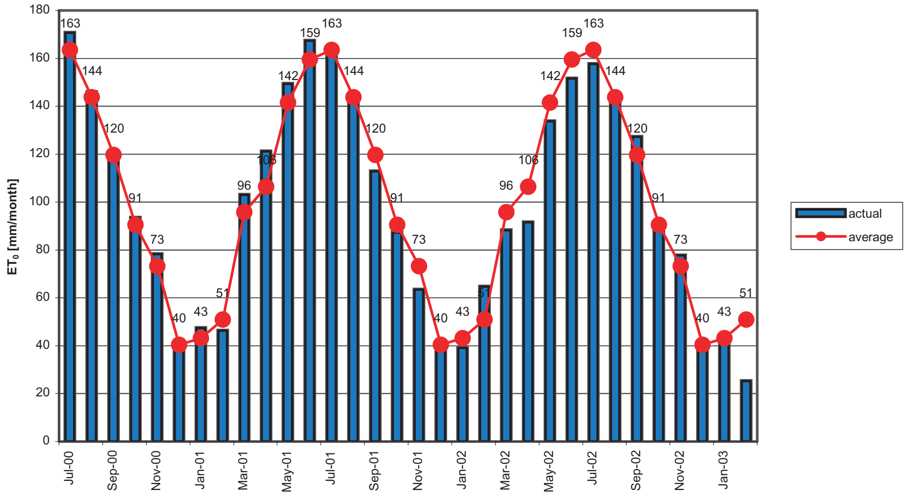


Fig. 11: Monthly reference evapotranspiration rates ET_0 at Deir Allah Station

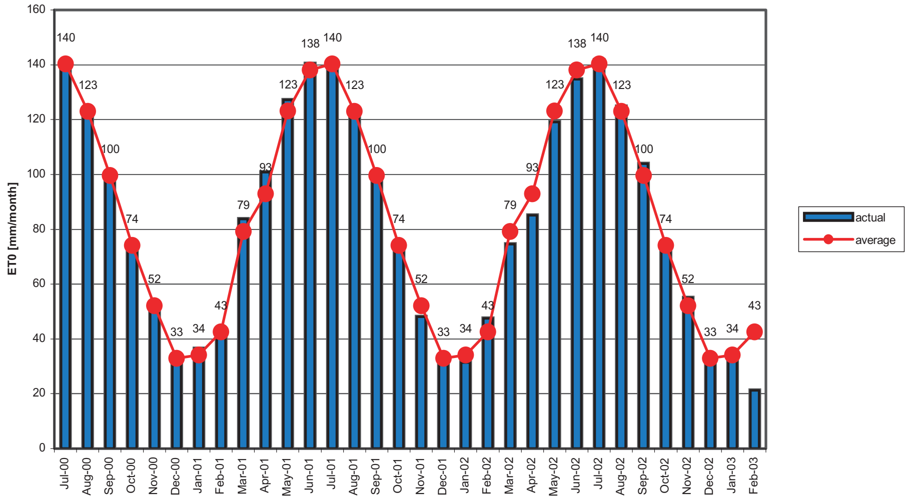


Fig. 12: Monthly reference evapotranspiration rates ET_0 at Karamah Station

Most of the farmers in the Jordan Valley base their irrigation management on weekly application rates. The average weekly ET_0 values for Deir Allah and Karamah Stations used for calculation of crop water requirements are shown in Fig. 13 and Fig. 14.

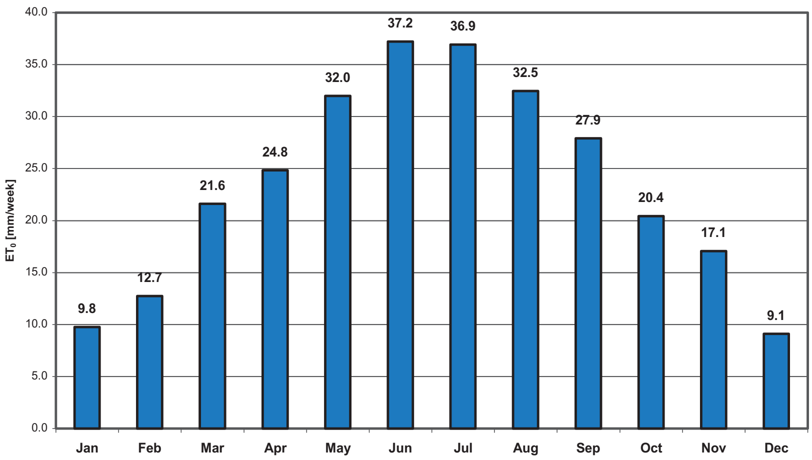


Fig. 13: Average weekly ET_0 per month at Deir Allah Station

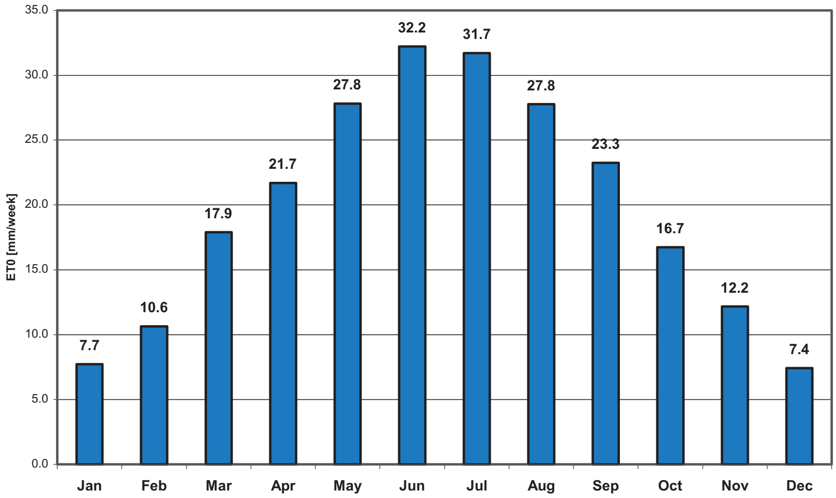


Fig. 14: Average weekly ET_0 per month at Karamah Station

A surprising observation is that values measured at the Karamah Station are lower than at Deir Allah, although temperatures in Karamah are higher. The main reason for this is the generally higher wind speed at Deir Allah.

For ease of calculation, the weekly ET_0 values for both stations, Deir Allah (middle Jordan Valley) and Karamah (southern Jordan Valley) are given in Tab. 3.

Month	weekly ET_0 Deir Allah	weekly ET_0 Karamah
January	9.8	7.7
February	12.7	10.6
March	21.6	17.9
April	24.8	21.7
May	32.0	27.8
June	37.2	32.2
July	36.9	31.7
August	32.5	27.8
September	27.9	23.3
October	20.4	16.7
November	17.1	12.2
December	9.1	7.4

Tab. 3: Average weekly ET_0 at Deir Allah and Karamah Station

Tab. 4 provides the crop coefficients k_c and - in brackets - the average locally observed duration of the particular growth stage in days for all major crops (spinach representing leaf crops), which are irrigated with brackish water in the Jordan Valley.

Crop	k_{c1}	k_{c2}	k_{c3}	k_{c4}
Alfalfa	0.6 (10 d)	0.83 (20 d)	1.05 (90 d)	1.05
Barley	0.6(20 d)	0.9 (25 d)	1.2 (50 d)	0.2
Sweet corn	0.6 (20 d)	0.9 (30 d)	1.2 (30 d)	1.1
Eggplant	0.6 (30 d)	0.85 (40 d)	1.1 (40 d)	0.9
Potato	0.6 (30 d)	0.9 (30 d)	1.2(30 d)	0.75
Spinach	0.6 (20 d)	0.83 (20 d)	1.05 (20 d)	1.0
Squash	0.6 (10 d)	0.8 (20 d)	1.0 (20 d)	0.8
Tomato	0.6 (30 d)	0.93 (40 d)	1.25 (40 d)	0.65
Wheat	0.6 (20 d)	0.83 (25 d)	1.2 (50 d)	0.2

Tab. 4: Crop coefficients k_c (*FAO, 1992* and *Euroconsult, 1989*, modified)

These coefficients give orientation for the specific crop water requirement of crops at particular growth stages:

k_{c1} initial stage: germination, seedling growth, hardly any ground cover (< 10 %)
k_{c2} crop development stage: until effective full cover (~ 70 - 80 %)
k_{c3} mid season stage: full cover until start of maturing, discoloring, normally well past the flowering stage of annual crops
k_{c4} late season: full maturity, discoloring, leaves dropping, harvest.

An appropriate and comparatively easy approach developed by the Brackish Water Project (BWP) to calculate the crop water requirement of a crop is to multiply the weekly values of ET_0 (Tab. 3) for each month by the crop coefficients k_{ci} for the particular growth stage (Tab. 4).

$\mathbf{ET_c = k_{ci} \times ET_0}$ [mm/week].

The resulting values represent the CWR determined on a weekly basis as shown in Tab. 5 for eggplant.

Month	weekly ET_0 [mm/week]	Weekly crop water requirement [mm]			
		Initial $k_{c1} = 0.6$ (30 days)	Development stage $k_{c2} = 0.85$ (40 days)	Mid season $k_{c3} = 1.1$ (40 days)	Late season $k_{c4} = 0.9$
Jan	7.7	4.6	6.6	8.5	6.9
Feb	10.6	6.4	9.0	11.7	9.6
Mar	17.9	10.7	15.2	19.7	16.1
Apr	21.7	13.0	18.4	23.9	19.5
May	27.8	16.7	23.6	30.6	25.0
Jun	32.2	19.3	27.4	35.5	29.0
Jul	31.7	19.0	26.9	34.9	28.5
Aug	27.8	16.7	23.6	30.5	25.0
Sep	23.3	14.0	19.8	25.6	20.9
Oct	16.7	10.0	14.2	18.4	15.1
Nov	12.2	7.3	10.3	13.4	10.9
Dec	7.4	4.5	6.3	8.2	6.7

Tab. 5: Example for calculation of weekly crop water requirement for eggplant (ET_0 data of Karamah Station)

This simple calculation allows the average weekly water requirement of a crop in its particular growth stage to be estimated at any time of the year either for the middle Jordan Valley (DA 20 - 26) with ET_0 values of Deir Allah Station or the southern Jordan Valley (DA 27 - 52) with ET_0 values of Karamah station (Tab. 3). Corresponding tables for the major crops irrigated with brackish water are presented in the crop related part of these guidelines.

The crop water requirement values (ET_c) consider the plant water requirement assuming a technically optimal irrigation system with no further influencing factors. Since the reality on the fields is more complex (technical losses, leaching requirements because of salinity, etc.), it is recommended to calculate the Field Water Requirement (FWR) with the following formula :

$$\mathbf{FWR} = \frac{\mathbf{ET_c}}{\mathbf{(1\text{-}LF) \times E_{is}}}$$

where ET_c = crop water requirement
LF = leaching fraction,
E_{is} = efficiency of the irrigation system[2] on the farm reflecting all losses from the farm turn out assembly to the emitters.

In the following chapter, 'Soil Salinity and Leaching', examples for the application of the above formula are given.

[2] Due to relatively rare replacement of drip irrigation equipment and low level maintenance, is estimated to be around 80%, or 0.80.

The formula does not consider groundwater and stored soil water. Furthermore it does not include the precipitation, which can amount up to about 400 mm per winter season in the middle and up to 200 mm in the southern Jordan Valley in exceptional years like 2003. Only a part of the precipitation is available to crops depending on factors like temperature, wind velocity, topography, soil texture and many others. For the middle and southern Jordan Valley, the effective rainfall, (i.e. the amount after deduction of interception, surface runoff and deep percolation losses), is estimated to be about 80 %. It can have beneficial leaching effects and contribute considerably to the crop water requirements. On the other hand, in arid regions, where salts tend to accumulate in the root zones, the drip irrigation system might have to be operated during rainfalls in order to keep the salts out of the root zone. Under such conditions the effective rainfall should not be considered when determining the crop water requirements. The farmer has to decide from case to case if he should take into account the effective precipitation in his field water requirement determinations.

Fig. 15: Eggplant irrigated with brackish water

Since an irrigation application of 1 mm is equivalent to 1 m^3/du, it is also possible for the farmer to easily convert these figures into hours of irrigation, provided the irrigated area and the discharge of the irrigation water source (e.g. spring, pump) are known.

It should be mentioned here that there are also other approaches for calculation of crop water requirement applied in the Jordan Valley, which are briefly described and compared below.

The Control Directorate of JVA at Deir Allah calculates the amounts of irrigation water to be provided to the farmers based on the cultivated crop (vegetables, citrus, cereals and banana) and standard factors which are constant for the entire year differentiating between KAC-north and KAC-south water (the higher values for KAC-south consider the lower water quality, i.e. higher salinity of the irrigation water).

Crop	KAC-north [mm/day]	KAC-south [mm/day]
Vegetables	2	3
Citrus	4	5
Cereals	5	5
Banana	7	8

Tab. 6: Water requirements for crop groups used by Control Directorate of JVA (personal communication)

These figures allow fairly general calculations of the water requirement on the Jordan Valley farms.

The Irrigation Advisory Service (IAS) calculates crop water requirement based on the reference evapotranspiration ET_0 and particular crop coefficients. This approach assumes pre-determined cultivation and harvest periods. Farmers who apply different cultivation schedules or are driven by spontaneous decisions with regard to planting dates and prolongation of harvesting periods cannot directly apply this approach. Annex 1 provides calculated ET_c values for crops cultivated in the Jordan Valley.

The Ministry of Water and Irrigation (MoWI) has calculated irrigation water requirements for all important crops nationwide including the Jordan Valley. These values are long-term average values for the main cultivation periods. Comparison of values from IAS and MoWI show differences, which can be explained by the following reasons:

- crop water requirement calculated by IAS covers the crops' direct physiological needs, whereas irrigation water requirement calculated by MoWI considers also the losses due to irrigation application methods and the type of cultivation (open field, greenhouse) (*Taha et al.*, without year)
- both approaches differ in the assumed cultivation periods, i.e. different sowing, transplanting and harvest dates
- the length of the period (plant growth stage) for which the specific plant coefficients have to be applied is not specified and thus may vary between the two approaches.

Fig. 16: Rain gauge on monitored FU

A comparison of all four approaches described above (BWP, JVA, IAS, MoWI) is shown in Fig. 17. The example is elaborated for eggplant cultivated in autumn (Tab. 5). As reference, the actual evapotranspiration ET_c for eggplant is also provided.

The JVA approach assumes almost the same water requirement throughout the entire cultivation season with values far above the actual evapotranspiration, especially between November and February, resulting in a high total water quantity applied, which may include also a certain leaching fraction.

The IAS recommendation is standardized and suggests a fixed cultivation period, in this case from August till December, whereas in the example eggplant was cultivated from September to June, including a long harvest period. Especially for the extended harvest period no particular recommendation is given. It has to be noted that in October the calculated irrigation water quantity with this approach is nearly twice the actual ET_c.

The MoWI approach follows very closely the actual ET_c, although the harvest is assumed to stop about two months earlier than is actually the case. A limitation of this approach is that the required values for irrigation water requirement are usually not available to farmers.

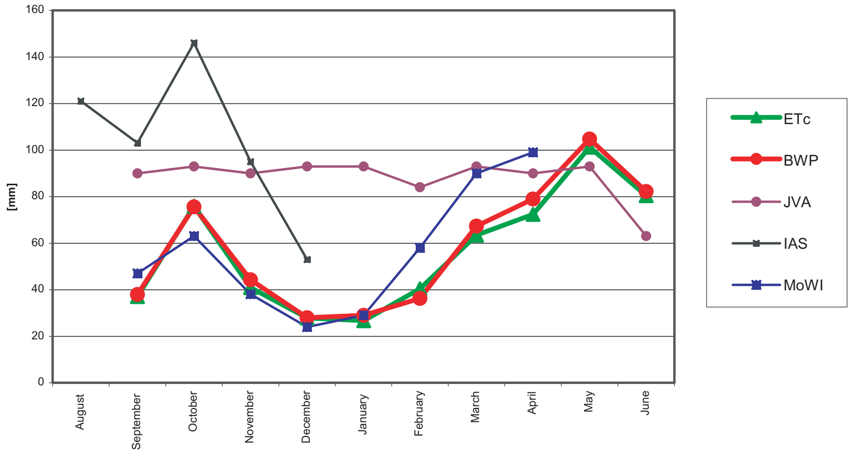


Fig. 17: Comparison of different calculation methods for crop and irrigation water requirement

The comparison of the different methods implies that the BWP approach - i.e. the application of weekly evapotranspiration values of the closest agro-climatological station (Deir Allah Station for the middle and Karamah Station for the southern Jordan Valley) in combination with the particular crop coefficient - provides a method that is easy to handle and precise enough for practical farmers to determine the crop water requirement at any date of the cultivation season.

Soil Salinity and Leaching

THE BUILD-UP of salinity in soils due to brackish irrigation water is a complex process and can be assessed according to *FAO (1985)* given certain assumptions. As a rule of thumb the salinity of the irrigation water EC_{iw} can be used to appraise the soil water salinity. At a leaching fraction of 15 - 20 %, the soil water salinity EC_{sw} is about 3 times the irrigation water salinity EC_{iw} ($EC_{sw} = 3\ EC_{iw}$). Since the particular soil water salinity EC_{sw} cannot be measured easily in the field, the EC of the saturated soil paste EC_e is normally measured in the lab. The value of the saturated soil paste extract EC_e is about ½ of EC_{sw} ($EC_e = 0.5\ EC_{sw}$, or $EC_{sw} = 2\ EC_e$). Thus for practical applications it can be stated:

$$\mathbf{EC_e = 1.5\ EC_{iw}}$$

This equation describes a steady state. Practically it means that after several years of irrigation with a given irrigation water salinity, the soil salinity measured on the saturated paste extract (EC_e) will adjust to about 1.5 times the irrigation water salinity (EC_{iw}) when applying a LF of 15 - 20 %.

In case of other leaching fractions, different factors have to be calculated, which are given as concentration factors in Tab. 7. These values apply to long-term irrigation periods, not for single seasons or periods between single irrigation applications. Tab. 7 also gives for a particular leaching fraction (LF) the corresponding amount of water to be applied as a percentage of the evapotranspiration demand (see chapter 'Leaching Requirement'). With these relations the long-term effects of the irrigation water salinity on the soils can be estimated, as shown in Fig. 18.

LF [%]	Applied water needed (% ET)	Concentration factor (EC_e/EC_{iw})	EC_e								
			EC_{iw} = 3	3.5	4	4.5	5	5.5	6	6.5	7
5	105	3.2	9.6	11.2	12.8	14.4	16.0	17.6	19.2	20.8	22.4
10	111	2.1	6.3	7.4	8.4	9.5	10.5	11.6	12.6	13.7	14.7
15	118	1.6	4.8	5.6	6.4	7.2	8.0	8.8	9.6	10.4	11.2
20	125	1.3	3.9	4.6	5.2	5.9	6.5	7.2	7.8	8.5	9.1
25	133	1.2	3.6	4.2	4.8	5.4	6.0	6.6	7.2	7.8	8.4
30	143	1.0	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0

Tab. 7: Estimated long-term EC_e values depending on irrigation water salinity EC_{iw} and the leaching fraction LF (*FAO, 1985,* modified)

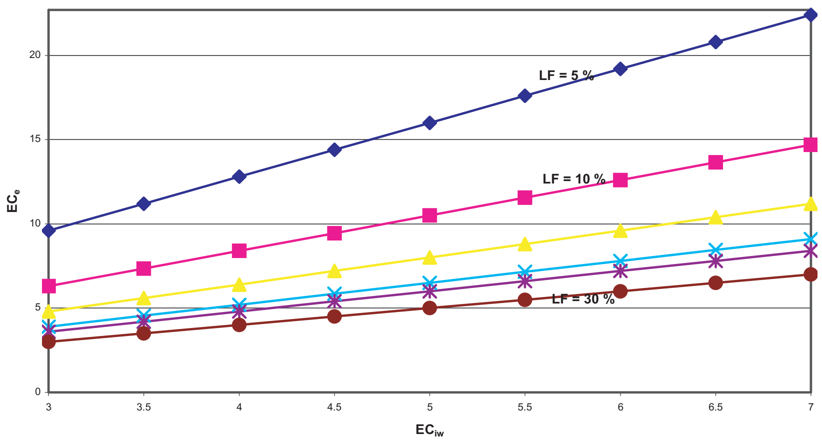


Fig. 18: Steady state soil salinity EC_e depending on irrigation water salinity EC_{iw} and leaching fraction LF

Within the farm monitoring program, irrigation water salinity as well as soil salinity were measured on selected plots of the monitored FUs. The observed relations between both parameters, EC_{iw} and EC_e, are displayed in Fig. 19. The FUs in cluster A are well in line with the steady state for 15 - 20 % LF described by $EC_e = 1.5\ EC_{iw}$ (see gray line in Fig. 19).

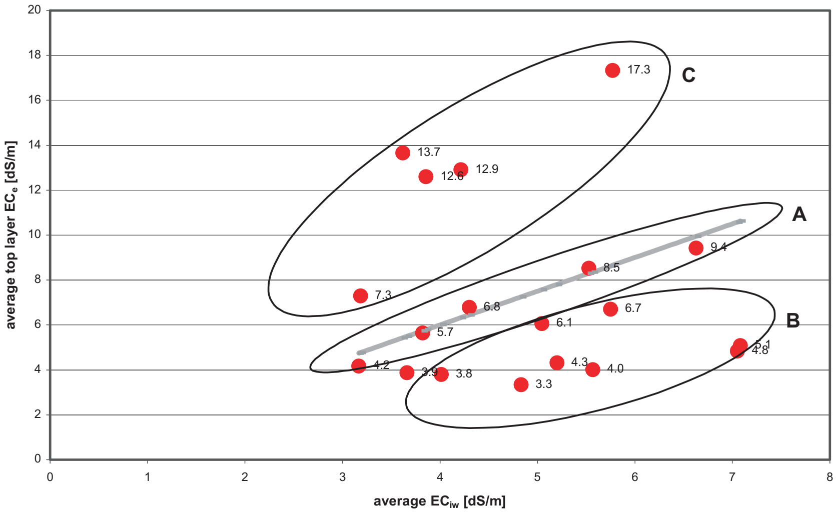


Fig. 19: Relation of EC_{iw} and EC_e on monitored FUs

Magnesium (Mg) content of most brackish water sources is high and can cause plant mutritional disorders

In clusters B and C the relation is different. The interesting observation is that, on the FUs in cluster B, furrow and basin irrigation are practiced, which usually tend to a certain over-irrigation. On the other hand, the FUs in cluster C are located in the southern Jordan Valley area which is hotter and where capillary rise can cause particular accumulation of salts in the top soil layer (20 cm), resulting in relatively high EC_e values. On most of the FUs of cluster C, water is scarcer than on FUs in the middle Jordan Valley, which makes over-irrigation and leaching less probable.

The three clusters in Fig. 19 imply that the empirical relation between EC_{iw} and EC_e for the Jordan Valley is dependent on local climatic conditions and different irrigation practices. The observations suggest that for the prevailing irrigation management on BW using farms in the Jordan Valley, the following approximate relations apply:

middle Jordan Valley:

$EC_e = 1.5\ EC_{iw}$	**drip irrigation (cluster A)**
$EC_e = 1.0\ EC_{iw}$	**furrow and basin irrigation (cluster B)**

southern Jordan Valley:

$EC_e = 3\ EC_{iw}$	**drip irrigation (cluster C).**

Summarizing the above observations based on the available data leads to the conclusion that the risk of over-salinization of the soils in the Jordan Valley due to brackish irrigation water is relatively low. This is especially valid in the middle Jordan Valley because of appropriate irrigation practices. In the southern Jordan Valley a salinity hazard is more likely due to the arid conditions, the existing water scarcity and as a result of the usually lower LF applied by the farmers.

Leaching Requirement

WHEN IRRIGATING with brackish water, the focal question is how to get the salts contained in the irrigation water out of the root zone. This is normally achieved by leaching the salt into deeper soil layers. The amount of irrigation water that has to pass effectively through the root-zone to leach the salts beyond it, thus preventing salinity build-up, is the leaching requirement (LR) usually given in the form of irrigation depth [mm].

Often that part of the irrigation water which leaches the salts beyond the root zone is expressed as a fraction of the total irrigation water applied, thus defining the leaching fraction (LF); e.g. a LF = 0.2 means that 20 % of the total water applied is the part passing beyond the root-zone. The efficiency of the leaching process depends on physical soil properties like texture and structure, and can range from 100 % for sandy soils to 30 % - 60 % for clay soils. The leaching efficiency for problematic soils should be measured or estimated in order to consider it accordingly when determining the leaching requirement (*FAO, 1992*).

Pre-irrigating fields before sowing or trans-planting with about 100 mm is a recommendable practice for furrow and basin irrigation to create favorable growing conditions. For drip irrigation one or two pre-irrigations will move salts out of the root zone

Fig. 20: Pre-irrigation of basins

One approach is to practice leaching by pre-irrigation before planting. At the beginning of the winter season, from September onward, the root zone might contain high salt contents left from the previous season and from the capillary rise during the summer fallow. When furrow or basin irrigation is applied, one to three pre-irrigations of the field with a total depth of about 100 mm will provide a seedbed low in salinity and therefore give the seedlings good starting conditions in the sensitive initial development stage. If the crop is planted or sown shortly before the beginning of the rainy season, a pre-irrigation fills the surface soil layer with moisture and helps to increase the infiltration rate. This will also increase the leaching effect of the following rainfalls.

In the case of drip irrigation, one or two initial pre-irrigation applications are recommended to create a salt-free root zone around the emitters.

The leaching requirement depends on two factors: the sensitivity of the crop (i.e. what level of soil water salinity the crop tolerates) and on the salinity of the applied irrigation water. An approximate assessment is possible using the values of Tab. 7 and Fig. 18. For more precise calculations, the equations below (*FAO, 1992 after Rhoades, 1974, Rhoades and Meryll, 1976 in FAO 1985, Keller and Bliesner, 2000*), which are based on empirical research, can be applied:

$$\mathbf{LF} = \frac{\mathbf{EC_{iw}}}{\mathbf{5\ (EC_e) - EC_{iw}}} \quad \textbf{for furrow and basin irrigation.}$$

It should be noted that this formula is restricted to positive denominators. For high envisaged yields of sensitive crops irrigated with relatively saline water, the denominator can become negative. These cases have to be excluded when applying the above formula.

For drip irrigation, which provides the possibility to continuously (daily or frequently) flush salts accumulating below the emitters down, the following formula applies:

$$\mathbf{LF} = \frac{\mathbf{EC_{iw}}}{\mathbf{2\ (maxEC_e)}} \quad \textbf{for drip irrigation.}$$

EC_e in both equations is the average soil salinity of the soil extract tolerated by the crop. The values refer to *FAO (1985)* and other internationally available tables with regard to the achievable yield percentage. According to *FAO (1985),* in gypsiferous soils plants tolerate about 2 dS/m higher soil salinity. Accordingly it is recommended for the Jordan Valley to add 2 dS/m to the EC_e of the average soil salinity in both formulas, because the majority of the soils have relatively high gypsum contents (3 - 5 %). The term *2(max* EC_e*)* is empirical and refers to high frequency (daily or alternate-day) drip irrigation where the EC of the leached drainage water can equal twice the maximum tolerable EC_e *(Keller and Bliesner, 2000)*, which is the salinity at which the yield would be theoretically 0 (see Tab. 8). The second formula provides generally lower values for the LF than the first formula for furrow and basin irrigation. Its applicability for the Jordan Valley has to be verified under field conditions, with the precondition of high irrigation application frequencies.

As an <u>example</u> for <u>basin irrigation,</u> durum wheat irrigated with Jordan River water (EC_{iw} = 5.4 dS/m) between the middle of January and the end of May is taken. According to FAO (1985) the EC_e for 100 % yield for durum wheat is 5.7 dS/m. Adding 2 dS/m for gypsiferous soils results in 7.7 dS/m as threshold. Therefore

$$\mathbf{LF} = \frac{\mathbf{5.4}}{\mathbf{5\ (7.7) - 5.4}} = \mathbf{0.16.}$$

This means that 16 % of the total water applied is needed for leaching. With a crop water requirement of about 290 mm for wheat in the middle Jordan Valley, the field water requirement (FWR) including the leaching requirement for 100 % yield is

$$\mathbf{FWR} = \frac{\mathbf{ET_c}}{\mathbf{1 - LF}} = \frac{\mathbf{290}}{\mathbf{1 - 0.16}} = \mathbf{345\ \ mm.}$$

Thus the leaching requirement is 55 mm (345 - 290 = 55 mm).

On the other hand, it has to be considered that the irrigation efficiency of furrow and basin irrigation for this example is about 60 % *(Euroconsult, 1989)*. In order to compensate for the application losses, an additional 193 mm have to be irrigated beyond the crop water requirement of 290 mm, leading to a total irrigation water application of 483 mm (290/0.6 = 483 mm, 483 - 290 = 193 mm). This supplement of 193 is higher than the LR of 55 mm. The supplement will - except on very heavy soils - percolate below the root zone and can therefore be considered as the leaching requirement *(FAO, 1985)*. In reality, effective rainfall (about 80 % of the actual rainfall) has to be deducted.

As an <u>example</u> for <u>drip irrigation</u> eggplant irrigated with well water (ECiw = 6 dS/m) is taken. According to *FAO (1985)* the EC_e for 0 % yield is 15.6 dS/m. Adding 2 dS/m for gypsiferous soils results in 17.6 dS/m as threshold. Therefore

$$\mathbf{LF} = \frac{\mathbf{6}}{\mathbf{2\ (17.6)}} = \mathbf{0.17.}$$

The crop water requirement for eggplant in the southern Jordan Valley is about 526 mm (see chapter 'Crop Water Requirement'). The field water requirement (FWR) is

$$FWR = \frac{ET_c}{(1 - LF) \times E_{is}} = \frac{526}{(1 - 0.17) \times 0.8} = 792 \text{ mm.}$$

Since drip irrigation systems on the FUs of the southern Jordan Valley are supposed to have an efficiency of about 80 %, a supplement for application losses has to be added. Accordingly a total supplement of 266 mm should be applied (792 - 526 = 266 mm) because of leaching on the one hand and reduced efficiency of the irrigation system on the other hand. In the case of drip irrigation, it is assumed that losses occur between the farm turn-out assembly and the dripper, as well as due to low distribution uniformity of the emitters. Thus - different from the above example with basin irrigation - the irrigation system losses cannot be balanced with the leaching requirement, and both fractions should be added.

The main difference between the two formulas for leaching requirement is that the one for drip irrigation assumes the worst case (0 % yield), whereas the formula for furrow and basin irrigation differentiates for different yield levels. For a given water quality this results in a constant value of the LF for drip irrigation. For furrow and basin irrigation the LF decreases along with decreasing yield levels.

Common Name	Botanical Name	100 % yield	90 % yield	75 % yield	50 % yield	0 % yield
Vegetable Crops						
Squash, zucchini	*Cucurbita pepo melopepo*	4.7	5.8	7.4	10	15
Squash, scallop	*C. pepo melopepo*	3.2	3.8	4.8	6.3	6.4
Tomato	*Lycopersicon esculentum*	2.5	3.5	5.0	7.6	13
Spinach	*Spinacia oleracea*	2.0	3.3	5.3	8.6	15
Potato	*Solanum tuberosum*	1.7	2.5	3.8	5.9	10
Corn, sweet	*Zea mays*	1.7	2.5	3.8	5.9	10
Onion	*Allium Cepa*	1.2	1.8	2.8	4.3	7.4
Eggplant[3]	*Solanum melongena*	1.1	2.5	4.7	8.3	15.6
Field Crops						
Barley	*Hordeum vulgare*	8.0	10	13	18	28
Wheat, Durum	*Triticum turgidum*	5.7	7.6	10	15	24
Forage Crops						
Alfalfa	*Medicago sativa*	2.0	3.4	5.4	8.8	16

Tab. 8: Soil salinity EC_e [dS/m] tolerated by crops at different yield potentials adapted from *Maas and Hoffman (1977), Maas (1984)* in: *FAO, 1985*.

[3] After *Heuer et al., 1986 in Tanji, 1996*

Field Measurement of Soil Salinity

THE INTERNATIONALLY accepted way to measure soil salinity is the preparation of a saturated soil paste and the measurement of the electrical conductivity of the water extracted from this paste (EC_e) as described in the chapter 'Soil Salinity and Leaching'. The advantage of this method is that the paste comes close to the natural soil conditions in the field. However, for farmers this method is laborious and time consuming because the samples have to be analyzed in laboratories.

An appropriate alternative is the preparation of a 1:1 extract of soil and distilled water directly in the field. For this purpose, e.g. 50 g of soil are mixed with 50 ml of distilled water, stirred well and the $EC_{1:1}$ of the soil-water solution is measured after 5 minutes. The values of EC_e and $EC_{1:1}$ are not identical because they depend on the moisture of the sample as well as on the texture of the soil. Accordingly certain conversion factors have to be used when assessing the EC_e based on measured $EC_{1:1}$ values.

Fig. 21: Measuring $EC_{1:1}$ extract in the field

Schleiff (*1986*) suggests conversion factors $f_{c1:1}$ based on literature and personal experiences as shown in Tab. 9.

Soil	moisture content of field sample	assumed water content at saturation [%]	conversion factor $f_{c1:1}$
Sand	dry	30	3.6
	fresh		4.1
	humid		4.6
	wet		5.0
Loam	dry	45	2.7
	fresh		3.1
	humid		3.3
	wet		3.6
Clay	dry	60	2.2
	fresh		2.5
	humid		2.7
	wet		3.1

Tab. 9: Conversion factors $f_{c1:1}$ depending on soil moisture and soil texture (after *Schleiff*, 1986, adopted)

In order to identify particular conversion factors for the Jordan Valley, about 110 soil samples have been taken for comparison on the monitored FUs. Their soil salinity was measured in the lab (EC_e) as well as in the field ($EC_{1:1}$). The soil moisture contents of the samples were normally dry to fresh since they were not directly taken after rains or high irrigation applications.

Based on the obtained EC_e and $EC_{1:1}$ values, it is possible to determine conversion factors for the particular soil texture classes in the Jordan Valley (see Fig. 22). These factors are compared with the conversion factors of *Schleiff (1986)* for dry and fresh moisture status (shaded cells in Tab. 9) and adopted values from the *Department of Agriculture - Western Australia* (without year).

The general trend of all three approaches (BWP, Schleiff, Australia) is similar: the conversion factor $f_{c1:1}$ is higher for lighter soils and decreases with increasing clay content because of the higher water content of clay under saturation conditions.

Under Jordan Valley conditions, the salinity of loamy soils (EC_e) can be easily assessed from field measurements ($EC_{1:1}$) applying a conversion factor of around 4.0

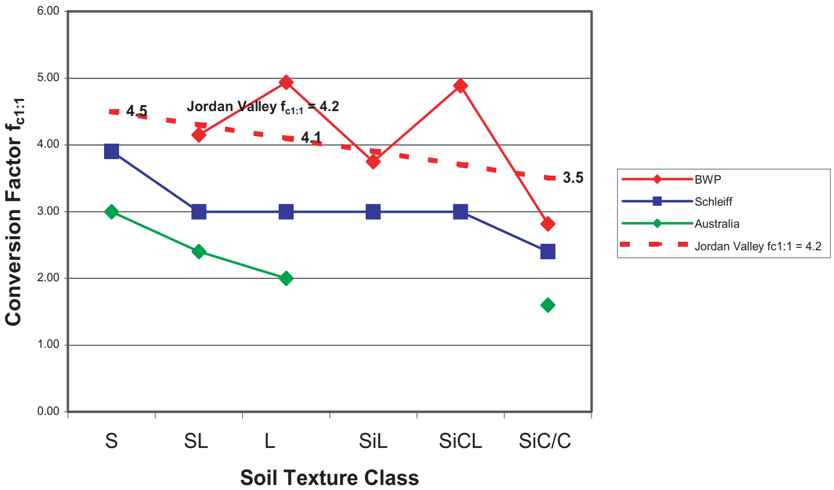


Fig. 22: Comparison of conversion factors $f_{c1:1}$ from different sources

As a conclusion from Fig. 22, an average conversion factor $f_{c1:1}$ of 4.0 is recommended when assessing the soil salinity EC_e of the predominantly loamy soils in the Jordan Valley based on the values $EC_{1:1}$ of the 1:1 extract. With regard to sandy and silty soils, the conversion factor can be assumed to be around 4.5 and 3.5 respectively.

The empirical conversion factor for the Jordan Valley appears relatively high when compared with the international values. The main reason could be the high gypsum (2 - 4 %) and $CaCO_3$ (30 - 50 %) content of the soils in the Jordan Valley.

Irrigation Management

THE IRRIGATION system of about 70 % of the farms in the Jordan Valley is drip irrigation. The remainder practice furrow, basin, and occasionally, flood irrigation. Sprinkler irrigation is exceptional, mainly for fodder crops like alfalfa.

Fig. 23: Drip irrigation and mulch

When irrigating with brackish water the utilization of drip irrigation equipment is highly appropriate due to the following advantages:

Drip irrigation equipment allows control of salinity through appropriate application of irrigation water quantities, appropriate timing and high application uniformity

- water is directly applied to the root-zone creating a wet zone which pushes the salts to the outer fringes/periphery; thus a wet and relatively salt free, bulb shaped sphere for the roots is created
- high application efficiency and saving of irrigation water
- high irrigation frequency with short intervals is possible
- minimization of deep percolation losses
- limited need for field leveling
- injection of nutrients/fertilizers into the irrigation water allows precise and efficient plant nutrition (fertigation)
- use of mulch is easy thus improving weed control and decreasing evaporation and salt accumulation at the soil surface.

Beside these positive impacts of drip irrigation, some unfavorable practices have been observed on several monitored FUs in the Jordan Valley that rule out the advantages of drip irrigation and contribute to adverse effects of brackish irrigation water:

- no water filters are used or filters are not regularly cleaned and maintained leading to clogging problems
- equipment is often used for longer than 3 - 4 years resulting in clogged emitters, low water and fertilizer application efficiency and low distribution uniformity
- emitters are perforated with nails in order to increase the discharge, which leads to low distribution uniformity and application efficiency.

In the literature, the application efficiency for drip irrigation is normally given as 100 % *(Euroconsult, 1989)*. If the complete drip irrigation system - from the farm turn-out assembly till the emitter - of a FU is considered, lower efficiencies are observed due to evaporation losses from the storage pools, leakages at pumps, main pipes and joints, as well as low distribution uniformities of the emitters. The on-farm <u>irrigation system efficiency</u> (E_{is}) ranges between 90 and 70 % with an average of 80 %. For sprinkler irrigation, it is estimated at about 70 % and for furrow, flood and basin irrigation at about 60 %.

<u>Furrow</u> and <u>flood irrigation</u> is mainly applied on FUs along the Jordan River, often for cereal cultivation. <u>Basin irrigation</u> is dominant for leaf crop cultivation around Karamah village. Both surface irrigation techniques require considerable effort for land leveling in order to ensure an equal distribution of water and to prevent accumulation of salts on exposed areas, particularly under the arid conditions of the Jordan Valley.

Fig. 24: Furrow irrigation

<u>Sprinkler irrigation</u> is used on few FUs for cultivation of fodder crops. Generally this technique might cause problems of leaf burn in case of high chloride content in the irrigation water (see also the chapter on 'Water Quality'). However, on the monitored FUs, leaf burn symptoms have not been observed.

Fig. 25: Sprinkler irrigation

One important irrigation parameter with regard to salinity is the irrigation frequency. Salts in the root-zone reduce the availability of water to crops because the plants need more energy to extract water from the soil solution when the salt concentration is high. The more water the crop takes up without replenishment by irrigation in the soil, the higher the salt concentration in the soil water becomes, and the more energy is needed for further water uptake. At the so-called permanent wilting point the water is retained by the soil with higher forces than the crop can mobilize for water extraction.

Directly after an irrigation application, the soil water content is at the maximum and the salt concentration at the minimum. When the duration between irrigation applications becomes too long, the salt concentration can reach stress level for the crop. Accordingly, maintaining the soil moisture on a favorable level by an appropriate irrigation frequency enables the crop to cope with high salt concentration in the soil solution, thus avoiding salinity stress.

As a rule of thumb, higher irrigation frequencies with lower application rates help to compensate for the adverse effects of brackish irrigation water. This is usually not easy to accomplish by the farmers in the Jordan Valley, because there is no on-demand irrigation water delivery to the farms. The common water provision schedule is twice per week for eight hours with a discharge of about 8 l/s. However, even this schedule can often not be followed due to water scarcity and low pressure in the supply system. Consequently, most farmers have constructed storage pools on their FUs. This way they are - to a certain degree - independent from the distribution schedule of the JVA, gaining flexibility to irrigate more often than water is delivered by JVA to the farm turn-out.

Fig. 26: Blending irrigation water in a storage pool

Fig. 27 shows that farmers have the tendency to slightly increase the irrigation frequencies during the course of the cultivation period.

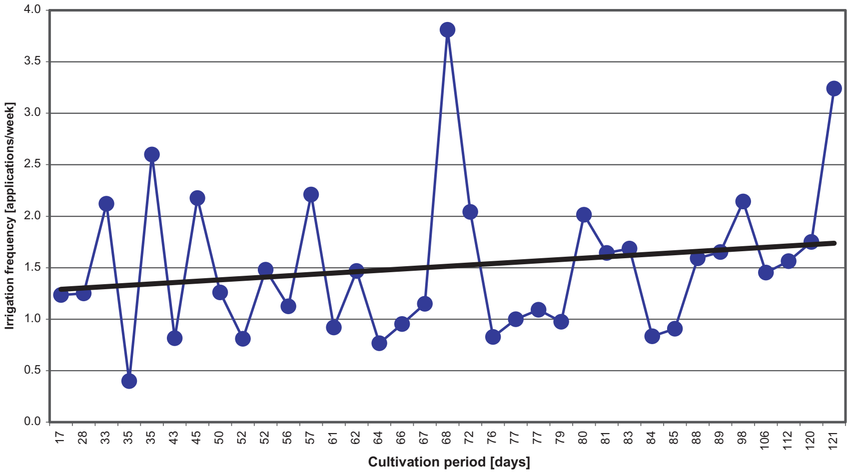


Fig. 27: Average weekly irrigation frequency over cultivation period

The average frequency is 1.5 applications per week. Fig. 28 shows that farmers irrigate more frequently in the south where temperatures are higher and soils are lighter with less water-holding capacity.

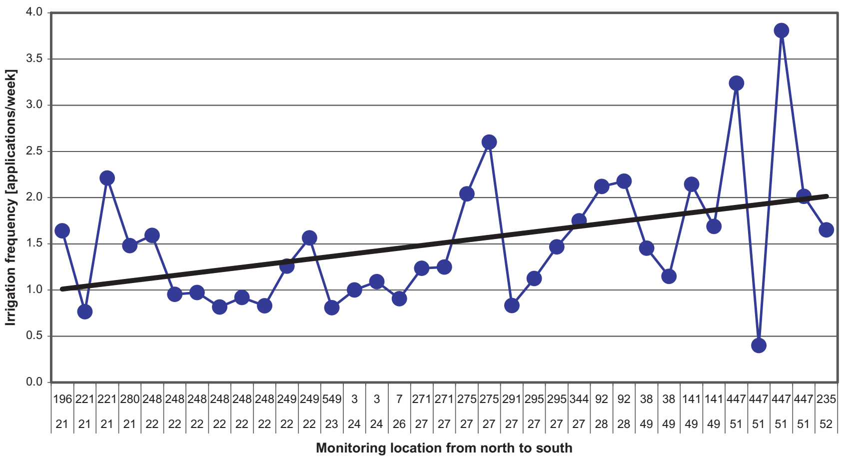


Fig. 28: Average weekly irrigation frequency from north to south

Although it is difficult to monitor the application frequencies due to spontaneous decisions of farmers and irregular rainfall patterns, the general impression is that the frequencies applied on most of the monitored FUs are appropriate because the yields achieved are generally satisfactory.

One additional important aspect of concern is the mode in which the brackish irrigation water is applied to the crop: either pure, or blended or alternating with freshwater. When only brackish water is available on a FU for irrigation, or when a farmer decides for economic reasons to use only brackish water, pure brackish water application must be practiced. On the monitored FUs, pure application is the 'standard mode' where KAC water is not available. This is the case on many farms in the 'Zor' close to the Jordan River and in the so-called 14.5 km-extension area in the south (DA 49 - 52). Also, one farmer near Karamah village uses only brackish water for his leaf crops. In general FUs irrigating with pure brackish water apply LFs high enough to prevent salt accumulation in the root-zone at a level that would result in low yields. This demonstrates that, even with pure brackish water irrigation, reasonable yields can be obtained provided salt tolerant crops, good irrigation management, and appropriate agricultural practices are applied.

Another 'application mode' is the blending of brackish and freshwater. Observations and measurements on several monitored FUs have shown that this practice is generally not recommendable because the amount of freshwater needed to dilute brackish water significantly is high. If, e.g. a farmer of the Karamah well association wants to blend the well water with an EC_{iw} = 7 dS/m with KAC water of EC_{iw} = 2 dS/m in order to achieve an EC_{iw} = 3 dS/m in his pool, he has to use about 80 % of KAC water and 20 % well water (7 dS/m x 0.2) + (2 dS/m x 0.8) = 3 dS/m). This blending ratio is unrealistic because of limited KAC water availability. A more realistic 50:50 blend would result in a salinity of about 4.5 dS/m.

Blending of fresh and brackish water is usually not economic. Alternate irrigation with freshwater and brackish water respectively during sensitive and then tolerant crop growth stages is generally more recommendable

From an economic point of view, this is a waste of fresh water and it is definitely better to save the fresh water for sensitive crops or for sensitive growth stages. Blending of fresh water and brackish water is therefore only recommendable if the conductivities (EC_{iw}) of the water sources available are relatively close together or if freshwater is available in abundance.

The alternate irrigation mode applies fresh water during sensitive crop growth stages like germination and emergence in order to provide good starting conditions for the plant. In later stages, when the crop is more tolerant, the irrigation is changed to brackish water. A good example of this practice is the farmers' association around Karamah village, where during the sensitive germination and emergence stage the leaf crops are usually irrigated with freshwater from KAC. Later, brackish water from the well with EC_{iw} = 7 dS/m is applied for irrigation. This has proven to be an appropriate method and is recommended particularly for low and medium tolerant crops.

Fertilization

WITH REGARD to salinity, the salt index of fertilizers indicates their contribution to the salinity of the soil solution. The salt index of sodium nitrate ($NaNO_3$) is normally taken as a standard and set to 100. The higher the index, the higher the contribution to soil salinity. Salt indices for common fertilizers in the Jordan Valley range from 105 for ammonium nitrate (NH_4NO_3) to 8 for super phosphate, $Ca(H_2PO_4)_2$ with the latter being more favorable under saline conditions. For more details see Annex 3.

The salt index of fertilizers provides an orientation of their contribution to soil salinity. Fertilizers with low salinity indices, i.e. ammonium sulfate are preferable

Fig. 29: Basic fertigation system in the Jordan Valley

Farmers in the Jordan Valley prefer acid fertilizers because they help to minimize chemical precipitation and keep the drippers unclogged. Ammonium sulfate, $(NH_4)_2SO_4$, with a salt index of 69 is the most popular fertilizer because of its acidifying property and low price.

Since the majority of the farmers in the Jordan Valley use drip irrigation equipment, fertigation (i.e. the injection of soluble fertilizers into the irrigation water) is the dominant fertilization practice.

The set-up of the fertigation system on most farms is very basic (see Fig. 29): the fertilizer is mixed in a barrel with water, from where it is injected into the drip irrigation system. There are many possibilities to improve the fertigation practices: e.g. better injection equipment and better dissolution practices in order to apply the nutrients more efficiently and with fewer losses.

So far, many farmers stick to simple technical solutions and thereby probably waste resources. However, on the monitored FUs there is no indication that the current fertigation practices contribute to an increase of soil salinity. Nevertheless other studies warn of too high fertilizer application rates contributing to soil salinity (*GTZ, 2001*).

Recommendations for fertilizer application rates require particular information on the plant density, intended yields, fertility level of the soil, climate, and other factors. For orientation, typical uptake values of N for important crops cultivated under brackish water irrigation in the Jordan Valley are provided in Tab. 10. The table is limited to nitrogen because P and K are normally not deficient in the soils of the Jordan Valley. Generally it is highly recommended to have soil samples analyzed in a laboratory at least once per year in order to have reliable information with regard to macro nutrient status and soil fertility.

Crop	Source	Part	Yield [kg/du]	N-removal [kg/du]
Barley	*Heyland, 1961*	grain	480	7.2
Sweet corn	*Fow, 1973 and others*	cobs fresh weight	2,000	20.8
Eggplant	*Pasterson, 1989*	fruit	4,000	7.5
Potato	*Smith, 1990*	tubers	3,600	15.3
Spinach	various	leaves	2,100	13.1
Cucumber (for squash)	various	fruits	2,000	3.9
Tomato	various	fruits	2,400	17.7
Wheat	*Aigner et al., 1988*	grain	450	10

Tab. 10: Seasonal uptake of N for selected crops *(IFA, 1992)*

As it is mentioned in the chapter 'Water Quality', the nitrate-nitrogen content of irrigation water from KAC-south and of some other water sources varies from 5 - 40 ppm. Farmers using such water benefit from the nutrient content. Assuming an average content of 20 ppm and an application of about 1,000 mm per year (2 seasons), this results in about 20 kg/du/year of NO_3-N. Farmers should consider the nutrient content of the irrigation water in order not to over-fertilize their FUs and to save money. Over-fertilization with nitrogen can result in adverse effects on crop health, e.g. lodging of cereals, and in the accumulation of nitrogen in the ground water.

Application of manure in the range of 1,000 - 3,000 kg/du when irrigating with brackish water helps to maintain soil fertility and create good leaching conditions

One very important aspect of fertilization and soil fertility is the content of organic matter and the application of manure. Organic matter content in the soils of the Jordan Valley is relatively low, around 1 % and less. A general recommendation of *GTZ (2001)* is to increase the organic matter content to 2 - 2.5 %, although it is difficult to achieve under the prevailing climatic conditions of the Jordan Valley. Organic matter content on this level will stabilize the soil structure and pore volume; increase biological activities, clay-humus complex, and cation exchange capacity (CEC); and contribute to improved water holding capacity and aeration of the soil. Particularly, the positive impacts with regard to physical soil properties and nutrient availability will help to decrease adverse effects of brackish irrigation water.

Farmers in the Jordan Valley apply generally 1,000 - 2,000, sometimes up to 3,000 kg/du of chicken manure, which is a highly recommendable practice. However, it is also a widespread habit to leave the manure for many days, sometimes weeks, on the field before it is finally incorporated into the soil. This leads to volatilization and loss of the nitrogen and also to decomposition of the organic matter, thus eliminating the benefits and favorable impacts of manure on soil fertility and soil salinity control. Therefore manure should not be stored - unless for composting or fermenting - or exposed to the sun for a long period but be incorporated into the soil as soon as possible.

Crops

General Remarks

THE APPROACH of the monitoring program of the BWP is to 'capture' the reality on farms where brackish water is applied for irrigation. The selection of the farms, which are located in various parts of the middle and southern Jordan Valley, is based on an assessment of the duration and relevance of experience of the particular farmers. The analysis of the data focuses on single factors of the crop production process under brackish water irrigation. The influences of the single factors, mainly on the yield, are evaluated; obvious trends are described, compared and discussed and conclusions are drawn. These conclusions form the backbone of the guidelines.

In total, 8 Crop Guidelines covering 9 important crops that are irrigated with brackish water in the Jordan Valley are elaborated in detail. This does not imply that irrigation with brackish water is limited to these crops, but the selected crops have been chosen because of their present importance as well as with regard to their future potential for farms using brackish water.

Because agriculture is a complex system, the guidelines go beyond provision of simple recipes. Reading, understanding, and applying the guidelines in practical agriculture require some agricultural background of the reader. However, as an overview Fig. 30 and Tab. 11 provide condensed and highly generalized information of the Guidelines and allow a first orientation regarding irrigation with brackish water in the Jordan Valley.

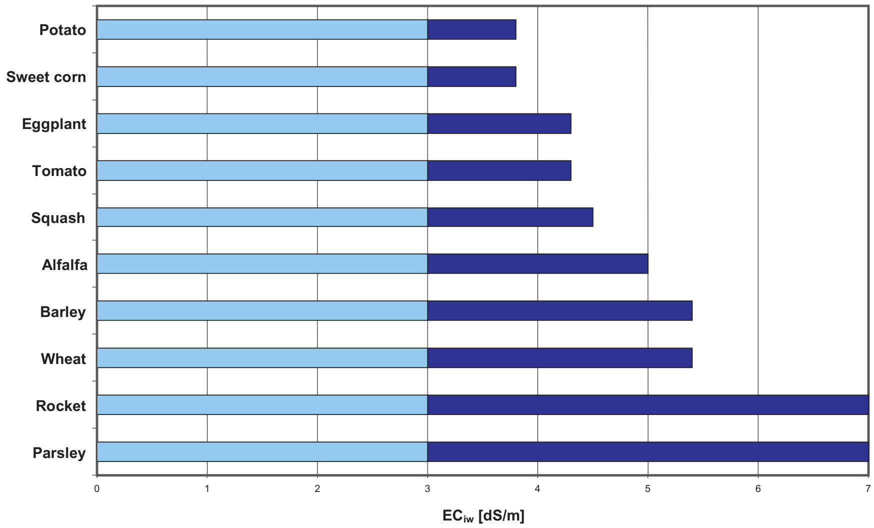


Fig. 30: Recommended threshold values of irrigation water salinity for cultivation of crops in the Jordan Valley

Crop	EC_{iw} threshold JV [dS/m]	Avg. yield [kg/du]	Varieties	Soil Texture Classes				pre-irrigation	seasonal FWR range [mm]	LF (furrow, basin)	LF (drip)	Cultivation period												Planting density [cm] or seed rate [kg/du]	N [kg/du]	Fermented manure
				SiCL	SiL	L	SL					A	S	O	N	D	J	F	M	A	M	J	J			
Potato	3.8	1,600	Alaska, Mondial					recomm.	230 - 400	0.26	0.16													125 x 40 cm	11 - 24	recomm.
Sweet corn	3.8	720	Merit, NK 1999						210 - 430	0.26	0.16													150 - 180 x 25 - 30 cm	> 10	recomm.
Eggplant	4.3	5,900	Ajami, Classic					recomm.	500 - 1010	0.38	0.12													150 - 170 x 40 cm	25 - 35	recomm.
Tomato	4.3	5,900	Farida, Wafa					recomm.	480 - 720	0.24	0.14													160 - 200 x 40 cm	up to 26	recomm.
Squash	4.5	1,200	Anita, Cedar						125 - 330	0.16	0.13													150 x 40 cm	6	recomm.
Alfalfa	5.0	2,300 (9 cuts/year)	Hijazi						1,270	0.33														6 kg/du	Legume	
Wheat	5.4	270	Mexican						340 - 690	0.16	0.10													12 - 16 kg/du	7	
Barley	5.4	160	Local						340 - 690	0.12														7 - 15 kg/du	7	
Parsley	7.0	4,400	Cham						620 - 780	0.54	0.21													6 - 10 kg/du	14 - 17	recomm.
Rocket	7.0	2,600	Local						210 - 470	0.54	0.21													3 -10 kg/du	8 - 14	recomm.

Tab. 11: Selected observations and recommendations for crops irrigated with brackish water

Squash

Summer Squash, Field Pumpkin, (*Cucurbita pepo* L. subsp. *melo pepo*)

SQUASH IS one of the oldest cultivated crops originating in America. It has been recorded from many archeological sites, the oldest being from Mexico dated 7,000 - 5,500 B C (*Purseglove*, *1979*).

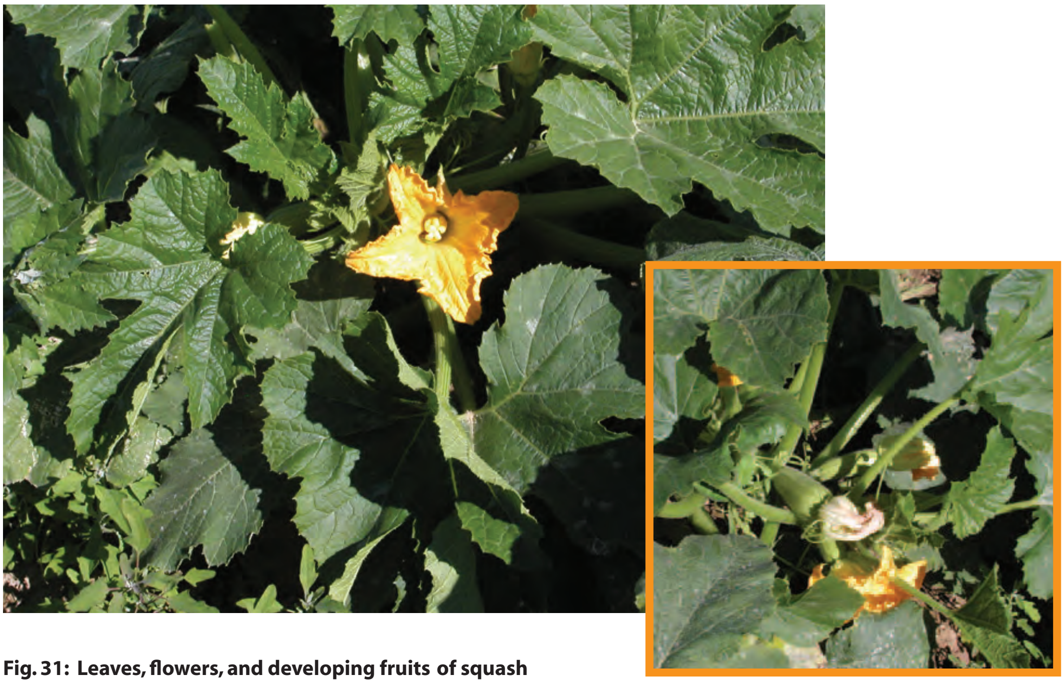


Fig. 31: Leaves, flowers, and developing fruits of squash

The modern varieties are adapted to wide ranges of ecological conditions. They are insensitive to day length and can be grown on most soil types, preferably well-drained and with good fertility. Squash is an important crop in the Jordan Valley because of its short growing season, relatively easy cultivation and popularity with consumers. It can also be cultivated in hot summer temperatures due to the fact that it prefers warm temperatures for germination and the initial growth stage.

Yields

Yields on the monitored FUs vary between 254 - 3,300 kg/du. It should be mentioned that not all reported yields represent the maximum possible values because farmers often stop harvesting when market prices decline.

Fig. 32 presents the yields obtained on the monitored FUs during the years 2000 - 2003 and their average as well as the averages of *Soer (1998)* and *Mahadin (1999)* for the entire Jordan Valley.

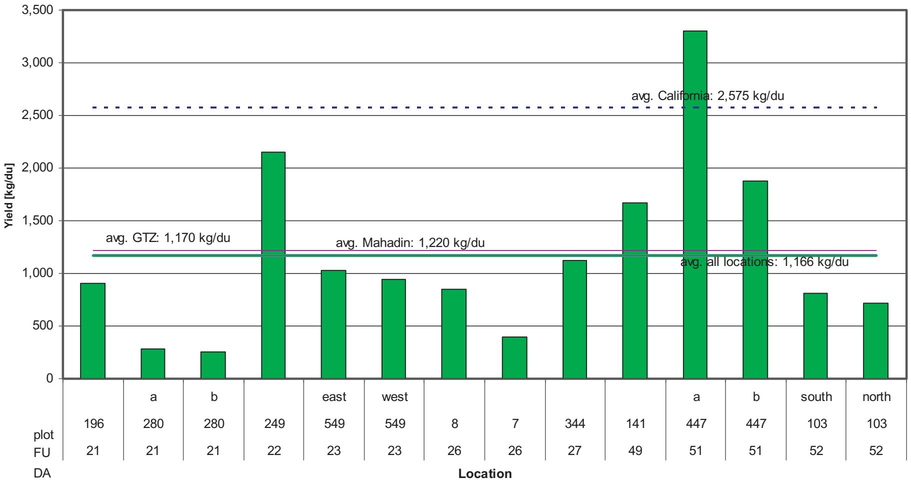


Fig. 32: Squash yields

Well-managed and irrigated squash under brackish water conditions can at least achieve the same yields that are obtained under freshwater irrigation in the Jordan Valley

On the monitored plots, an average of 1,166 kg/du was achieved, which is about equivalent to averages for mainly freshwater irrigation reported by *GTZ (1998)* with 1,170 kg/du, and *Mahadin (1999)* with 1,220 kg/du. Taking into consideration that the monitored farmers used brackish water for irrigation, the comparison suggests that the cultivation of squash under irrigation with brackish water is appropriate and feasible.

As the comparison in Fig. 32 also depicts, the average yield in California between 1994 - 1996 was about 2,575 kg/du *(Annual California Agricultural Commissioners' Report, in Molinar et al.* without year*)*. However a direct comparison with the yields achieved in the Jordan Valley is difficult because of the lack of information about the particular irrigation water and soil salinity conditions for the results from California. Furthermore - besides far higher production intensity - the main growing season for squash in California is summer whereas in the Jordan Valley it is autumn and winter.

Varieties

The dominating varieties grown on the monitored FUs are 'Amira', 'Anita', 'Cedar', and 'Luna'. According to the agricultural input suppliers in the Jordan Valley, salinity tolerance is not a criterion for the varieties offered to the farmers. The main features of the common varieties on the market are high yield and, sometimes, disease tolerances. For this reason the suitability of the main varieties used on the monitored FUs irrigating with brackish water is evaluated.

'Anita' is an appropriate squash variety under irrigation with brackish water

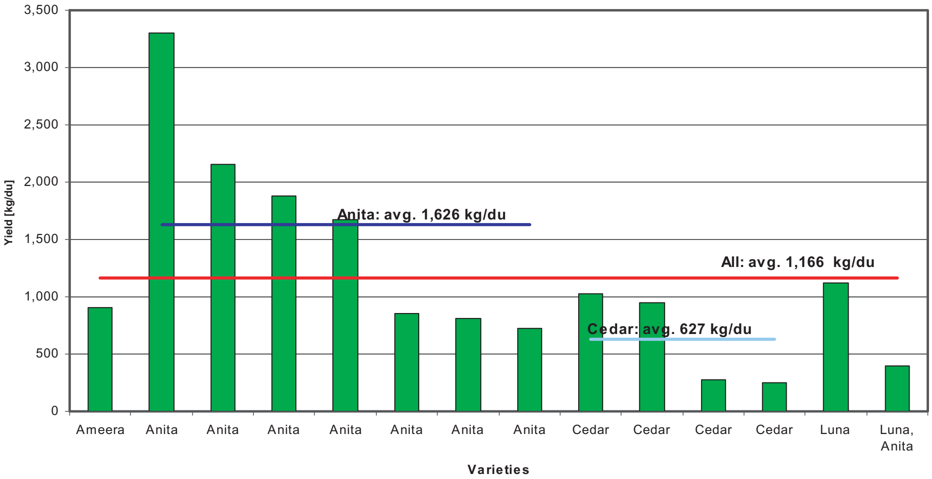


Fig. 33: Yields of squash varieties

The comparison between the varieties in Fig. 33 shows that the average yield of 'Anita' was 1,626 kg/du. This is about 40 % more than the average of all monitored plots and also significantly higher than values reported by *Soer (1998)* and *Mahadin (1999)* and more than double the yield of Cedar (627 kg/du). These figures do not reflect the absolute yield potentials of the varieties, but they allow the conclusion that especially the squash variety 'Anita' is recommendable for the cultivation under brackish water conditions in the Jordan Valley.

Irrigation Water Salinity

The main yield results and their related irrigation water salinities are shown in Fig. 34. The first cluster (A) comprises yields above the overall average (1,166 kg/du), which were obtained within the EC_{iw} range of about 3.8 - 4.5 dS/m.[4]

In the second cluster (B), the yields are fairly close to the average, with EC_{iw} ranges covering a wide spectrum, from around 2 up to 7 dS/m.

The third cluster (C) refers to the low yields and is related to the EC_{iw} range of 5 - 7 dS/m. Here the low yields are obviously determined by the high irrigation water salinity.

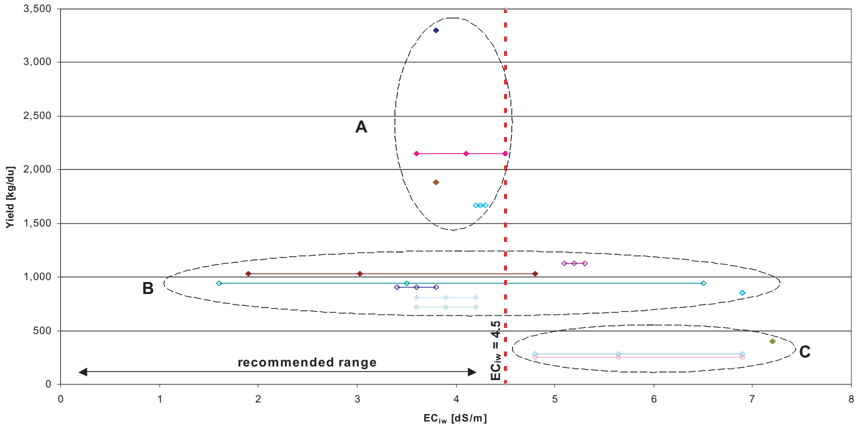


Fig. 34: Squash yields and irrigation water salinity

The cultivation of squash in the Jordan Valley is feasible up to an irrigation water salinity of EC_{iw} = 4.5 dS/m

According to international research compiled in *FAO (1985)*, the salinity threshold (100 % yield) for brackish irrigation water is 2.1 dS/m for the squash variety 'Scallop' and 3.1 dS/m for the variety 'Zucchini'. The corresponding slopes of yield decrease are 24.0 and 14.5 [%/(dS/m)].

Due to prevailing drip irrigation, gypsiferous and/or calcareous soils and predominant winter cultivation, these threshold values can be set higher in the Jordan Valley.

From the above observations, the general conclusion can be drawn that irrigation with water salinity up to EC_{iw} = 4.5 dS/m can achieve relatively high yields, even above 1,166 kg/du, when good agricultural practices are applied. With water salinity of EC_{iw} > 4.5 dS/m yields lower than 1,000 kg/du have to be expected.

Soil Texture

The texture classes of the monitored soil classes range from heavier soil classes, e.g. silty clay loam, on the left hand side to lighter soils, e.g. sandy loam, on the right hand side in Fig. 35. The general impression is that higher silt percentages have a positive influence on the yields. The shown trend line supports this hypothesis.

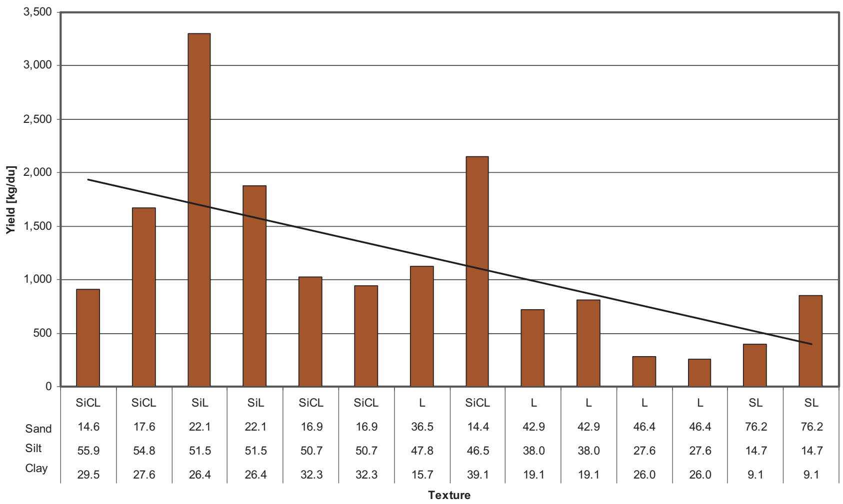


Fig. 35: Squash yields and texture

Medium textured soils with high silt content create favorable growing conditions for squash

[4] The ranges cover the spectrum of the lowest, average and highest applied irrigation salinity during the growing period.

An explanation for this relation is the fact that higher contents of silt result in higher water and nutrient holding capacities of the soil. This helps the plant to better cope with water stress and can compensate for periods of nutrient deficiency.

Irrigation Practices and Total Water Supply

Drip irrigation equipment and FWR between 125 to 330 mm per season help to compensate for adverse effects of brackish irrigation water

All monitored FUs applied drip irrigation and used black plastic mulch except the FU with the lowest yields. This suggests that drip irrigation in combination with black plastic mulch is the appropriate irrigation method for squash cultivation under brackish water conditions in the Jordan Valley.

Fig. 36 shows that the total water applied (TWA) [5] on the monitored FUs is in the range between 150 and more than 400 mm (the green dots).

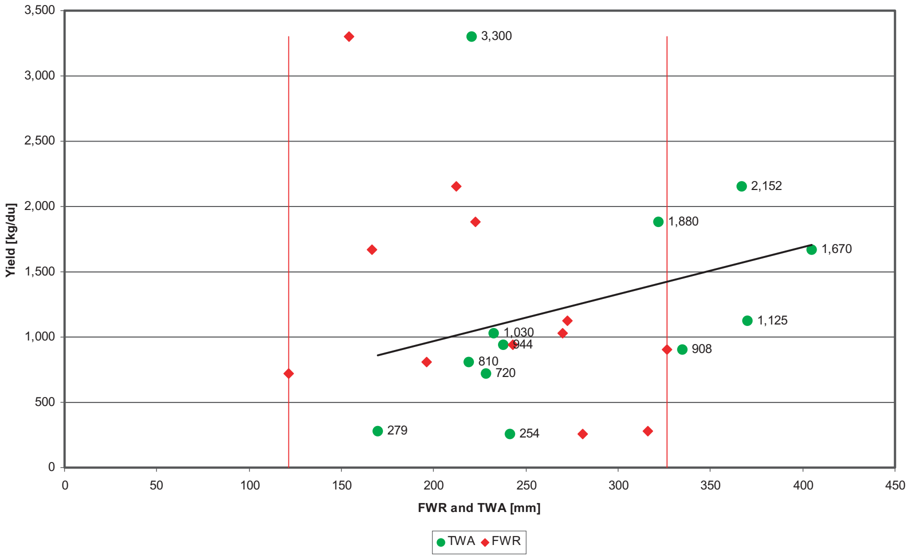


Fig. 36: Squash yields, FWR and TWA

The trend line reveals increasing yields with increasing total water supply. Nevertheless, the exceptionally high (3,300 kg/du) and low (279 respectively 254 kg/du) yields do not fit well into the series.

Looking closer at the two lowest yields, the following facts are relevant: The range of the irrigation water salinity was relatively high, between 5 - 7 dS/m. Furthermore, both yields were obtained on a FU with a soil of relatively high sand content, practicing furrow irrigation without mulch, thus causing low water-use efficiency. The yield of 3,300 kg/du was achieved with relatively low water salinity and drip irrigation on a soil relatively high in silt content, which is favorable for squash production because of its water and nutrient holding capacity, and with a preferable variety (Anita). The focal question for farmers is how much water to apply, particularly when irrigating with brackish water.

As a general orientation, Tab. 12 and Tab. 13 provide crop water requirement values [mm/week] as described in chapter 'Water Requirements' in the General Guidelines.

Middle Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (10 days)	k_{c2} (20 days)	k_{c3} (20 days)	k_{c4}
January	0.6	0.8	1	0.8
February	5.9	7.8	9.8	7.8
March	7.6	10.2	12.7	10.2
April	13.0	17.3	21.6	17.3
May	14.9	19.9	24.8	19.9
June	19.2	25.6	32.0	25.6
July	22.3	29.8	37.2	29.8
August	22.2	29.5	36.9	29.5
September	19.5	26.0	32.5	26.0
October	16.8	22.3	27.9	22.3
November	12.3	16.3	20.4	16.3
December	10.2	13.7	17.1	13.7

Tab. 12: Weekly crop water requirement ET_c for squash in the middle Jordan Valley (DA 21 - DA 26)

[5] Total irrigation water plus effective rainfall estimated as 80 % of total rainfall.

Southern Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (10 days)	k_{c2} (20 days)	k_{c3} (20 days)	k_{c4}
January	0.6	0.8	1	0.8
February	4.6	6.2	7.7	6.2
March	6.4	8.5	10.6	8.5
April	10.7	14.3	17.9	14.3
May	13.0	17.4	21.7	17.4
June	16.7	22.3	27.8	22.3
July	19.3	25.8	32.2	25.8
August	19.0	25.4	31.7	25.4
September	16.7	22.2	27.8	22.2
October	14.0	18.6	23.3	18.6
November	10.0	13.4	16.7	13.4
December	7.3	9.7	12.2	9.7

Tab. 13: Weekly crop water requirement ET_c for squash in the southern Jordan Valley (DA 27 - DA 52)

The weekly ET_c values can be used to calculate the field water requirement (FWR) as explained in the chapter 'Water Requirements'. The effective rainfall should be deducted - if relevant - and the leaching fraction and a supplement for the technical losses in the on-farm irrigation system should be added. The leaching fraction for squash on gypsiferous soils under drip irrigation is assessed as 0.13, for furrow irrigation as 0.16. The efficiency of most drip irrigation systems in the Jordan Valley is estimated to be 80 %.

The calculated field water requirements (FWR) are represented by the red series in Fig. 36 and suggest that, for squash under drip irrigation with brackish water in the middle and southern Jordan Valley, the FWR is between 125 and 330 mm per season.

If the discharge of the pump and the area irrigated are known, the calculated values for the FWR can be converted easily into hours of irrigation, which is the preferred 'irrigation unit' of the farmers in the Jordan Valley.

When comparing the depth of water applied and the calculated FWR values in Fig. 36, it is obvious that all FUs applied more water than needed. The main reason is probably that farmers tend to over-irrigate because they want to leach. However, there is potential to save water and nutrients by increasing the irrigation application efficiency. Fig. 36 also reveals that higher water application rates do not necessarily result in higher yields. The highest yield, e.g. , was obtained with much less water than the second highest yield. This indicates that on the latter FU the use of the irrigation water was not optimal.

Growing Season

The growing season, which is the time between sowing or planting and harvest[6], in relation to the different yields is displayed in Fig. 37. There is no clear evidence for a relationship between the length of the growing period and the corresponding yields.

[6] The left dot of the line graph marks the sowing start, the middle dot the beginning of the harvest and the right dot the end of the harvest.

The favorable growing season for squash in the Jordan Valley is from August to March

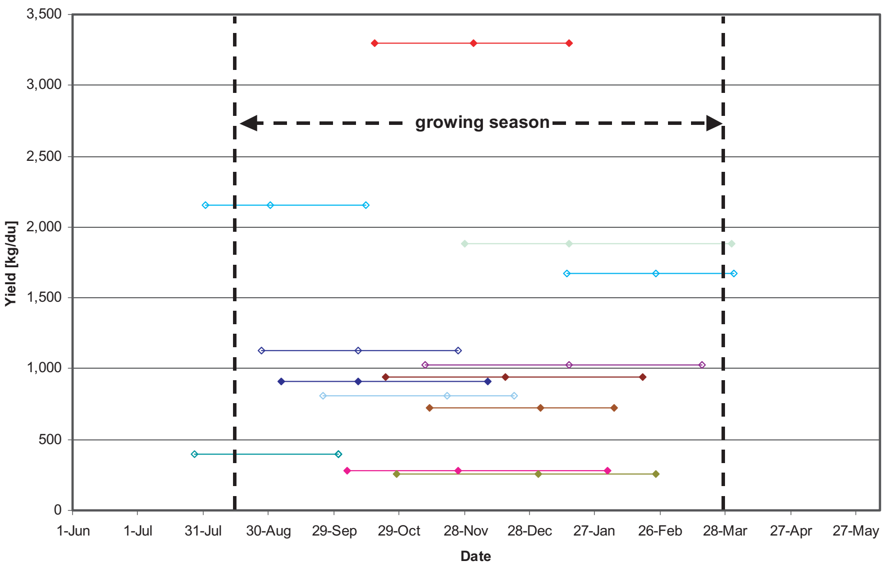


Fig. 37: Squash yields and growing season

The general conclusion is that the favorable growing season for squash in the Jordan Valley stretches from August to the end of March.

Planting Density and Spacing

With respect to planting density, the trend line in Fig. 38 based on the yield series shows slightly decreasing yields with increasing densities. This is contradictory to recommendations from California where the minimum recommended density is 2,200 plants/du *(Molinar et al.,* without year*)*. Taking into account the reliable water supply and high mechanization level in California, this is probably appropriate.

Squash should be planted in rows 150 cm apart and with a spacing of 40 cm or less within the rows

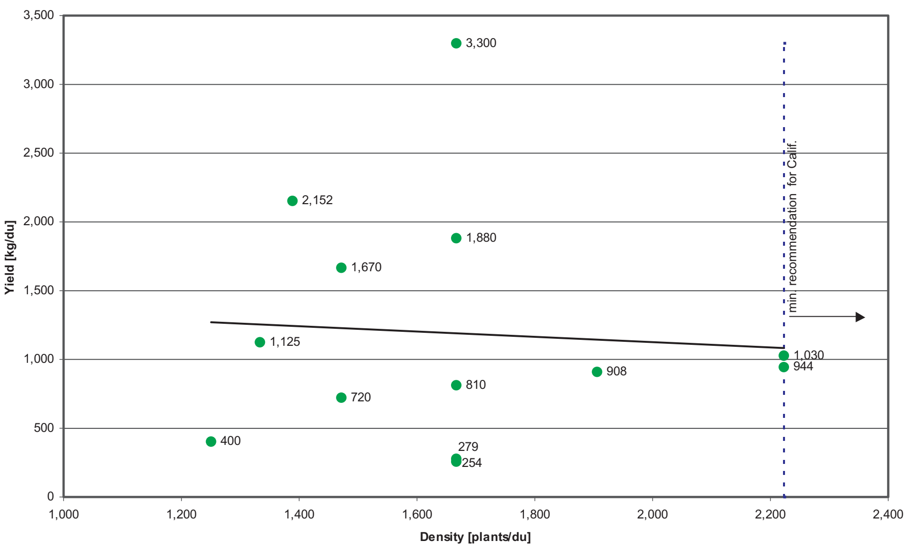


Fig. 38: Squash yields and planting density

Looking at the distances between the rows, the prevailing distance is 150 cm. Spacing of 150 x 40 cm shows the highest yields. This leads to the recommendation that farmers should plant rows 150 cm apart with spacing between the plants of 40 cm or less. In the case of increasing the planting density, a respectively higher irrigation water supply has to be applied.

When discussing this recommendation with farmers, they admit that e.g. two rows of squash planted with lower distances at the edges of each plastic mulch-line might result in higher yields. However, they argue for not doing so because the workers often have to walk between the rows when weeding or spraying and thus might destroy the sensitive creeping tendrils of the plants.

Fertilization

Fertilizer applications on the monitored FUs differ greatly and range from about 0.5 - 18 kg/du of total nitrogen (N). All FUs with drip irrigation practiced fertigation; only on one FU with furrow irrigation, the fertilizer is broadcast.

Farmers using brackish water for irrigation of squash should consider nitrogen (N) application rates of about 6 kg/du for average yields

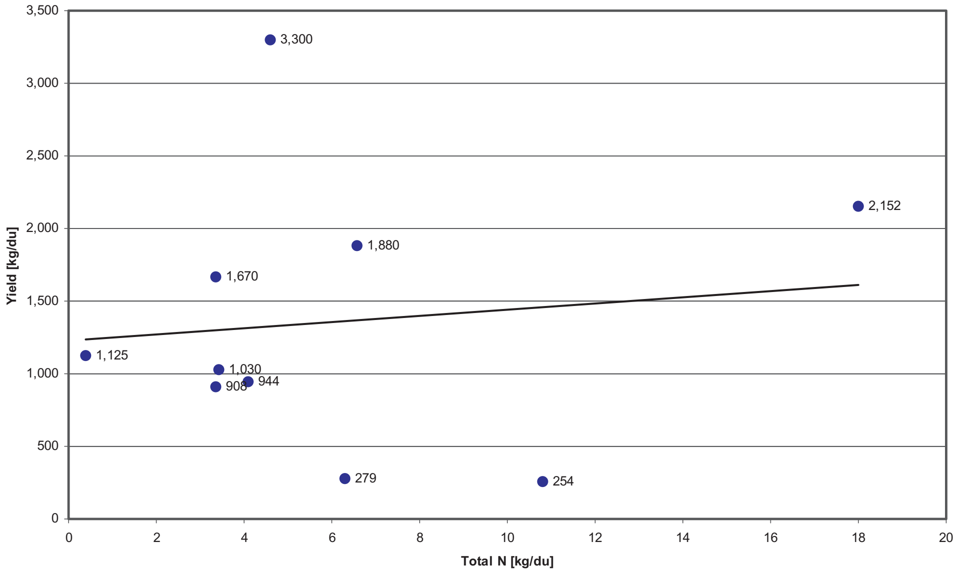


Fig. 39: Squash yields and N application

Focusing on nitrogen, it is found that the application of total N on the monitored FUs is relatively low - except one FU - as compared to the recommendation for California (*Molinar et al.*, without year), which is 9.0 - 16.8 kg/du (total P_2O_5: 6.7 - 13.4 kg/du, total K_2O: 0 - 16.8 kg/du). The recommendation of the 'Jordan Blending and Packing Fertilizer Company' is even higher and ranges between 36 - 46 kg/du for nitrogen.

The trend line in Fig. 39 indicates slightly increasing yields with increasing N application. However, when comparing the three highest yields, it is obvious that the application of 18 kg/du N is too high and a waste of nutrients. When assuming that in California the average yield of 2,575 kg/du was obtained with an average N application rate of 13 kg/du, the conclusion is that the average yield of all monitored FUs (1,166 kg/du) would need about 6 kg/du of N. This value, which is above the N uptake of 2,000 kg/du of cucumber (see chapter 'Fertilization' of the General Guidelines), is regarded as an appropriate N application rate.

General Agricultural Practices

The common **tillage** practice on the monitored FUs is two times disc plowing with a depth of about 20 - 30 cm and one harrow. There is no tillage when plastic mulch from the previous season is used.

Black plastic mulch is recommended when irrigating with brackish water

On all FUs where drip irrigation is used, black **plastic mulch** is also applied. This ensures a higher germination temperature in the soil and prevents germination of weeds. In two cases, the plastic mulch of previous seasons was used again. In general, black plastic mulch in combination with drip irrigation is recommended as a good practice for irrigation with brackish water.

Many farms apply **organic fertilizer** in the form of chicken manure before planting. Taking into account the generally low organic matter contents in the Jordan Valley of less than 2 % (*GTZ, 2000 and 2001 a*), and that squash responds well to humus (*Purseglove, 1979*), this is a recommendable practice. The 'Jordan Blending and Packing Fertilizer Company' recommends application of 750 – 1,000 kg/du manure before planting. Also *GTZ (2001 b)* recommends adding organic matter in order to amend growing conditions for crops and eventually buffer soil salinity. However it is often observed that the chicken manure remains for weeks on the fields before it is incorporated into the soil, minimizing the benefit of the manure considerably.

About 1,000 kg/du of manure should be applied and incorporated immediately before transplanting

In summary, the advice to brackish water farmers is to apply about 1, 000 kg/du of manure and incorporate it immediately into the soil.

Weeding is normally done manually, sometimes with horse drawn cultivators. No special effects of particular practices with regard to salinity were observed.

Pest management is heterogeneous. The general impression is that satisfactory know-how among farm managers is lacking and that pesticide application is high. No interactions between pesticide application and brackish water irrigation have been observed.

On three FUs, 'white mesh' was used for tunnels in order to protect the plants from insects.

Plots with low yields had major problems with **diseases**, mostly with mite, water melon virus 2 (WMV2), zucchini yellow mosaic virus (ZYMV) and fungi.

Another factor for yield reduction could be insufficient **pollination**. Squash is monoecious (female and male flowers on the same plant), and the ratio of female to male flowers is 3:1 or higher. The main pollinators are honeybees and one hive of bees should be available for every 2 - 4 du.

Eggplant

Aubergine (*Solanum melongena* L.)

EGGPLANT IS well adapted to warm and hot climates with relatively little temperature variation. Optimal temperatures are 26^0 C for days and 20^0 C for nights (*Aguiar et al.* without year).

The plant develops a strong taproot and responds positively to well–drained, medium textured soils with good aeration (*IFA, 1992*).

Fig. 40: Leaves, flowers, and fruits of eggplant

World production averages 1,400 kg/du; on experimental plots, yields of more than 9,000 kg/du have been achieved, and 3,000 kg/du should be considered an acceptable yield (*IFA, 1992*).

Yields

The yields of the monitored FUs during the years 2001 - 2003 cover a range between 2,000 - 8,220 kg/du as presented in Fig. 41.

On the monitored plots, an average of 5,897 kg/du was achieved. This is considerably higher than averages reported by *Soer (1998)* with 2,828 kg/du and *Mahadin (1999)* with 3,157 kg/du, which were mainly obtained under freshwater irrigation. Taking into consideration that the monitored farmers used brackish water for irrigation with EC_{iw} values in the range between 3 - 7 dS/m, the comparison between the monitored FUs and the total of the Jordan Valley farmers allows the conclusion that the cultivation of eggplant under irrigation with brackish water is very appropriate and feasible.

Under brackish water irrigation well-managed eggplant cultivation can achieve yields around 5,500 kg/du and more

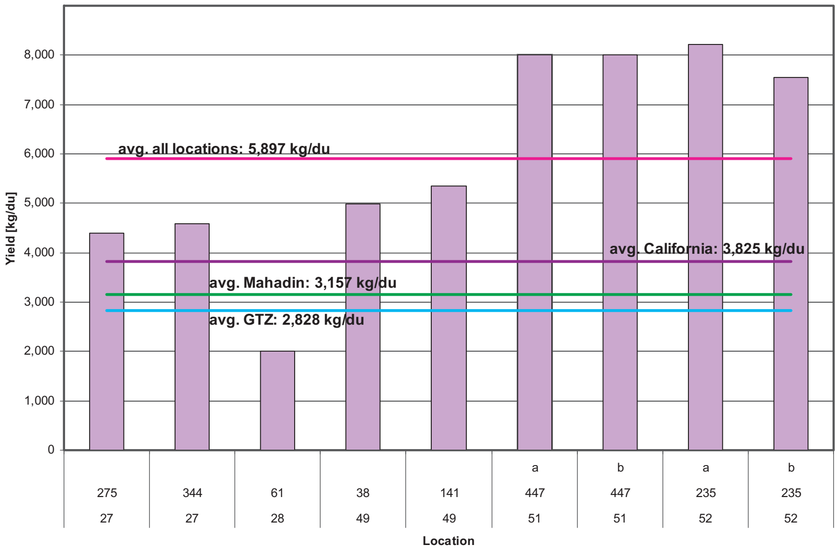


Fig. 41: Eggplant yields

Surprisingly, the average yield in California between 1993 - 1995 which was about 3,825 kg/du *(Annual California Agricultural Commissioners' Report, in Aguiar et al.* without year) is far lower than the observed average on the monitored FUs. The main reasons are probably the different varieties cultivated, harvesting periods of different durations, and consumer preferences.

The Jordanian consumers generally like larger fruits for the preparation of the popular purees served as 'mezzes', whereas in California smaller fruits (e.g. from Asian varieties) for frying and cooking are preferred.

Varieties

The dominating varieties grown on the monitored FUs are 'Ajami' and 'Classic'.

The comparison in Fig. 42 shows that the average yields are the same for both varieties (around 6,640 kg/du) and allow the conclusion that 'Ajami' as well as 'Classic' are similarly adopted for cultivation with brackish water.

The practice of cultivating two varieties on one plot resulted in two cases in lower yields as compared to cultivation of a single variety, and is therefore not recommended.

'Ajami' and 'Classic' are appropriate eggplant varieties for irrigation with brackish water

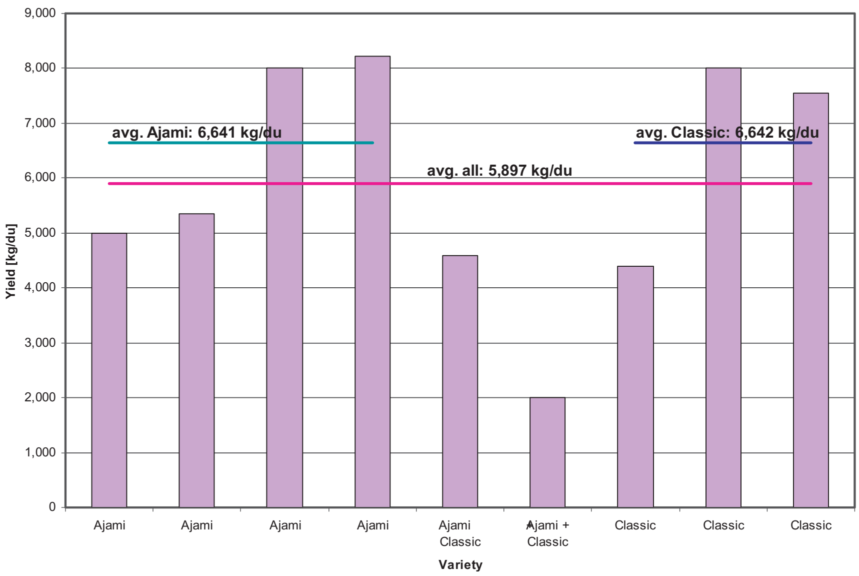


Fig. 42: Yields of eggplant varieties

Irrigation Water Salinity

The yield results and the corresponding ranges of the irrigation water salinities are displayed in Fig. 43.

Cluster A comprises the high yield segment above the overall average (5,897 kg/du) and was obtained within the EC_{iw} range between 3 - 4 dS/m.[7]

Cluster B shows the yields still fairly close to the average achieved within a wide EC_{iw} range from around 2 to 7.5 dS/m.

According to *Maas and Grattan (1999)*, the salinity threshold (100 % yield) for brackish irrigation water is 0.7 dS/m in California.

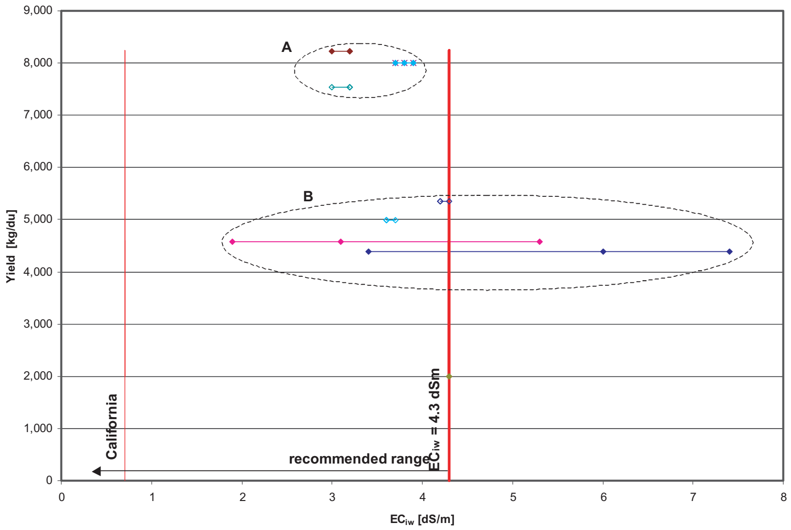


Fig. 43: Eggplant yields and irrigation water salinity

The cultivation of eggplant in the Jordan Valley is feasible up to an irrigation water salinity of EC_{iw} = 4.3 dS/m

Obviously this threshold value can be set much higher in the Jordan Valley, probably due to prevailing drip irrigation, gypsiferous and/or calcareous soils and predominant winter cultivation.

A closer look at the average EC_{iw} values in Fig. 44 reveals that, except for one value, they are in the range between EC_{iw} = 3.0 - 4.3 dS/m. An interesting case is the yield for EC_{iw} = 6.0 dS/m because the yield is higher than the Californian average although achieved with relatively high irrigation water salinity. Looking into the irrigation and farming practices of this FU, it is found that three pre-irrigations (total: 48 mm), high irrigation depths and also a high amount of nitrogen were applied. This supports the hypothesis that high input of water and fertilizer can compensate for adverse effects of brackish irrigation water.

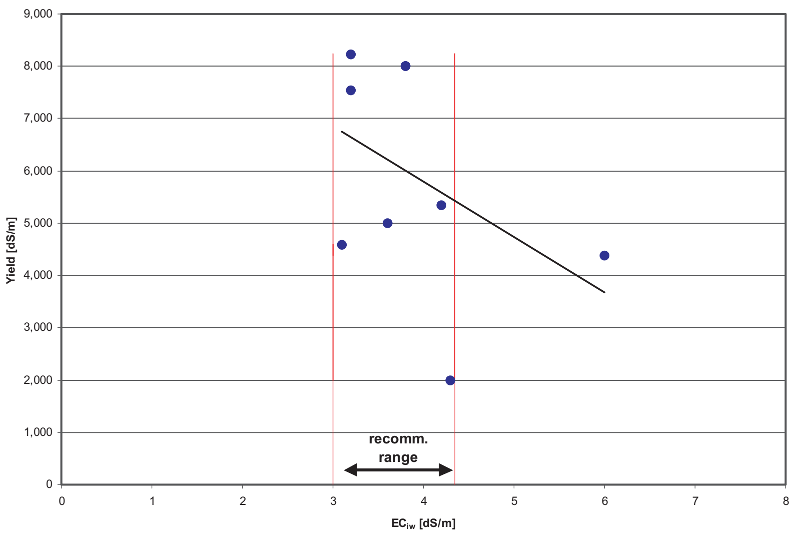


Fig. 44: Eggplant yields and average irrigation water salinity

Irrigation water salinity with EC_{iw} > 4.3 dS/m will decrease yield of eggplant

[7] The ranges cover the spectrum of the lowest, average and highest applied irrigation salinity during the growing period.

However, salinity imposes limitations on the cultivation of eggplant. The trend line in Fig. 44 shows clearly that increasing salinity causes decreasing yields. Farmers irrigating with water of $EC_{iw} >$ 4.3 dS/m should expect yields to drop below 5,000 kg/du even with high water and fertilizer input.

Soil Texture

The textural classes of the monitored farms do not differ much; they are in the heavy to medium heavy range. Considering the clay content does not show a clear trend, but with regard to silt content, it is obvious that the yields increase with lower silt contents.

Eggplant prefers medium textured and well- drained soils

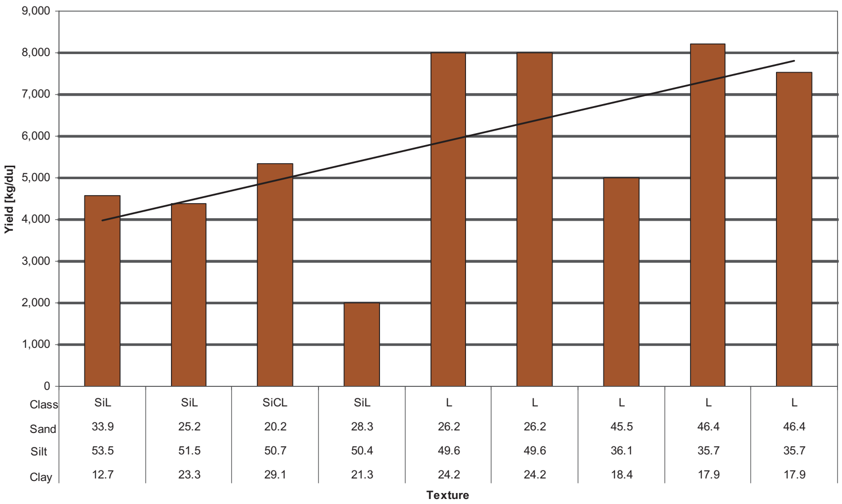


Fig. 45: Eggplant yields and texture

This is in line with international experiences that eggplant grows well in light or sandy well-drained soils with good aeration and a deep rooting zone (*Aguiar*, without year).

Irrigation Practices and Total Water Supply

All monitored FUs applied drip irrigation and used black plastic mulch. Because of the good results, drip irrigation in combination with black plastic mulch is considered the appropriate irrigation method for eggplant cultivation under brackish water conditions in the Jordan Valley.

When analyzing the total water applied (TWA)[8] on the monitored FUs, it is obvious that the amounts applied are very high.

In the southern Jordan Valley, FWR for eggplant ranges between 500 and 1010 mm when irrigating with brackish water. Drip irrigation equipment is recommended

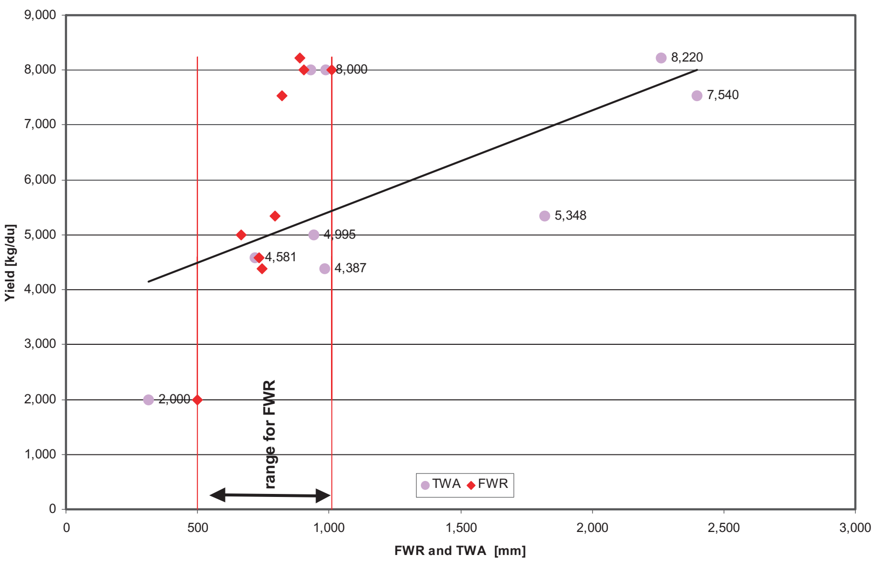


Fig. 46: Eggplant yields, FWR and TWA

[8] Total irrigation water plus effective rainfall estimated as 80 % of total rainfall.

The trend line in Fig. 46 reveals increasing yields with increasing total water supply; but if the amount of water applied and the yields obtained are compared, it is obvious that similar yields are possible with very different water quantities; e.g. the 8,220 kg/du were produced with about 150 % more water than the 8,000 kg/du. This leads to the conclusion that up to about 1,000 mm, a positive correlation between irrigation water input and yields can be expected, but higher irrigation water amounts are not economic and result in leaching not only of salts but also of nutrients.

To provide a general orientation for practical irrigation water application, Tab. 14 and Tab. 15 display crop water requirement values based on climatic data of Deir Allah and Karamah Agricultural Stations.

Middle Jordan Valley	**Weekly crop water requirement [mm]**			
	k_{c1} (30 days)	**k_{c2} (40 days)**	**k_{c3} (40 days)**	**k_{c4}**
January	5.9	8.3	10.7	8.8
February	7.6	10.8	14.0	11.5
March	13.0	18.4	23.8	19.4
April	14.9	21.1	27.3	22.3
May	19.2	27.2	35.2	28.8
June	22.3	31.6	40.9	33.5
July	22.2	31.4	40.6	33.2
August	19.5	27.6	35.7	29.2
September	16.8	23.7	30.7	25.1
October	12.3	17.4	22.5	18.4
November	10.2	14.5	18.8	15.4
December	5.5	7.7	10.0	8.2

Tab. 14: Weekly crop water requirement ET_c for eggplant in the middle Jordan Valley (DA 21 - DA 26)

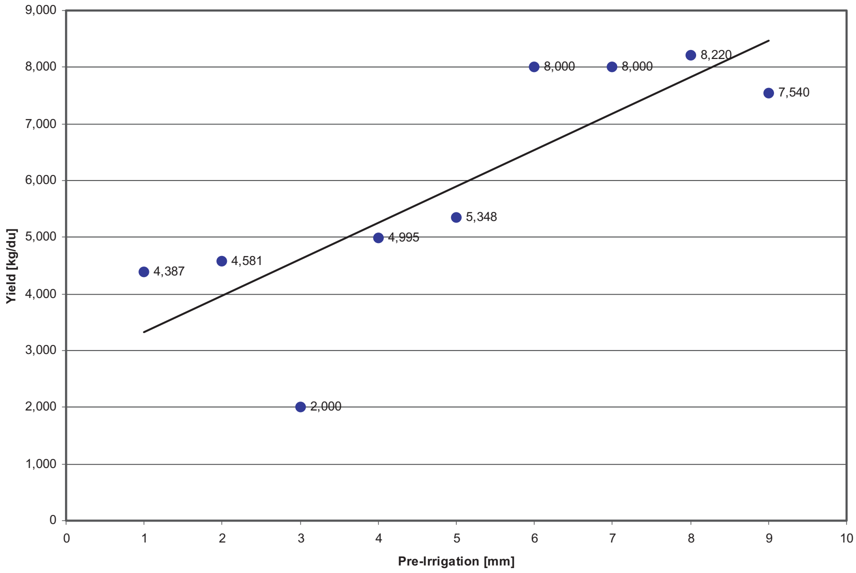
Southern Jordan Valley	**Weekly crop water requirement [mm]**			
	k_{c1} (30 days)	**k_{c2} (40 days)**	**k_{c3} (40 days)**	**k_{c4}**
January	4.6	6.6	8.5	6.9
February	6.4	9.0	11.7	9.6
March	10.7	15.2	19.7	16.1
April	13.0	18.4	23.9	19.5
May	16.7	23.6	30.6	25.0
June	19.3	27.4	35.5	29.0
July	19.0	26.9	34.9	28.5
August	16.7	23.6	30.5	25.0
September	14.0	19.8	25.6	20.9
October	10.0	14.2	18.4	15.1
November	7.3	10.3	13.4	10.9
December	4.5	6.3	8.2	6.7

Tab. 15: Weekly crop water requirement ET_c for eggplant in the southern Jordan Valley (DA 27 - DA 52)

The weekly ET_c values can be used to calculate the field water requirements (FWR) as explained in the chapter 'Water Requirements'. The effective rainfall - if relevant - should be deducted and the leaching fraction and the technical losses should be added. The leaching fraction for eggplant irrigated with drip irrigation on gypsiferous soils is assessed as 0.12, for furrow irrigation as 0.38. The efficiency of most of the drip irrigation systems in the middle and southern Jordan Valley is estimated to be 80 %.

The calculated FWR values are shown in Fig. 46 by the red series and reveal that the majority of the FUs applied high irrigation rates, probably to be on the safe side with respect to the leaching requirements. However, irrigation water and nutrients can be saved if irrigation water application is based on the parameters described above.

Pre-irrigation is practiced on all monitored FUs. Analyzing the depth of the pre-irrigation application, the trend line in Fig. 47 indicates that this practice contributes to high yields when brackish water is used for irrigation.



Pre-irrigation is recommended for eggplant cultivation under irrigation with brackish water

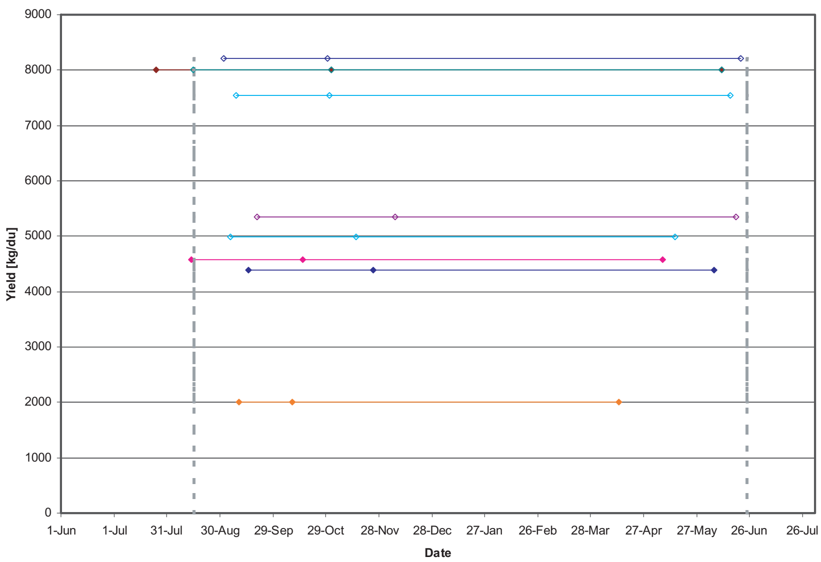
Fig. 47: Eggplant yields and pre-irrigation

The general conclusion is that pre-irrigation is a recommendable practice, and high leaching fractions help to achieve high yields under brackish water irrigation.

Growing Season

Eggplant is a crop preferring warm temperatures with optimum seed germination between 21 - 24° C and for growth between 21 - 29° C (*IFA, 1992*). Accordingly the transplanting on the monitored FUs takes place in August and September and harvest starts around November.

In Fig. 48, the growing season[9] in relation to the different yields is displayed, but there is no clear evidence for a relationship between the length of the growing season and the corresponding yields. In all cases the harvesting period was very long (i.e. up to 7 months).



The favorable growing season for squash in the Jordan Valley is from August to June

Fig. 48: Eggplant yields and growing season

The general conclusion is that the favorable growing season for eggplant in the Jordan Valley stretches from August to the end of June.

[9] The left dot of the line graph marks the transplanting start, the middle dot the beginning of the harvest and the right dot the end of the harvest.

Planting Density and Spacing

The planting densities observed on the monitored FUs range from about 1,100 - 2,000 plants/du. The trend line in Fig. 49 based on the yield series indicates increasing yields with increasing densities. This is supported by practices in California from where *Aguiar* et al. (without year) report densities of 1,600 to 3,700 plants/du.

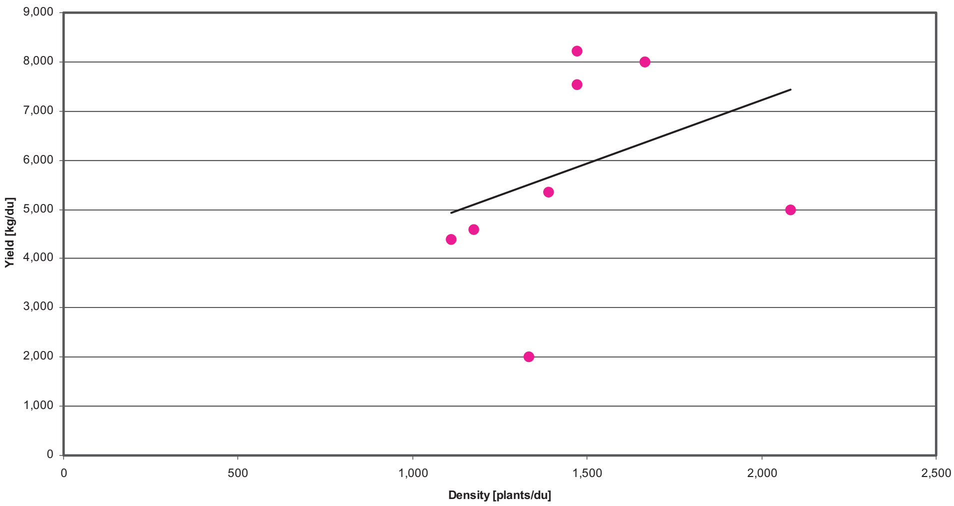


Fig. 49: Eggplant yields and planting density

Eggplant should be transplanted into rows 150 - 170 cm apart with an in-row spacing of 40 cm or less

The trend line in Fig. 49 leads to the assumption that farmers in the Jordan Valley can still increase the densities to achieve higher yields, especially considering the high water and fertilizer application rates. The limiting factor for narrow spacing of rows is that workers need space between the rows during the harvesting period.

Looking at the distances between the rows, a spacing of 150 to 170 cm shows the highest yields and leads to the recommendation that farmers should plant rows 150 - 170 cm apart with in-row spacing of 40 cm or less.

Fertilization

The harvesting time for eggplant in the Jordan Valley is extremely long, lasting for 6 to 7 months. Taking into consideration the high yields on the monitored FUs, it becomes clear that the nutrient removal from the farms is high. According to *IFA (1992)*, 4,000 kg yield of eggplant remove 7.5 kg/du of N. The recommendation for California (*Aguirr et al.*, without year) is 16.8 - 22.4 kg/du total N (for information: total P_2O_5 and total K_20 is 9 - 13.4 kg/du).

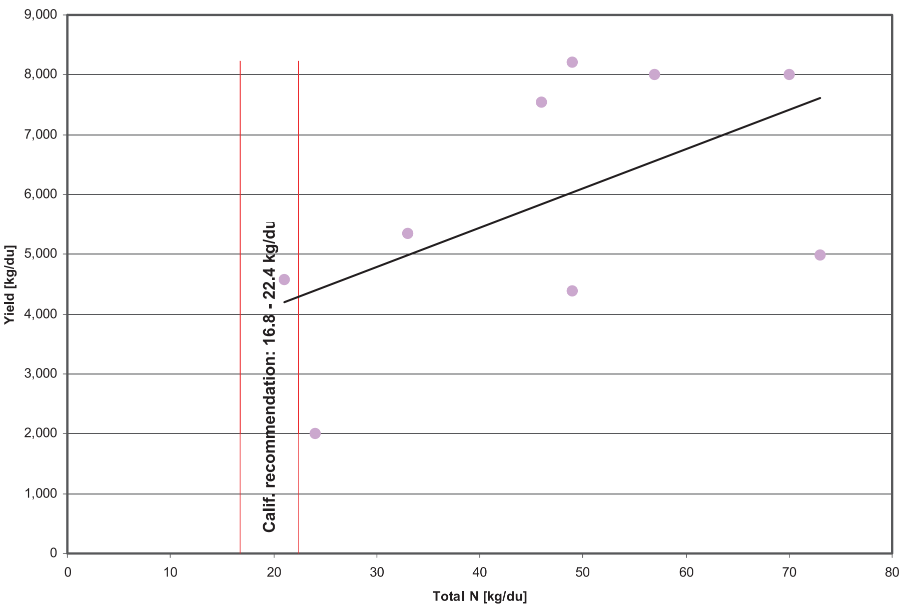


Fig. 50: Eggplant yields and N application

Farmers using brackish water for irrigation should consider nitrogen (N) application rates in the range of 25 - 35 kg/du

Fertilizer applications on the monitored FUs differ greatly and range from about 21 - 73.5 kg/du of total nitrogen (N). All FUs with drip irrigation practiced fertigation.

The trend line in Fig. 50 indicates higher yields with increasing N application rates. As pointed out earlier, the average yield on the monitored FUs (5,897 kg/du) is about 1.5 times higher than the average yield in California (3,825 kg/du). Accordingly the recommendation for total N fertilization in the Jordan Valley would be in the range of 25 - 35 kg/du for total N under freshwater irrigation.

General Agricultural Practices

The common tillage practice on the monitored FUs is two times disc plowing with a depth of about 20 - 30 cm and one harrow.

On two FUs, deep plowing was practiced as first tillage. The farmers believe that this practice helps to control the weeds and brings the salts from the surface layer into deeper layers. However, since eggplant has a deep reaching taproot, the roots might reach the salts also in a deep layer, and if deep plowing is practiced in the following season it will bring the salts back to the surface layer.

Black plastic mulch is recommended when irrigating with brackish water

On all FUs where drip irrigation is used, black **plastic mulch** is also applied. This ensures a higher germination temperature in the soil and prevents germination of weeds. In general, black plastic mulch in combination with drip irrigation is recommended as a good practice for irrigation with brackish water.

About 1,500 kg/du of manure should be applied and incorporated immediately before transplanting

On all FUs, **organic fertilizer** in the form of chicken manure was applied before planting with a rate ranging from 500 - 2,500 kg/du. Taking into account the generally low organic matter contents in the Jordan Valley of less than 2 % (*GTZ, 2000 and 2001 a*), this is a recommendable practice. However it is often observed that the chicken manure remains for weeks on the fields before it is incorporated into the soil, minimizing the benefit of the manure considerably.

Weeding is normally done manually. No special effects of particular practices with regard to salinity were observed.

Pest management is heterogeneous. The general impression is that satisfactory know-how among farm managers is lacking and that pesticide application is high. No interactions between pesticide application and brackish water irrigation have been observed.

Eggplant suffered on many plots from white cottony rot/mold (*Sclerotina sclerotiorum*), powdery mildew (*Leveillula taurica*), and red spider mite (*Tetranychus ssp*).

Tomato

(Lycopersicon esculentum Mill.*)*

TOMATO PREFERS the warm season with optimal production temperatures between 21° and 27° C for vegetative growth, fruit set, and development (*Le Strange et al.*, without year).
In California and in other countries, the cultivation techniques are different for fresh-market and processing tomato. These differences are not observed in the Jordan Valley.

Fig. 51: Tomato cultivation in the Jordan Valley

According to *Soer (1998),* tomato occupied the largest vegetable production area in Jordan Valley. For brackish water users it is also one of the important crops due to its high yields and relatively easy cultivation.

In the open field, tomatoes in the Jordan Valley are cultivated as bushes. A considerable part of the harvest is exported to Eastern Europe because the size of the fruits meets consumers' preferences there. When market prices are low, tomato is not sold as fresh market crop but to a processing factory.

Yields

Taking the general importance of tomato in the Jordan Valley into account, their share in the cropping pattern on the monitored FUs between 2000 - 2003 was not as high as expected, probably because market prices in the previous season had been low. For this reason the sample is relatively small.

Under brackish water irrigation, well-managed tomato cultivation can achieve average yields up to 6,000 kg/du

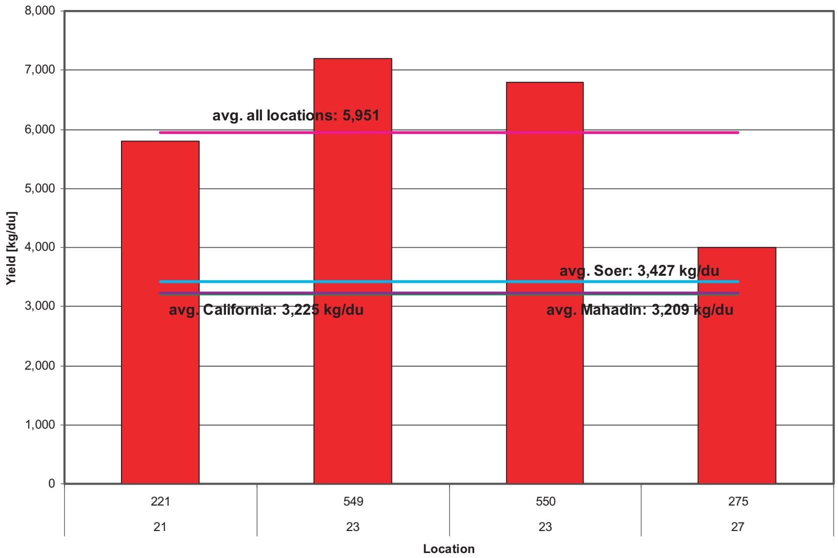


Fig. 52: Tomato yields

The yields on the monitored FUs during the years 2001 - 2003 ranged between 4,000 - 7,200 kg/du with an average of 5,951 kg/du as shown in Fig. 52. This is much higher than averages reported by *Soer (1998)* with 3,427 kg/du and *Mahadin (1999)* with 3,209 kg/du, which were mainly obtained under freshwater irrigation. Taking into consideration that the monitored farms used brackish water for irrigation with EC_{iw} values up to 7.2 dS/m, the comparison between the monitored FUs and the total of the Jordan Valley farms allows the conclusion that the cultivation of tomato under irrigation with brackish water is very appropriate and feasible.

Surprisingly, the average yield in California between 1997 - 1999 was about 3,225 kg/du (Source: *Annual California Agricultural Commissioners' Report*, in *Le Strange et al.* without year). This is far lower than the observed average on the monitored FUs. The main reasons are probably different varieties and the longer harvesting periods in the Jordan Valley with more than one pick. However, *IFA (1992)* reports yields of 2,000 - 6,000 kg/du for out-door and up to 10,000 kg/du for under glass production in temperate climates.

Varieties

The varieties grown on the monitored FUs are 'GS', 'Farida' and 'Wafa'. The crop and variety survey carried out in 2000 by the BWP concludes that the main features of the tomato varieties sold in the Jordan Valley are high production and tolerance to tomato yellowing leaf curl virus (TYLCV) and root knot nematode (RKN).

The only variety that was cultivated under brackish water irrigation is 'Hector F1'. It was irrigated with EC_{iw} up to 4.5 dS/m in Morocco (personal communication April 2001, O. Auriol, Clause Seed Company). The variety is offered in Jordan but it is rarely cultivated. Obviously farmers are not aware of this particular trait of 'Hector F1'. It would be worth testing this variety with brackish water irrigation in the Jordan Valley in order to find out if it out-yields other varieties.

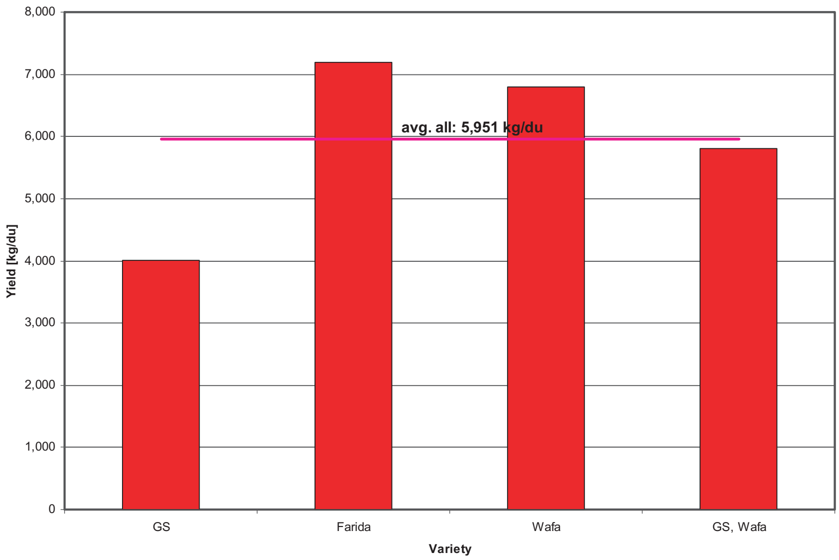


Fig. 53: Yields of tomato varieties

All cultivated varieties performed well under brackish water irrigation

As already mentioned, the extent of the sample is too small to recommend a particular variety cultivated on the monitored FUs, but with regard to international yields the performance of all cultivated varieties is satisfying.

Irrigation Water Salinity

The yield results and the corresponding ranges of the irrigation water salinities are displayed in Fig. 54.

Cluster A comprises the highest yield segment and was obtained within the wide EC_{iw} range between 1.5 - 6.5 dS/m and with an average EC_{iw} = 4.2 dS/m[10]. The yield in cluster B is related to a lower EC_{iw} range between 1.4 - 3.8 dS/m and with an average of EC_{iw} = 2.5 dS/m. The yield in cluster C is remarkable because it is still higher than the average yield in California although it was obtained with an average EC_{iw} of 6 dS/m.

The reason for the still high yield in cluster C is probably the relatively high N application rate (13.5 kg/du total N) and the very high total amount of water applied (888 mm). With such high inputs, the yields could perhaps have been even higher, but it was also observed that the weeding on this plot was poor and the high weed population probably competed with the tomato for water and nutrients and caused yield losses.

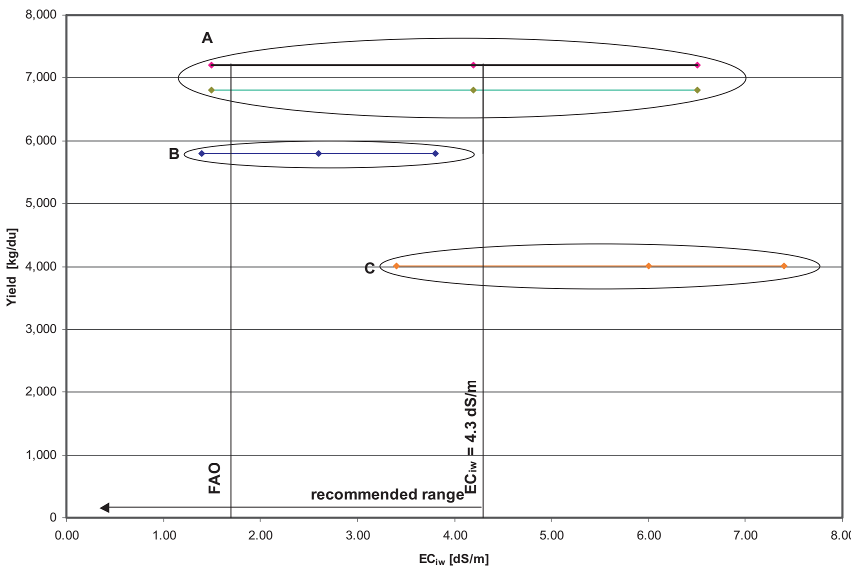


Fig. 54: Tomato yields and irrigation water salinity

The cultivation of tomato in the Jordan Valley is feasible up to an irrigation water salinity of at least EC_{iw} = 4.3 dS/m

[10] The ranges cover the spectrum of the lowest, average and highest applied irrigation salinity during the growing period.

The reason for the high yields in cluster A could be due to the relatively high pre-irrigation application: 28 mm as compared to 9.6 mm for cluster B and no pre-irrigation in cluster C. Another reason is probably the alternation between fresh and brackish water on the FUs of cluster A. Here, during transplanting and for the following 3 weeks brackish water was used, then for about 8 weeks freshwater was applied and later both sources were alternated. This explains the wide EC_{iw}-range in Fig. 54 and also supports the hypothesis that alternating between fresh and brackish water is preferable to blending, as practiced on the FUs of clusters B and C.

According to *FAO (1985)*, the salinity threshold (100 % yield) for brackish irrigation water is 1.7 dS/m. However, with regard to the irrigation water salinities used on the monitored FUs, this threshold value obviously can be exceeded in the Jordan Valley (s. Fig. 54 and Fig. 55). This is probably due to the fact that prevailing drip irrigation, gypsiferous and/or calcareous soils and winter cultivation in the Jordan Valley are more favorable to irrigation with brackish water than the conditions under which the FAO thresholds were determined.

The average irrigation water salinities of the monitored FUs are displayed in Fig. 55. The two highest yields are achieved around EC_{iw} = 4.3 dS/m. This hints at a threshold around this value in the Jordan Valley, provided good cultivation and irrigation practices are applied.

Irrigation water salinity with EC_{iw}> 4.3 dS/m will decrease yield of tomato

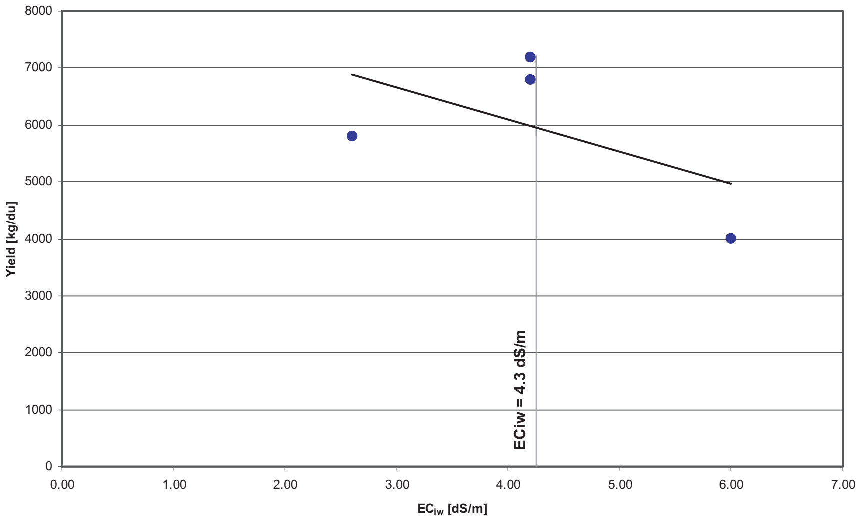


Fig. 55: Tomato yields and average irrigation water salinity

The trend line in Fig. 55 indicates that increasing salinity causes decreasing yields. This implies that farmers irrigating with water of EC_{iw} > 4.3 dS/m should expect yields to drop below the average of about 6,000 kg/du.

Soil Texture

The textural classes of the monitored farms are in the relatively heavy to medium heavy range.

From other countries it is known that a wide range of soil textures are used for tomato cultivation. For early planting, sandy soils are preferred, but clay and loam soils are more productive, provided they are well drained *(Le Strange et al.* without year).

Tomato prefers medium textured and well-drained soils

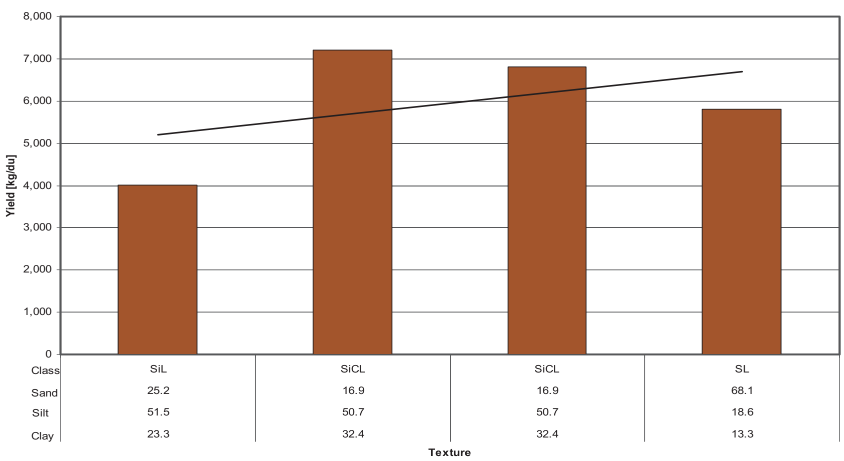


Fig. 56: Tomato yields and texture

With regard to the silt content in the soils of the monitored FUs, Fig. 56 implies that decreasing silt content might be more suitable for tomato. However, because of the low sample size, it is premature to draw conclusions with regard to relations between soil texture and yields. Nevertheless, the general assessment is that medium textured soils with good aeration and drainage properties are suitable for tomato cultivation under brackish water irrigation.

Irrigation Practices and Total Water Supply

All monitored FUs applied drip irrigation under black plastic mulch. Because of the good results achieved, drip irrigation and black plastic mulch is considered the appropriate irrigation method for tomato cultivation under brackish water conditions in the Jordan Valley.

Fig. 57 shows the total water applied (TWA) on the monitored FUs and the calculated field water requirement (FWR) based on crop water requirements (Tab. 16 and Tab. 17). The leaching fraction for tomato under drip irrigation on gypsiferous soils is assessed as 0.14 and added to the crop water requirement (ET_c). The efficiency of most of the drip irrigation systems in the Jordan Valley is estimated to be 80 %; accordingly a supplement for technical losses of the on-farm irrigation system is added (see chapter 'Water Requirements').

Drip irrigation equipment and FWR in the range from 480 to 720 mm help to compensate for adverse effects of brackish irrigation water

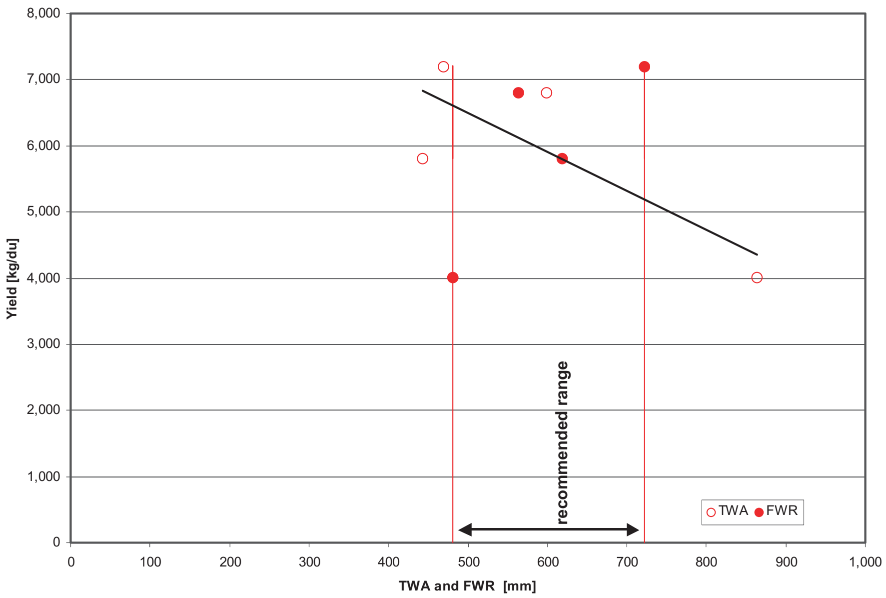


Fig. 57: Tomato yields, FWR and TWA

The comparison indicates that one of the monitored FUs applied irrigation water far higher than the FWR without achieving a yield of a relatively higher level than the other FUs (the reasons are given in chapter 'Irrigation Water Salinity).

Tab. 16 and Tab. 17 provide general orientation of crop water requirement values for tomato in the Jordan Valley.

Middle Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (30 days)	k_{c2} (40 days)	k_{c3} (40 days)	k_{c4}
January	5.9	9.1	12.2	6.3
February	7.6	11.8	15.9	8.3
March	13.0	20.1	27.0	14.0
April	14.9	23.1	31.0	16.1
May	19.2	29.7	40.0	20.8
June	22.3	34.6	46.5	24.2
July	22.2	34.3	46.1	24.0
August	19.5	30.2	40.6	21.1
September	16.8	26.0	34.9	18.1
October	12.3	19.0	25.5	13.3
November	10.2	15.9	21.3	11.1
December	5.5	8.5	11.4	5.9

Tab. 16: Weekly crop water requirement ET_c for tomato in the middle Jordan Valley (DA 21 - DA 26)

Southern Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (30 days)	k_{c2} (40 days)	k_{c3} (40 days)	k_{c4}
January	4.6	7.2	9.6	5.0
February	6.4	9.9	13.3	6.9
March	10.7	16.6	22.4	11.6
April	13.0	20.2	27.1	14.1
May	16.7	25.9	34.8	18.1
June	19.3	30.0	40.3	20.9
July	19.0	29.5	39.6	20.6
August	16.7	25.8	34.7	18.0
September	14.0	21.6	29.1	15.1
October	10.0	15.6	20.9	10.9
November	7.3	11.3	15.2	7.9
December	4.5	6.9	9.3	4.8

Tab. 17: Weekly crop water requirement ET_c for tomato in the southern Jordan Valley (DA 27 - DA 52)

Pre-irrigation was practiced on three out of four monitored FUs with application rates between 10 and 28 mm.

Pre-irrigation is recommended for tomato cultivation under irrigation with brackish water

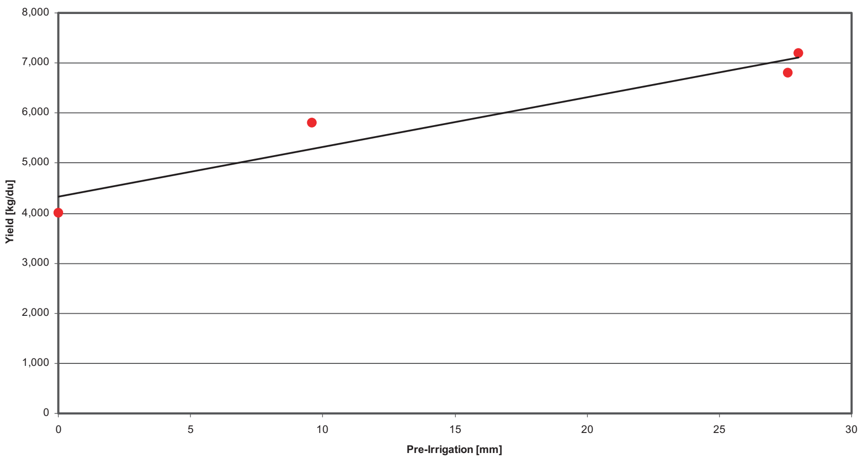


Fig. 58: Tomato yields and pre-irrigation

Analyzing the depth of the pre-irrigation application, the trend line in Fig. 58 indicates that this practice contributes to higher yields when brackish water is used for irrigation.

Growing Season

In Fig. 59, the growing season[11] in relation to the different yields is displayed; but there is no clear evidence for a relationship between the length of the growing season and the corresponding yields.

The favorable growing season for tomato in the Jordan Valley is from December to June

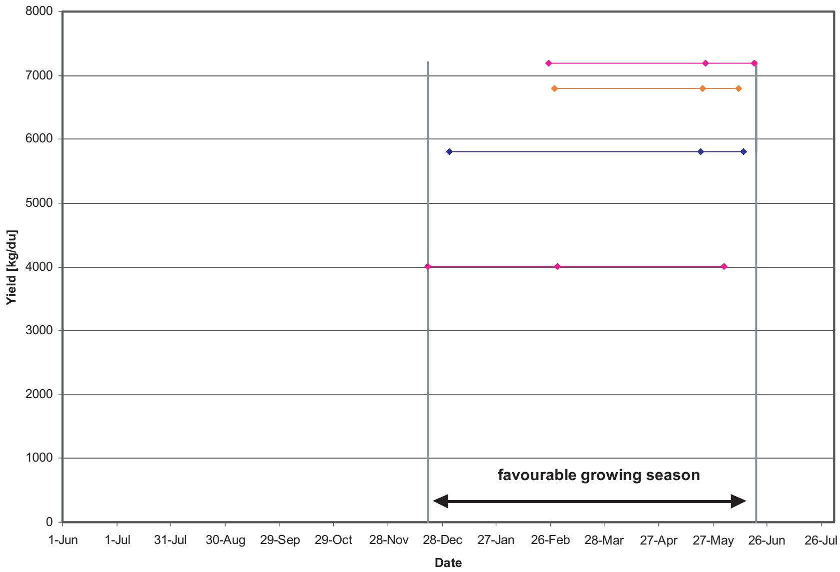


Fig. 59: Tomato yields and growing season

With regard to the highest yields, the general conclusion is that the favorable growing season for tomato after transplanting in the Jordan Valley stretches from middle December to the end of June.

Planting Density and Spacing

All FUs used the same spacing of 200 x 40 cm resulting in 1,250 plants/du. *Le Strange et al.* (without year) report densities of 1,310 - 1,430 plants/du from California, which is slightly higher than in the Jordan Valley.

Tomato should be transplanted into rows 160 - 200 cm apart with an in-row spacing of 40 cm or less

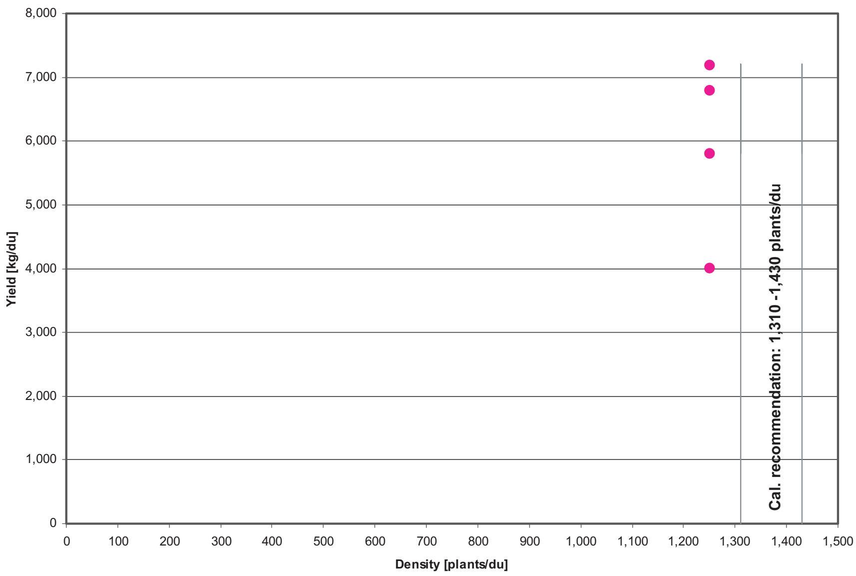


Fig. 60: Tomato yields and planting density

The spacing of 200 x 40 cm seems to be an appropriate practice because it gives high yields, even higher than in California. However, the recommendation to farmers using brackish water for irrigation is to test if reducing the distance between the rows, e.g. to 170 or 160 cm and thus increasing the density would also increase yields.

[11] The left dot of the line graph marks the transplanting start, the middle dot the beginning of the harvest and the right dot the end of the harvest.

Fertilization

Fertilizer applications on the monitored FUs differ in the range from about 2.8 - 13.5 kg/du of total nitrogen (N). All FUs used drip irrigation and practiced fertigation.

As mentioned earlier, the average yield on the monitored FUs (5,951 kg/du) is higher than the average yield in California (3,225 kg/du). The recommended fertilization for bush tomatoes in California (*Le Strange et al.*, without year) is 14 - 28 kg/du total N (total P_2O_5: 6.7 - 13.4 kg/du and total K_2O up to 13.4 kg/du).

Assuming that the Californian average (3,225 kg/du) was achieved with 14 kg/du of total N, the recommendation for the average yield on the monitored FUs (5,951 kg/du) would correspond to about 26 kg/du for total N under freshwater irrigation, which is quite high.

Farmers using backish water for irrigation should consider nitrogen (N) application rates of up to 26 kg/du as long as the N content of the irrigation water source is low

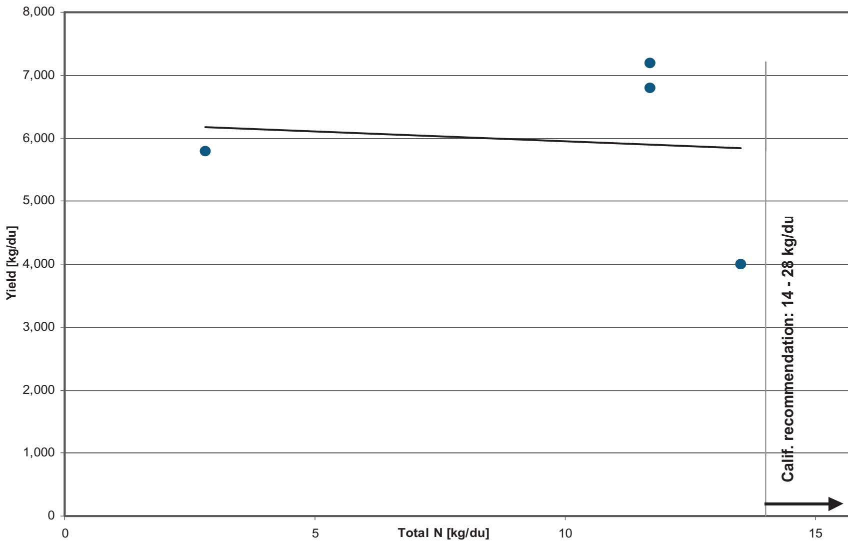


Fig. 61: Tomato yields and N application

Taking into account the higher fertilization practices of California, it is suggested that farmers in the Jordan Valley test the influence of N application rates up to 26 kg/du on the yields. However, in any case, they should give water samples of the irrigation water source to the laboratory in order to check the N content. As pointed out in the chapter 'Water Quality', many water sources have relatively high N contents. In order to avoid over-fertilization, the N content of the irrigation water should be included in the fertilization plan, especially when irrigating with water from KTR, from drains and for some springs and wells.

General Agricultural Practices

On two of the monitored FUs, the **tillage** practice is two times disc plowing with a depth of about 20 - 30 cm and one harrow; the other 2 FUs did not till because they continued using the plastic mulch of the previous crop. This is a good practice because it leaves the soil life undisturbed, saves the farmers money and relieves the environment of plastic residues.

Black plastic mulch is recommended when irrigation with brackish water

On all FUs where drip irrigation is used, black **plastic mulch** is also applied. This ensures a higher germination temperature in the soil and prevents germination of weeds. In general, black plastic mulch in combination with drip irrigation is recommended for irrigation with brackish water.

At least 500 kg/du of manure should be applied and incorporated immediately before transplanting

On two FUs, **organic fertilizer** in the form of chicken manure was applied before planting with a rate of 500 kg/du. Taking into account the generally low organic matter contents in the Jordan Valley of less than 2 % (*GTZ, 2000 and 2001 a*), this is a recommendable practice and it should even be amended to higher application rates. However, it is often observed that the chicken manure remains for weeks on the fields before it is incorporated into the soil, minimizing the benefit of the manure considerably.

Weeding is normally done manually. No special effects of particular practices with regard to salinity were observed.

Disease and Pest management is heterogeneous. The general impression is that satisfactory know-how among farm managers is lacking and that pesticide application is high. No interactions between pesticide application and brackish water irrigation have been observed.

Tomato suffered on many plots from *Orobanche* ssp., a parasite on the roots that occurs if there is no crop rotation.

Potato

(Solanum tuberosum L.*)*

HIGH POTATO yields are obtained in temperate regions, but they can also be cultivated in the cool season of subtropical climates under irrigation *(Euroconsult, 1989)*.

Fig. 62: Potato plant and harvest

Generally, potato cultivation is popular among farmers in the Jordan Valley, especially in the northern part of the project area; but at the same time it is regarded a risky crop because there is only one short harvest period (unlike many vegetables) and no export possibility. If potato cultivation is not successful within this time window, it is a definite economic loss for the farmer.

The importance of potato cultivation in the Jordan Valley is increasing. Several brackish water farmers cultivate potato although it is known to be susceptible to salinity.

Yields

The yields on the monitored FUs during the years 2001 - 2003 range between 540 and 3,300 kg/du as shown in Fig. 63.

Under brackish water irrigation potato cultivation does not reach average yields of freshwater irrigated potatoes

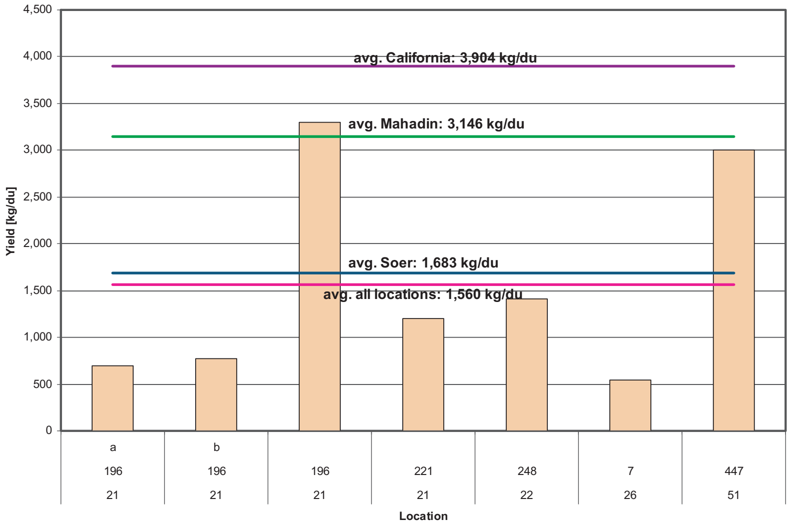


Fig. 63: Potato yields

The average yield of 1,560 kg/du on the monitored FUs under brackish water irrigation is slightly lower than averages reported by *Soer (1998)* with 1,683 kg/du, and significantly lower than average values reported by *Mahadin (1999)* with 3,146 kg/du, which were mainly obtained under freshwater irrigation.

As an international comparison within similar climatic conditions, *Mayberry (2000)* states an average yield of 3,904 kg/du for California; thus the monitored FUs in the Jordan Valley reached not more than 40 % of this value.

The comparison of the yields under brackish water irrigation and freshwater irrigation indicate that successful potato cultivation with brackish water requires very careful agricultural and irrigation management practices and the full attention of the farm manager.

Varieties

The varieties grown on the monitored FUs are 'Alaska, 'Lacetta', 'Mondial', 'Samantha', and 'Sponta'.

Under brackish water irrigation 'Alaska' and 'Mondial' perform better than other varieties

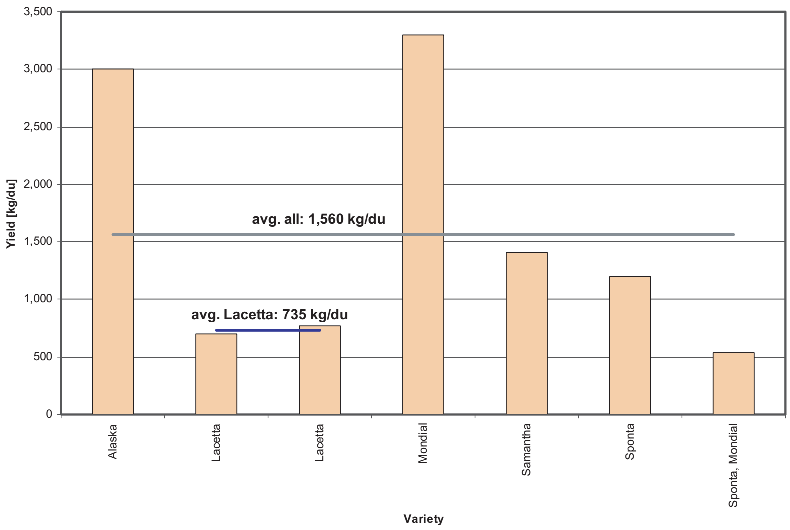


Fig. 64: Yields of potato varieties

Although there are only single results available for the different varieties (except two for 'Lacetta') the yields obtained under brackish water irrigation suggest that 'Alaska' and 'Mondial' perform better under brackish water irrigation than other varieties. It is worth mentioning that 'Lacetta' and 'Mondial' were cultivated on the same FU. However, 'Mondial' out-yielded 'Lacetta' by about 4 times.

Irrigation Water Salinity

The yield results and the corresponding ranges of the irrigation water salinities are displayed in Fig. 65.

Cluster A comprises the highest yield segment and was obtained within the EC_{iw} range of 0.9 - 3.8 dS/m.[12] Cluster B covers the medium yields achieved with salinities between 1.9 - 4.1 dS/m. The yield in cluster C was obtained with the highest irrigation water salinity EC_{iw} = 4.8 - 7.5 dS/m and was low with 540 kg/du.

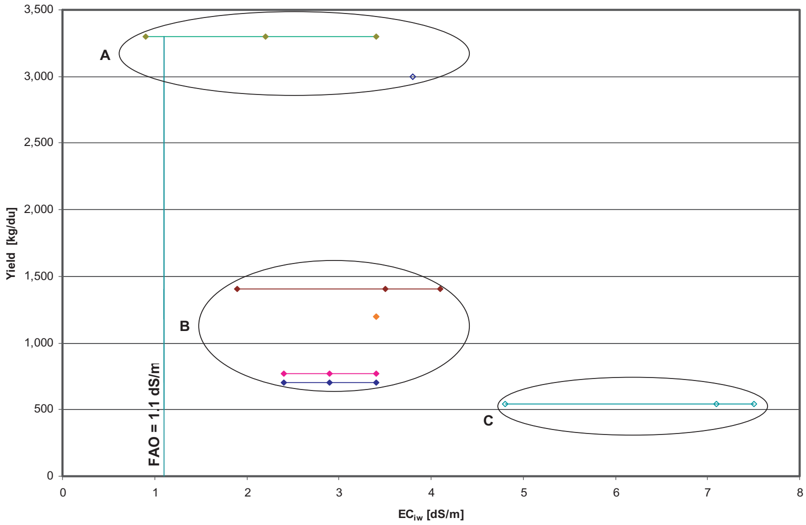


Fig. 65: Potato yields and irrigation water salinity

The cultivation of potato in the Jordan Valley is feasible up to an irrigation water salinity of EC_{iw} = 3.8 dS/m

According to *FAO (1985)* the salinity threshold (100 % yield) for brackish irrigation water is 1.1 dS/m. This means that potato is relatively sensitive to saline irrigation water.

The fact that the irrigation water on the monitored FUs is higher than 1.1 dS/m explains partly the overall low yield level. On the other hand there are two cases in cluster A demonstrating that good yields can be achieved in the Jordan Valley with EC_{iw} values higher than known from international literature.

The highest yield (3,300 kg/du) was achieved with irrigation water of freshwater quality (average EC_{iw} = 2.2 dS/m) and the second highest yield (3,000 kg/du) was obtained with an average irrigation water salinity of ECiw = 3.8 dS/m.

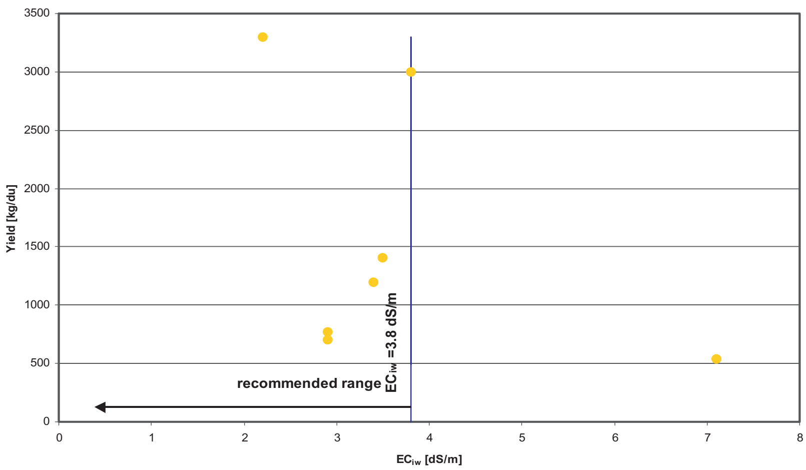


Fig. 66: Potato yields and average irrigation water salinity

Irrigation with brackish water significantly decreases yield of potato

From these data the conclusion is drawn that irrigating potato with brackish water up to about EC_{iw} = 3.8 dS/m in the Jordan Valley is only recommendable if careful agricultural and irrigation management practices are applied which are further discussed under 'Irrigation Practices' and 'Fertilization'.

[12] The ranges cover the spectrum of the lowest, average and highest applied irrigation water salinity during the growing period.

Soil Texture

The textural classes of the monitored farms are in the heavy to medium range (see Fig. 67).

Potato prefers medium textured and well-drained soils

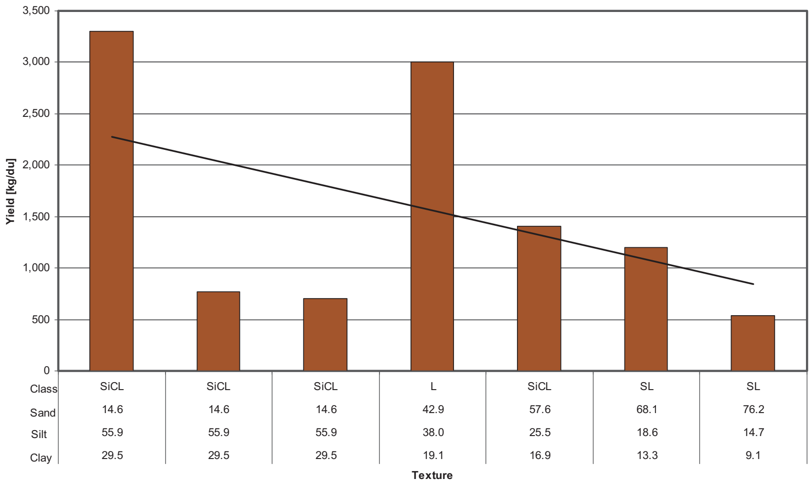


Fig. 67: Potato yields and texture

Considering the silt content, it is obvious that the yields decrease with lower silt contents. This is due to the lower water and nutrient holding capacity of soils with less silt content.

Normally potato can be cultivated on all soils with adequate drainage *(Euroconsult, 1989)*, but in modern agriculture, lighter soils are preferred because of easier mechanical harvest.

Irrigation Practices and Total Water Supply

All monitored FUs applied drip irrigation, but none used black plastic mulch. Since drip irrigation helps to keep salinity out of the root zone it is considered an appropriate irrigation method for potato cultivation under brackish water conditions in the Jordan Valley.

Fig. 68 compares the depths of Total Water Applied (TWA) and the FWR calculated according to the chapter 'Water Requirement'. The recommended range for the FWR ranges between 230 to 400 mm per season.

Drip irrigation equipment and FWR between 230 to 400 mm help to compensate for adverse effects of brackish irrigation water

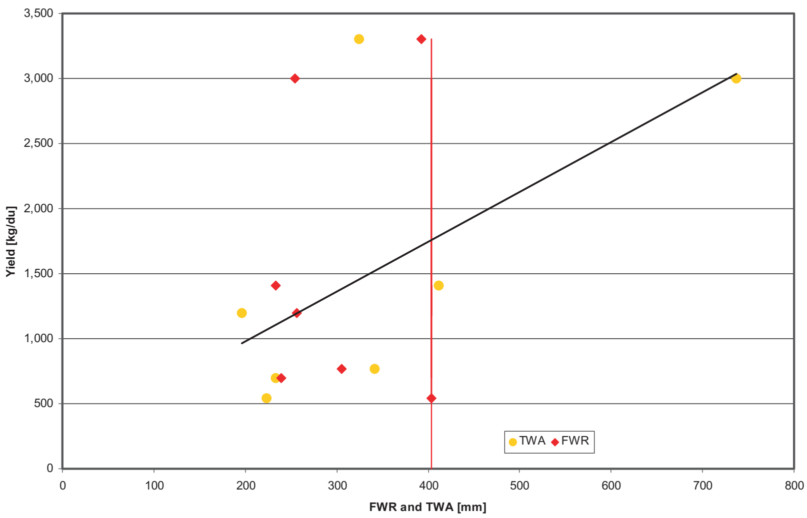


Fig. 68: Potato yields, FWR and TWA

The highest yield of 3,300 kg/du was obtained with a low amount of water. Reasons for the good result are probably the relatively low salinity and the good rains during the cultivation period: the potato received 320 mm of total water, of which 185 mm was precipitation. 105 mm of precipitation fell during the first month after planting and probably had a significant leaching effect comparable to a high pre-irrigation application.

For general orientation Tab. 18 and Tab. 19 provide weekly values of the water requirements of potatoes.

Middle Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (30 days)	k_{c2} (30 days)	k_{c3} (30 days)	k_{c4}
January	5.9	8.8	11.7	7.3
February	7.6	11.5	15.3	9.5
March	13.0	19.4	25.9	16.2
April	14.9	22.3	29.8	18.6
May	19.2	28.8	38.4	24.0
June	22.3	33.5	44.7	27.9
July	22.2	33.2	44.3	27.7
August	19.5	29.2	39.0	24.4
September	16.8	25.1	33.5	20.9
October	12.3	18.4	24.5	15.3
November	10.2	15.4	20.5	12.8
December	5.5	8.2	10.9	6.8

Tab. 18: Weekly crop water requirement ET_c for potato in the middle Jordan Valley (DA 21 - DA 26)

Southern Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (30 days)	k_{c2} (30 days)	k_{c3} (30 days)	k_{c4}
January	4.6	6.9	9.2	5.8
February	6.4	9.6	12.8	8.0
March	10.7	16.1	21.5	13.4
April	13.0	19.5	26.0	16.3
May	16.7	25.0	33.4	20.9
June	19.3	29.0	38.7	24.2
July	19.0	28.5	38.0	23.8
August	16.7	25.0	33.3	20.8
September	14.0	20.9	27.9	17.4
October	10.0	15.1	20.1	12.5
November	7.3	10.9	14.6	9.1
December	4.5	6.7	8.9	5.6

Tab. 19: Weekly crop water requirement ET_c for potato in the southern Jordan Valley (DA 27 - DA 52)

The weekly ET_c values can be used to calculate the field water requirement (FWR) as explained in the chapter 'Water Requirements'. The effective rainfall should be deducted - if relevant - and the leaching fraction and a supplement for the technical losses in the on-farm irrigation system should be added. The leaching fraction for potato on gypsiferous soils under drip irrigation is assessed as 0.16, for furrow irrigation as 0.26. The efficiency of most drip irrigation systems is estimated to be 80 %.

Pre-irrigation was practiced on 5 monitored FUs. Analyzing the depth of the pre-irrigation application, the trend line in Fig. 69 indicates that this practice contributes to high yields under brackish water conditions.

Pre-irrigation is recommended for potato cultivation irrigated with brackish water

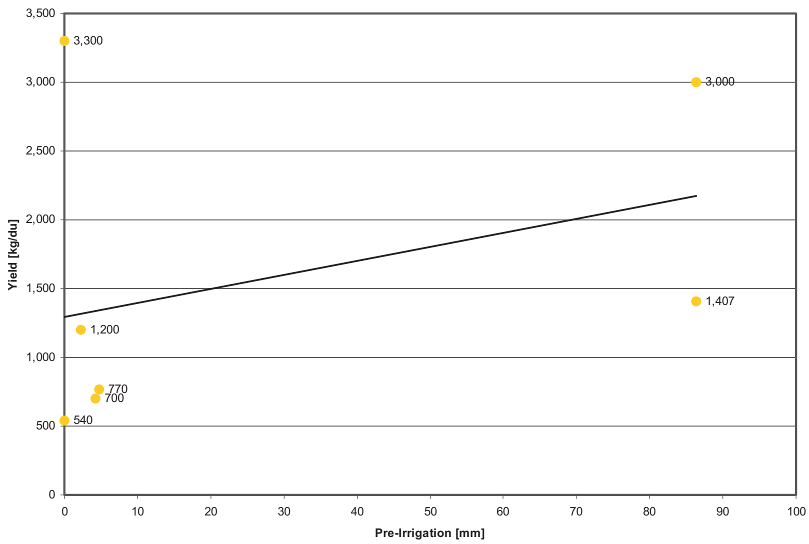


Fig. 69: Potato yields and pre-irrigation

The general conclusion is that pre-irrigation is a recommendable practice.

Growing Season

In Fig. 70 the growing season[13] in relation to the different yields is displayed. The chart shows that high yields are realized during the relatively cool season.

The favorable growing season for potato in the Jordan Valley is from December to end of April

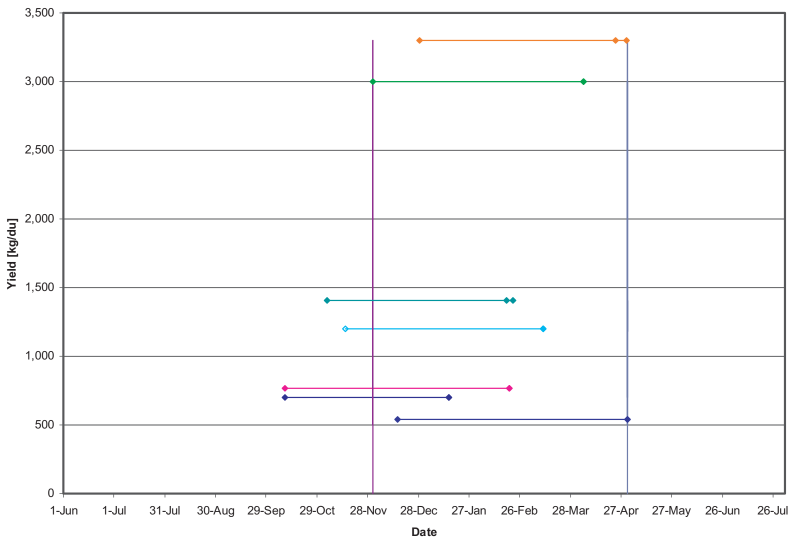


Fig. 70: Potato yields and growing period

The general conclusion is that the favorable growing season for potato in the Jordan Valley stretches from the beginning of December to the end of April.

Planting Density and Spacing

On most of the monitored FUs the spacing between the rows was 150 cm - only one FU used 70 cm. In-row spacing was 40 cm - only one exception used 20 cm. The FU with 70 cm between the rows planted potatoes with 25 cm spacing in the rows.

[13] The left dot of the line graph marks the planting start, the middle dot the beginning of the harvest and the right dot the end of the harvest.

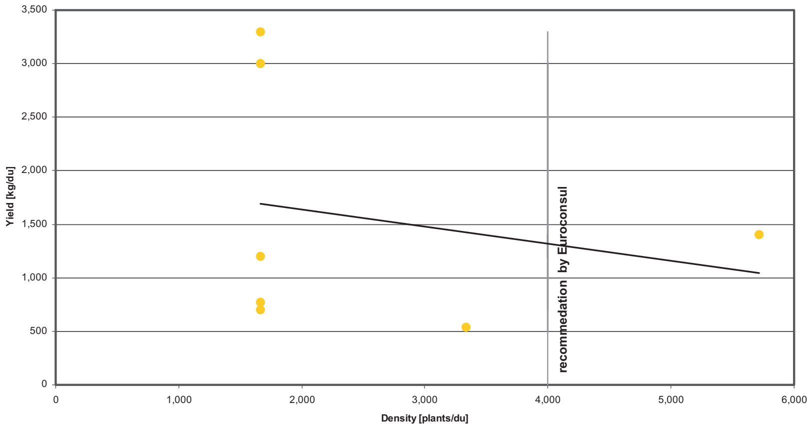


Fig. 71: Potato yields and planting density

Potato should be planted in rows 125 cm apart with a in-row spacing of 40 cm or less

The predominant planting density was 1,667 plants/du; the others were 3,333 and 5,714 plants/du respectively.

Euroconsult (1989) recommends a density of 4,000 plants/du, and the recommendation for California ranges from 5,384 - 7,666 plants/du. For local practices NCARTT recommends the spacing 125 x 40 cm, which would result in 2,000 plants/du (personal communication, Dr. Fardous).

Comparing the international spacing practices with those in the Jordan Valley leads to the suggestion to try higher plant densities than currently practiced in order to obtain higher yields.

Fertilization

In the international literature, the nitrogen fertilizer recommendation for potato is 22.4 - 33.6 kg/du total N under comparable climatic conditions *(Mayberry et al., 2000)*. Considering the average yield of the monitored FUs with regard to these reference values results in a recommendation of about 9 - 14 kg/du of total N for the Jordan Valley.

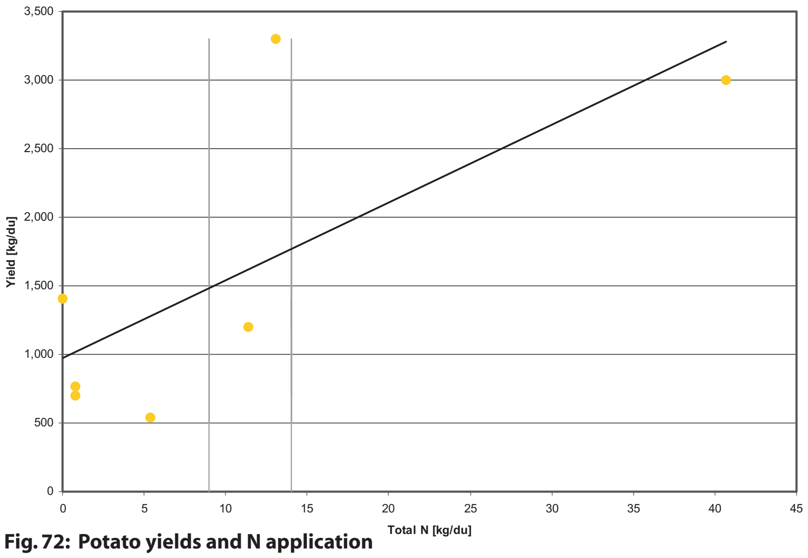


Fig. 72: Potato yields and N application

Farmers using brackish water for irrigation should consider nitrogen (N) application rates in the range of 9 - 14 kg/du

For the highest yield of 3,300 kg/du the total N applied was 13.1 kg/du, which corresponds with the recommendation given above. On the other hand, the low yield results between 500 and 800 kg/du were partly caused by low N fertilization of 5 kg/du or less.

The second highest yield of 3,000 kg/du was achieved with about 1,500 kg/du of chicken manure and 11 kg/du of additional mineral N fertilizer. Assuming an N content of about 2 % in chicken manure this results in 30 kg/du of N, which is much higher than any recommendation. Of course this N is not as readily available as mineral fertilizer N. However, it brings up the question if this manure application alone could assure a good yield, and if adding mineral fertilizer is causing over-fertilization in this case, unless a 'catch' crop follows.

On the other FUs, relatively low N application rates result in low yields. This suggests that sufficient N - partly in the form of manure - should be applied to potato in cases where they are irrigated with brackish water.

General Agricultural Practices

The **tillage** practice on the monitored FUs is not uniform. Two times disc plowing with a depth of about 20 - 30 cm and one harrow was observed as well as only harrowing once.

No FU used black **plastic mulch** because it would disturb the (mechanical) harvest.

Up to 1,500 kg/du of manure should be applied and incorporated immediately before transplanting

Only one FU applied **organic fertilizer** in form of chicken manure at a rate of 1,500 kg/du. Taking into account the generally low organic matter contents in the Jordan Valley of less than 2 % *(GTZ, 2000* and *2001 a)* this is a recommendable practice. However it is often observed that the chicken manure remains for weeks on the fields before it is incorporated into the soil, minimizing the benefit of the manure considerably.

Weeding is normally done manually. No special effects of particular practices with regard to salinity were observed.

Pest and disease management is heterogeneous. The main disease attacking potatoes in the Jordan Valley is potato blight (*Phytophtora infestans),* and the main pest is the potato tuber moth *(Phthorimaea operculella)*. Both can cause heavy yield losses, but did not occur on the monitored FUs to a disastrous extent.

The general impression is that decent know-how among farm managers is limited and that pesticide application is high. No interactions between pesticide application and brackish water irrigation have been observed.

Sweet Corn

(Zea mays convar. *saccharata* Koern.*)*

SWEET CORN is a mutation of the 'normal' corn with a higher sugar content in the seeds. It is used as a vegetable, as corn on the cob for boiling, as well as for canning and freezing.

Fig. 73: Sweet corn

Optimal seed germination is at 18° C and above, and optimal growth temperature is between 16° and 24° C (Smith et al., 1997).

In the Jordan Valley, sweet corn is mainly cultivated in the southern part. According to farmers of the northern area, cultivation along the Jordan River (Zor) would be suitable, but wild pigs cause too much damage.

The general impression is that farmers do not pay full attention to the cultivation of sweet corn because it is not considered a main crop due to the fact that there is no processing of sweet corn in Jordan, and that it is not a staple food.

Yields

The yields on the monitored FUs during the years 2001 - 2003 ranged between 500 and 1,100 kg/du as shown in Fig. 74.

Under brackish water irrigation yield of sweet corn in the Jordan Valley is low as compared to international average yields

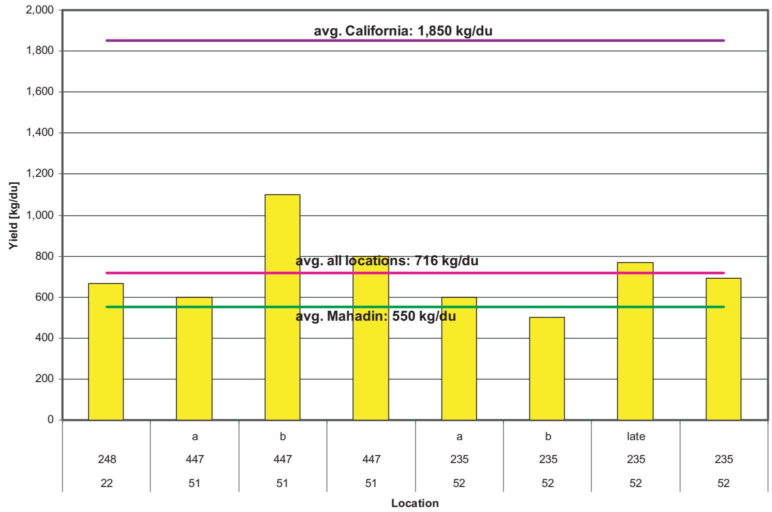


Fig. 74: Sweet corn yields

The average yield of 716 kg/du on the monitored FUs under brackish water irrigation is higher than averages reported by *Mahadin (1999)* with 550 kg/du, which were mainly obtained under fresh-water irrigation. No yields are reported by *Soer (1998)*.

The average yield reported from California (1,850 kg/du) between 1993 and 1995 was far higher - even 70 % higher than the best result on the monitored FUs. However, the average yield on the monitored FUs, which is higher than the average in the entire Jordan Valley, indicates that the production potential of sweet corn under brackish water irrigation is not fully exploited.

In general, yields of sweet corn in the Jordan Valley irrigated with brackish water could probably be higher if more attention were paid to its cultivation and irrigation management.

Varieties

The varieties grown on the monitored FUs are 'Bonanza, 'Merit', and 'NK 1999' with an obvious preference for 'Merit'.

All monitored varieties show similar yield results

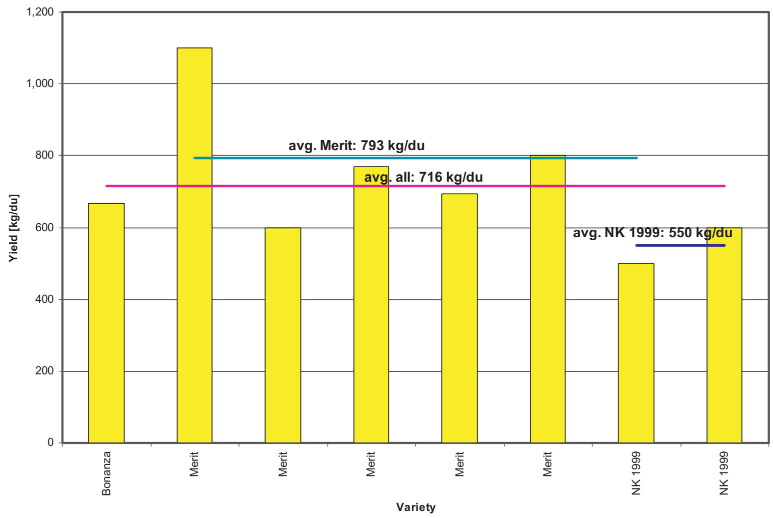


Fig. 75: Yields of sweet corn varieties

The comparison of the yields of the cultivated varieties implies that 'Merit' is above the average of the monitored FUs; but the deviation between the three values is relatively low. For this reason a recommendation for a particular variety is difficult. With regard to the relatively low average yield in the Jordan Valley, all three varieties appear acceptable.

Irrigation Water Salinity

The yield results and the corresponding ranges of the irrigation water salinities are displayed in Fig. 76.
Cluster A contains the highest yield and was obtained with EC_{iw} = 3.8 dS/m. Cluster B covers the medium and low yields that were achieved with salinities between 3 and 4 dS/m. [14]

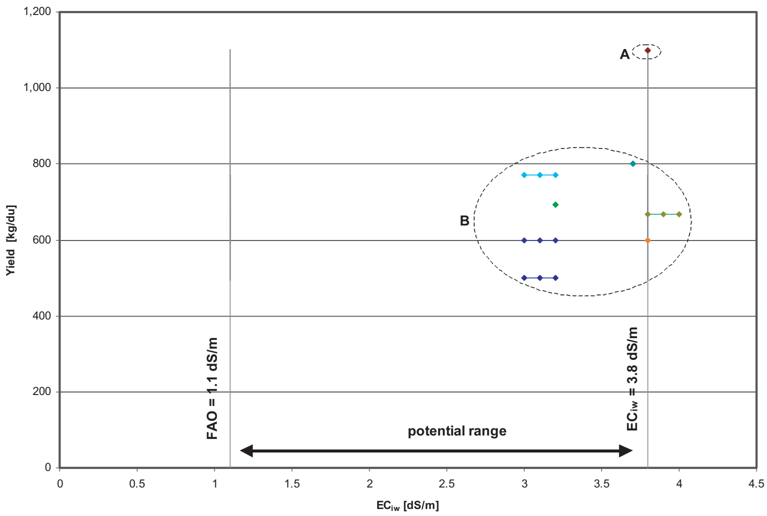


Fig. 76: Sweet corn yields and irrigation water salinity

The cultivation of sweet corn in the Jordan Valley is possible up to an irrigation water salinity of EC_{iw} = 3.8 dS/m, but low yields have to be expected

According to FAO *(1985)*, the salinity threshold of corn (100 % yield) for brackish irrigation water is 1.1 dS/m. The yields achieved on the monitored FUs support a low threshold; only one case of the monitored FUs demonstrates that a reasonable yield (1,100 kg/du) can be achieved in the Jordan Valley with irrigation water salinity of EC_{iw} = 3.8 dS/m.
A similar conclusion was drawn by *Abu-Awwad (1994)* from a field trial in the Jordan Valley. He found no significant yield reduction in sweet corn yield components with irrigation water salinity of EC_{iw} = 3.5 dS/m.

Soil Texture

The textural classes of the monitored farms are in the heavy to medium heavy range. With regard to the silt content, there is a slight tendency of decreasing yields with lower silt contents. This leads to the assessment that higher silt contents of the soil provide better growing conditions for sweet corn.

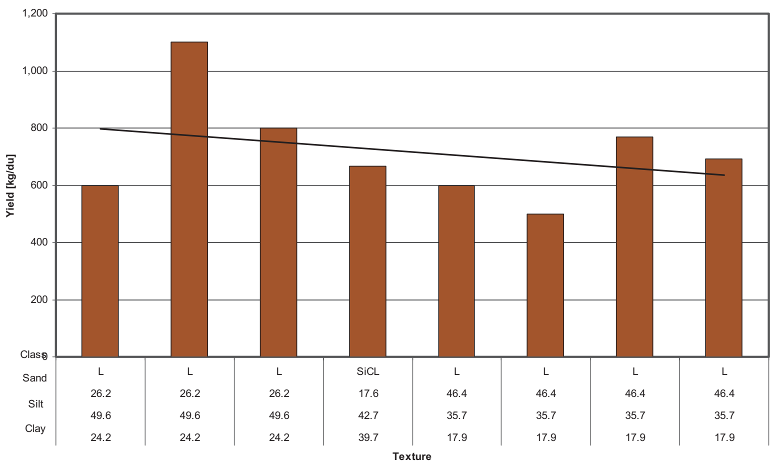


Fig. 77: Sweet corn yields and texture

Sweet corn prefers medium textured and well-drained soils

In California a variety of soil textures is used for sweet corn production. Sandy soils are suitable for early planting because they warm rapidly, whereas heavier soils are more productive, provided they are well-drained and irrigated carefully *(Smith et al, 1997)*. This corresponds to the above assessment for the Jordan Valley.

[14] The ranges cover the spectrum of the lowest, average and highest applied irrigation salinity during the growing period.

Irrigation Practices and Total Water Supply

All monitored FUs applied drip irrigation and two FUs used black plastic mulch, one from the previous crop.

The drip system is regarded appropriate for brackish water irrigation in the Jordan Valley because it keeps the root zone free of salts (bulb shape) and helps to save irrigation water.

Fig. 78 displays the yields obtained, the total water applied (TWA) and the field water requirements (FWR). The FU with the highest total water provided achieved only a medium yield (668 kg/du), probably because no fertilizer was applied. The second and third highest total water was applied on the same FU on different plots in different seasons. The farmer followed his usual irrigation schedule both in the summer and winter season. In the latter he benefited from 226 mm of rainfall and did not reduce the irrigation application accordingly. In both cases the yields are close to the average, but not as high as expected, probably due to relatively low fertilizer application rates.

Drip irrigation equipment, pre-irrigation and field water requirements between 210 and 430 mm are appropriate for irrigation with brackish water in the Jordan Valley

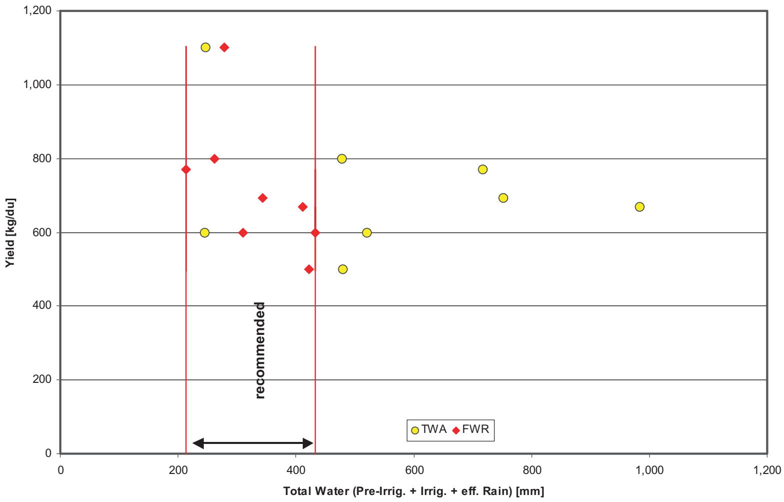


Fig. 78: Sweet corn yields, FWA and TWA

Surprisingly the highest yield was obtained with a low total of water. The main reason for the high yield is probably due to the relatively high rainfalls (120 mm) during December and January, with a considerable leaching effect before the crop was planted. This supports the recommendation for application of appropriate pre-irrigation for sweet corn cultivation under brackish water irrigation, which was not applied on all monitored FUs. The high rainfall also resulted in the storage of water in the loam soil, which was utilized by the crop after planting. Other reasons for the high yield are the suitable cultivation period (summer season), the selection of an appropriate variety and a sufficient N application rate.

Tab. 20 and Tab. 21 provide weekly crop water requirement values for sweet corn for general orientation.

Middle Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (20 days)	k_{c2} (30 days)	k_{c3} (30 days)	k_{c4}
January	5.9	8.8	11.7	10.7
February	7.6	11.5	15.3	14.0
March	13.0	19.4	25.9	23.8
April	14.9	22.3	29.8	27.3
May	19.2	28.8	38.4	35.2
June	22.3	33.5	44.7	40.9
July	22.2	33.2	44.3	40.6
August	19.5	29.2	39.0	35.7
September	16.8	25.1	33.5	30.7
October	12.3	18.4	24.5	22.5
November	10.2	15.4	20.5	18.8
December	5.5	8.2	10.9	10.0

Tab. 20: Weekly crop water requirement ET_c for sweet corn in the middle Jordan Valley (DA 21 - DA 26)

Southern Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (20 days)	k_{c2} (30 days)	k_{c3} (30 days)	k_{c4}
January	4.6	6.9	9.2	8.5
February	6.4	9.6	12.8	11.7
March	10.7	16.1	21.5	19.7
April	13.0	19.5	26.0	23.9
May	16.7	25.0	33.4	30.6
June	19.3	29.0	38.7	35.5
July	19.0	28.5	38.0	34.9
August	16.7	25.0	33.3	30.5
September	14.0	20.9	27.9	25.6
October	10.0	15.1	20.1	18.4
November	7.3	10.9	14.6	13.4
December	4.5	6.7	8.9	8.2

Tab. 21: Weekly crop water requirement ET_c for sweet corn in the southern Jordan Valley (DA 27 - DA 52)

The weekly ET_c values can be used to calculate the field water requirements (FWR) as explained in the chapter 'Water Requirements'. The effective rainfall should be deducted - if relevant - and the leaching fraction and a supplement for the technical losses in the on-farm irrigation system should be added. The leaching fraction for sweet corn on gypsiferous soils under drip irrigation is assessed as 0.16, for furrow irrigation as 0.6. The efficiency of most drip irrigation systems in the Jordan Valley is estimated to be 80 %.

Growing Season

In Fig. 79 the growing period[15] in relation to the different yields is displayed. The length of the growing period varies from 81 to 127 days. There is no significant relation between the length of the growing period and the yields.

The favorable growing season for sweet corn with regard to yields in the Jordan Valley is from March to end of May

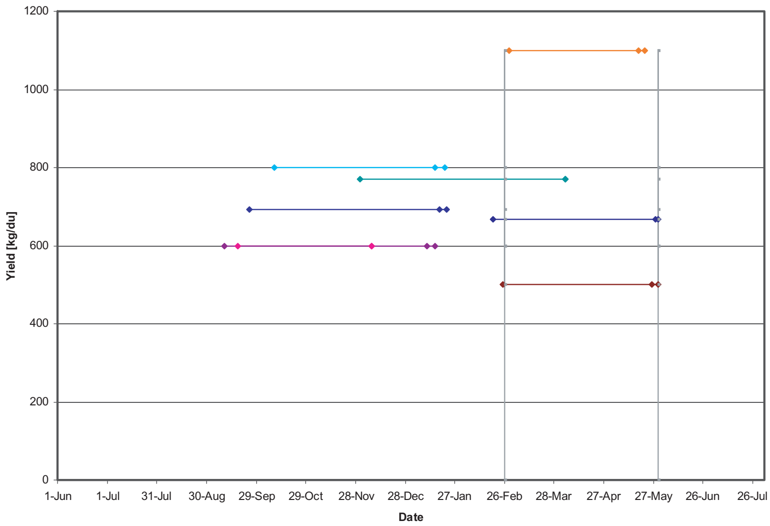


Fig. 79: Sweet corn yields and growing season

According to farmers' experience, the best time for sweet corn is the summer season, i.e. from about March to May. Expected yields are higher than in the winter season (September - January). Comparing the yields of the summer and winter season in Fig. 79, the advantage of the summer season is confirmed by the highest yield. On the other hand, the lowest yield was also achieved in the summer season, but mainly due to poor weeding despite decent irrigation. For the winter season the yields are close to or below the average yield. This implies a certain advantage of the summer season because it meets the climatic requirements of sweet corn (optimal germination temperature of 18° C and optimal growing temperatures from 16° to 24° C) slightly better than the winter season.

[15] The left dot of the line graph marks the sowing date, the middle dot the beginning of the harvest and the right dot the end of the harvest.

Planting Density and Spacing

The spacing between and in the rows on the monitored FUs differed widely. The following combinations were practiced: 40 x 30 cm, 50 x 25 cm, 150 x 40 cm, 160 x 10 cm, and 180 x 10 cm. These spacing practices resulted in a broad spectrum of plant densities ranging between 1,667 and 8,000 plants/du.

Sweet corn should be planted in rows 150 - 180 cm apart with an in-row spacing of 25 - 30 cm

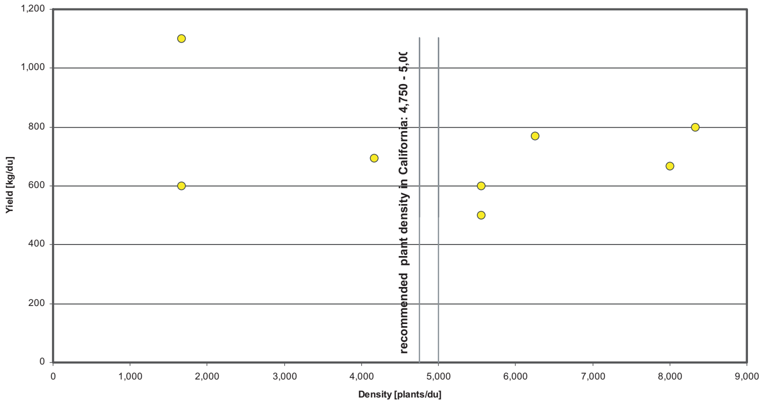


Fig. 80: Sweet corn yields and planting density

The general impression from Fig. 80 is that high planting densities do not necessarily result in higher yields on the monitored FUs. It is well-known that many factors have to be considered when choosing the appropriate spacing and thereby the plant density, e.g. the distance between the rows can influence the amount of sun energy used for photosynthetic processes by the plants. On the other hand, farmers do not always follow strict rules and sometimes improvise. For example, the two highest densities are results of two very low distances between the rows. In one case the farmer also had cucumbers on the same plot[16] and was using the same low distances between the mulch rows also for sweet corn. In the other case the farmer had sufficient irrigation pipes available and decided for narrow row spacing. The other high densities resulted from low in-row spacing (10 and 15 cm). This explains the high variation in densities and indicates that there is not always a clear rationale behind a certain practice, especially with regard to sweet corn, which is not perceived to be an important crop, as pointed out earlier.

Taking the above remarks into consideration, it appears that the full potential of optimal spacing and plant densities was not always utilized on the monitored FUs. It is recommended to take the internationally applied densities (4,750 - 5,000 plants/du as practiced in California) as orientation for local practices in order to identify the optimum practice for the Jordan Valley. The consequence would be reduced spacing between the rows, and the increased planting density would result in higher field water requirement.

Fertilization

Fertilizer management differed widely on the monitored FUs: on one FU no fertilizer at all was applied and on another FU the highest N application rate was 10.5 kg/du.

According to *IFA (1992),* 2,000 kg/du of sweet corn yield remove 20.8 kg/du of N. The recommendation for sweet corn in California *(Smith et al., 1997)*, is 10 - 22.4 kg/du total N (total P_2O_5: 4.5 - 5.6 kg/du, K_2O is normally regarded sufficient in the soil).

Compared with the Californian recommendation and the removal of N by sweet corn, the applications on the monitored FUs are low (Fig. 80); only two FUs are slightly above the lower Californian recommendation. This suggests that the usual N application on the monitored FUs is significantly below the optimum level.

[16] Cucumber in the open field is not a usual practice but was tried by the farmer with an appropriate variety.

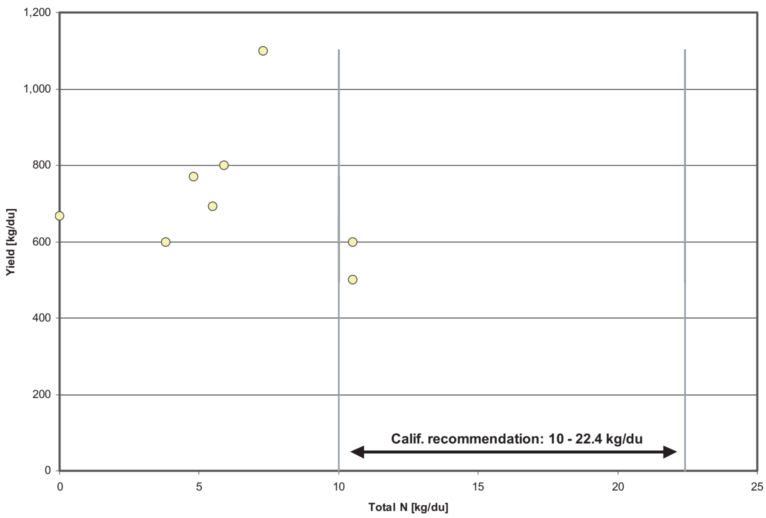


Fig. 81: Sweet corn yields and N application

Farmers using brackish water for irrigation should consider nitrogen (N) application rates above 10 kg/du

Taking into account that any decrease in the rate of N fertilizer applied will diminish yields in a linear manner *(IFA, 1992),* the fertilizer data from the monitored FUs imply that total N application rates should be at least about 10 kg/du in order to assure the minimum N requirements under salinity stress when irrigating with brackish water.

General Agricultural Practices

The **tillage** practice on the monitored FUs is one or two plowings and one harrowing. One farm deep plowed (50 cm) in the 2002/3 season. The idea of deep plowing is to bring salts and weed seeds into deeper soil layers. So far there is no relevant evidence that salts are moved to a deep layer, but if this were the case the salts were moved back to the surface layer with the next plowing.

One FU used black **plastic mulch** from the previous crop and one FU used new mulch. As mentioned above mulching is regarded a good practice in combination with drip irrigation because it helps to reduce capillary raise of water to, and salt accumulation at, the surface, and also suppresses weeds.

Manure should be applied at a rate of 1,500 kg/du before planting sweet corn

No FU applied **organic fertilizer** directly before planting sweet corn. This is regrettable because the application of organic matter improves the soil structure and the physical condition of the soil for cultivation, improves soil microbial activity, and increases the level of nutrients as well as the nutrient and water holding capacity of the soil *(GTZ, 2000 and 2001 a)*. With regard to these benefits it is recommended to apply manure before planting at a similar rate to that which is applied to other crops, i.e. 1,500 kg/du.

Weeding is - if at all - done manually. No special effects of particular practices with regard to salinity were observed, but the poor weeding practices certainly had a considerable influence on the generally low yield level.

With regard to **disease and pest management**, 'Confidor' was the main insecticide applied against aphides and caterpillars. However, the general perception is that the aspect of plant health in sweet corn production needs more intensive care and could contribute substantially to higher yields.

Wheat

(Triticum durum Desf.*)*

WHEAT IS the most important cereal crop worldwide. It is mainly grown in temperate climates but also in semi-arid areas during the cool season. In semi-arid areas, e.g. in the Mediterranean Region, durum wheat *(Triticum durum)* is more important than ordinary wheat *(Triticum aestivum)*. The yield of durum wheat is about 10 % lower, but the grains are richer in gluten, glassier and harder. Durum wheat prefers fertile soil with sufficient humidity up to the grain filling stage, with mild winters and warm summers *(IFA, 1992)*.

Fig. 82: Wheat at heading stage and after harvest

In Jordan the bulk of wheat is produced as rain-fed crop in the highlands. The government guarantees fixed prices for wheat and thereby provides a certain incentive for its cultivation. In total, less than 7 % of the wheat in Jordan is produced in the Jordan Valley. However, the production potential of cereals in the Jordan Valley is good, due to climatic factors. Wheat is known from international literature as medium salt-tolerant, making it suitable for cultivation around local brackish water resources in the Jordan Valley.

In the Jordan Valley wheat is predominantly cultivated during the relatively cool and rainy winter months because farmers want to make use of the rain. In the northern part of the Jordan Valley wheat is mainly grown along the Jordan River, and in the southern part predominantly in DA 51 and 52. The main reason is that in these areas FUs often exceed the common size of 30 du, and larger fields are more suitable for combine harvesters.

Yields

Yields of wheat on the monitored FUs during the years 2001 - 2003 ranged between 180 - 330 kg/du as shown in Fig. 83.

Wheat is an appropriate cereal under brackish water irrigation in the Jordan Valley

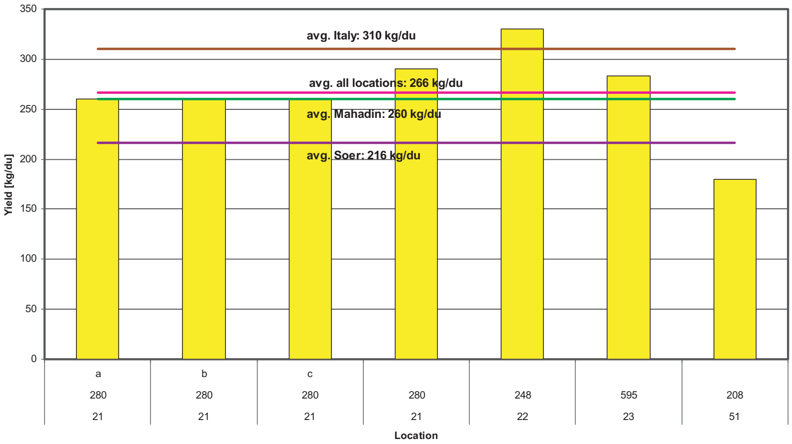


Fig. 83: Wheat yields

The average yield of 266 kg/du on the monitored FUs under brackish water irrigation is slightly higher than averages reported by *Mahadin (1999)* with 260 kg/du, and by *Soer (1998)* with 216 kg/du, which were mainly obtained under freshwater irrigation.

The average yield reported from Italy, one of the main durum wheat producers, was 310 kg/du between 1995 and 1997. Other average yields from the Near East are 230 kg/du in Syria and 560 kg/du in Egypt, and the Jordanian national average is reported in the same overview with 190 kg/du *(CIMMYT, 1999)*.

Against the background of these national and international yields, the production of wheat under brackish water irrigation in the Jordan Valley appears very appropriate.

Varieties

The varieties grown on the monitored FUs were 'Deir Alla 6', 'Hittiya', 'Mexican' and 'Sham 1'.

All monitored varieties show reasonable yields under brackish water irrigation

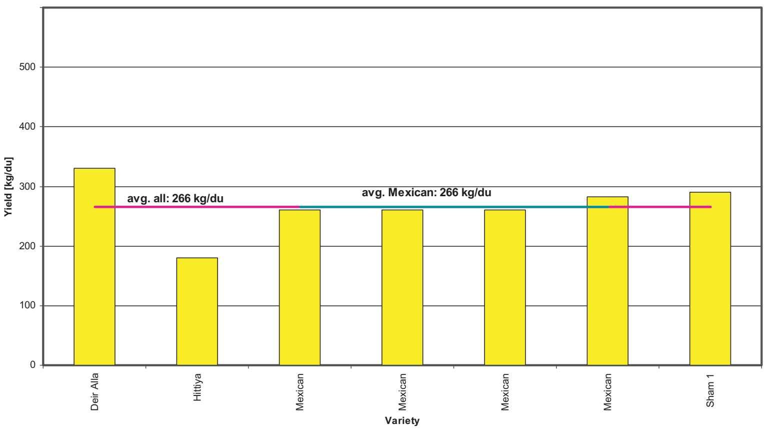


Fig. 84: Yields of wheat varieties

The dominant variety is 'Mexican', but it has to be mentioned that it was cultivated on three plots on the same FU. The variety 'Deir Allah 6' was grown on one plot with a slightly higher yield than the average of all plots.

According to the Ministry of Agriculture (MoA), three different varieties called 'Deir Alla' were available, but meanwhile only 'Deir Alla 6' is certified. All three of them were rated highly productive, but 'Deir Alla 2' and 'Deir Alla 4' are not any longer certified because of the bad quality of the hay which is not favorable for animals. Another certified variety in Jordan is 'Jubeiha'. This variety achieved yields around 650 kg/du in irrigated trials in the highlands (personal communication with Eng. Seetan Rabadi, Cereal Production Department, MoA).

A recommendation for a particular variety is difficult because of the small sample. However, the general assessment is that all varieties cultivated under brackish water irrigation on the monitored FUs performed well.

Irrigation Water Salinity

The yield results and the corresponding ranges of the irrigation water salinities are displayed in Fig. 85. Cluster A contains the highest yield and was obtained with an EC_{iw} range around 3.9 dS/m. Cluster B covers the medium yields that were achieved with salinities between EC_{iw} = 3.8 - 6.5 dS/m.[17] All plots in this cluster were irrigated with Jordan River water. Cluster C represents the lowest yield and was obtained with the salinity range around 5.4 dS/m.

With appropriate cultivation and irrigation practices wheat in the Jordan Valley can be grown up to an irrigation water salinity of EC_{iw} = 5.4 dS/m with yields around 266 kg/du and more

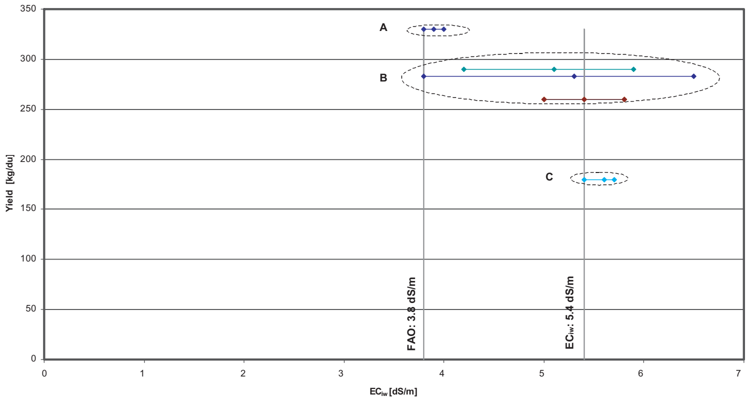


Fig. 85: Wheat yields and irrigation water salinity

The difference between cluster A and B is obvious: the higher yield is due to a considerably lower than average salinity of the irrigation water (EC_{iw} = 3.9 dS/m) as compared to 5.3 dS/m in cluster B. Also the maximum EC_{iw} was much higher in cluster B.

The FU in cluster C was irrigated with water of slightly higher average EC_{iw} than cluster B, but a significantly lower yield was obtained. The main reason for this is the low total amount of water applied on this FU (see chapter 'Irrigation Practices and Total Water Supply').

According to *FAO (1985)*, the salinity threshold of wheat (100 % yield) for brackish irrigation water is EC_{iw} = 3.8 dS/m. The comparison of the international threshold with the irrigation water salinities on the monitored FUs indicates that reasonable yields around the average of all monitored FUs (266 kg/du) can be achieved in the Jordan Valley even with a salinity up to EC_{iw} = 5.4 dS/m.

However, the trend line in Fig. 86 reflecting the relation between the yields and the average irrigation water salinities implies a trend of decreasing yields with increasing EC_{iw} values. Thus, lower irrigation water salinity definitely provides the chance for yields even above the average value of 266 kg/du.

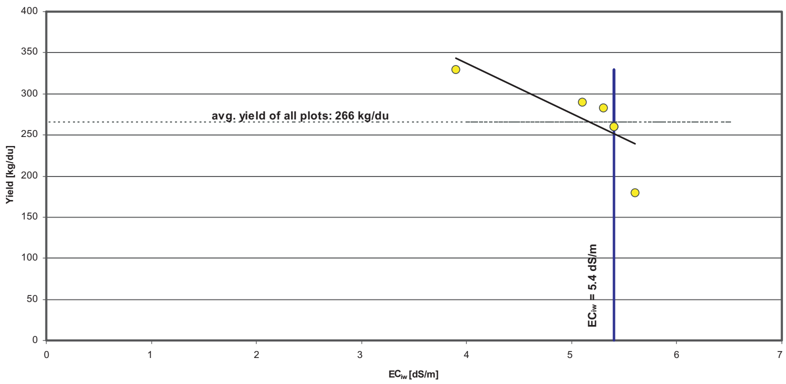


Fig. 86: Wheat yields and average irrigation water salinity

The general conclusion is that in the Jordan Valley wheat yields of about 266 kg/du and more can be expected when irrigating with brackish water with a salinity up to EC_{iw} = 5.4 dS/m, provided good agricultural and irrigation management is practiced.

[17] The ranges cover the spectrum of the lowest, average and highest applied irrigation salinity during the growing period.

Soil Texture

The textural classes of the monitored farms are in the medium range. Interestingly the textures of 4 out of 7 plots belong to the same textural class of sandy loam (see Fig. 87).

Wheat prefers medium textured and well drained soils

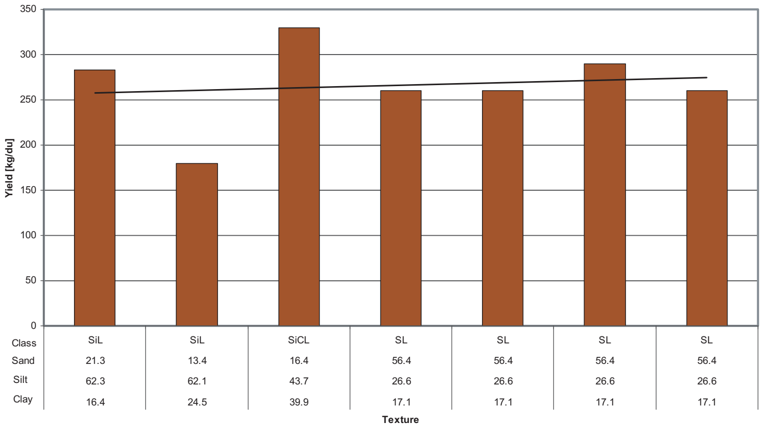


Fig. 87: Wheat yields and texture

According to international recommendations, wheat is best cultivated on medium to relatively heavy soils with good drainage properties *(Euroconsult 1989)*. This is in line with the general practice in the Jordan Valley and on the monitored FUs.

Irrigation Practices and Total Water Supply

All monitored FUs practiced flood irrigation resulting in relatively low irrigation application efficiency.

Fig. 88 displays the yields achieved and the quantities of total water applied[18] to the crop and the calculated field water requirement (FWR).

FWR between 340 -690 mm help to compensate for adverse effects of brackish irrigation water on wheat yields

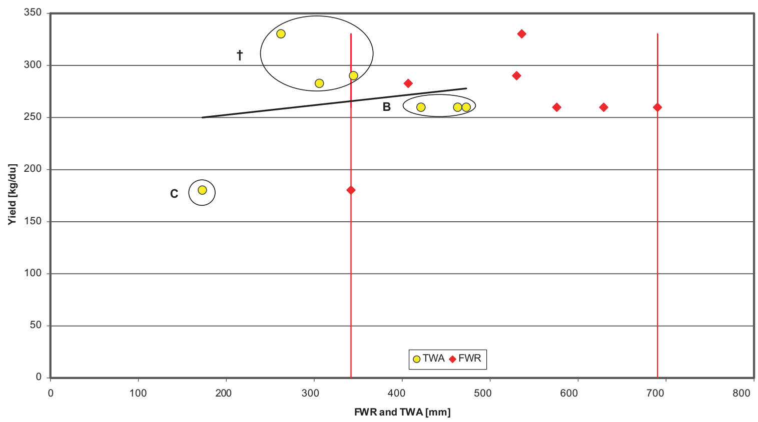


Fig. 88: Wheat yields, TWA and FWR

The trend line indicates that yields increase with higher water amounts applied. With regard to cluster A, it is amazing that the high yields were obtained with a relatively low water quantity.

For the highest yield in cluster A there are three explanations: in the first month after planting, i.e. during the germination, emergence and early tillering stage, the FU received 98 mm of effective rainfall, which had probably a good leaching impact and gave the plants excellent conditions for vegetative development. A good soil moisture level at the beginning of the vegetative development is important for sufficient forming of tillers. Furthermore the farmer sowed a variety ('Deir Allah 6') that is well adapted to the ecological conditions of Jordan. The farmer also applied the highest amount of seeds (18 kg/du) as compared to the other monitored FUs.

The second highest yield in cluster A was produced on the same FU as cluster B, but one year earlier (season 2000/1). Although the yield with less water in the first year was higher, the farmer waited too long for rain during the germination period as well as during the stem elongation and ear forming

[18] Total water applied: pre-irrigation, irrigation and effective rainfall (80 % of measured rainfall).

period. Sufficient water during these stages, or in other words supplemental irrigation, could have contributed to a higher yield. One reason for the relatively good result is probably the fact that the variety is certified in Jordan ('Sham') assuring a good adaptability to the environmental conditions.

On the same FU the yield in the 2001/2 season was lower although the crop received a higher total of water. But in this season the farmer's water application strategy was different: during the 2000/1 season the irrigation frequency was higher, whereas in the 2001/2 season the farmer irrigated only once per month with high application rates. This probably resulted in the lower yield and underlines the importance of a regular and equal water supply especially during the shooting stage.

The low yield of cluster C is clearly a result of the poor water application rate, and the farmer deliberately applied a low input production system for cereals.

Tab. 22 and Tab. 23 provide general orientation of crop water requirement values for wheat in the Jordan Valley.

Middle Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (20 days)	k_{c2} (25 days)	k_{c3} (50 days)	k_{c4}
January	5.9	8.1	11.7	2.0
February	7.6	10.6	15.3	2.5
March	13.0	17.9	25.9	4.3
April	14.9	20.6	29.8	5.0
May	19.2	26.5	38.4	6.4
June	22.3	30.9	44.7	7.4
July	22.2	30.6	44.3	7.4
August	19.5	27.0	39.0	6.5
September	16.8	23.2	33.5	5.6
October	12.3	17.0	24.5	4.1
November	10.2	14.2	20.5	3.4
December	5.5	7.6	10.9	1.8

Tab. 22: Weekly crop water requirement ET_c for wheat and barley in the middle Jordan Valley (DA 21 - DA 26)

Southern Jordan Valley	Weekly crop water requirement [mm]			
	k_{c1} (20 days)	k_{c2} (25 days)	k_{c3} (50 days)	k_{c4}
January	4.6	6.4	9.2	1.5
February	6.4	8.8	12.8	2.1
March	10.7	14.8	21.5	3.6
April	13.0	18.0	26.0	4.3
May	16.7	23.1	33.4	5.6
June	19.3	26.8	38.7	6.4
July	19.0	26.3	38.0	6.3
August	16.7	23.0	33.3	5.6
September	14.0	19.3	27.9	4.7
October	10.0	13.9	20.1	3.3
November	7.3	10.1	14.6	2.4
December	4.5	6.2	8.9	1.5

Tab. 23: Weekly crop water requirement ET_c for wheat and barley in the southern Jordan Valley (DA 27 - DA 52)

The weekly ET_c values can be used to calculate the field water requirements (FWR) as explained in the chapter on 'Water Requirements'. The effective rainfall should be deducted - if relevant - and the leaching fraction and a supplement for the technical losses in the on-farm irrigation system should be added. The leaching fraction for wheat on gypsiferous soils under basin and furrow irrigation is assessed as 0.16, for drip irrigation as 0.10. The efficiency of basin or flooding irrigation in the Jordan Valley is estimated to be 60 %.

When calcualting the FWR according to the procedure described above and with the actual climatic data, a range between 340 and 690 mm is obtained (see red series in Fig. 88). This also applies to barley. Comparing the TWA and the FWR shows that some farmers tend to under-irrigate the wheat.

Pre-irrigation was not practiced on any of the monitored FUs. This is probably a consequence of the farmers' attitude to utilize the rainfall as much as possible. However, in the literature there are indications that, in dry areas, sufficient soil moisture at the sowing time is important. This can be achieved by pre-irrigation rates of up to 150 mm before sowing in order to ensure good root growth and early emergence *(Achtnich, 1980)*.

The general conclusion is that wheat farmers in the Jordan Valley should adjust their irrigation management to the pattern and depth of the rainfall, because irrigation is regarded as supplemental. Since wheat is known to be sensitive to water deficiency during tillering and heading stages, sufficient water has to be provided during these stages.

Growing Season

In the Jordan Valley wheat is preferably cultivated during the rainy season. In Fig. 89 the growing season[19] in relation to the different yields is displayed. The length of growing period varies from 94 to 188 days. There is no significant relation between the length of the growing period and the yields.

The favorable growing period for wheat is from December to June, depending on the rainfall

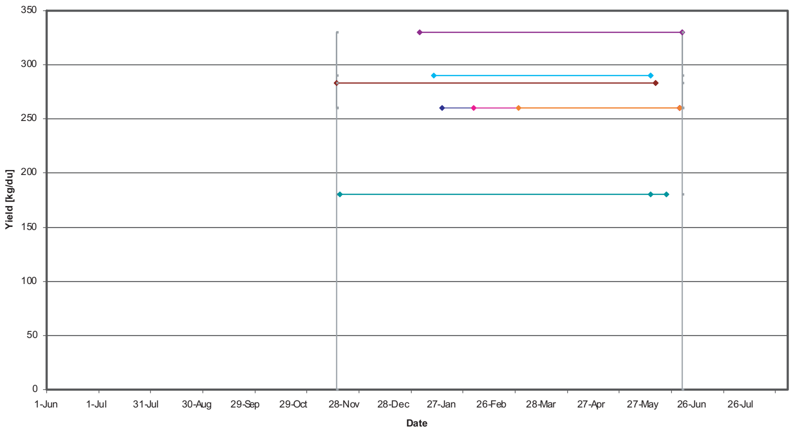


Fig. 89: Wheat yields and growing period

In some cases the crop remained on the field for an extremely long time after the optimum maturity stage was reached. This can cause losses due to fall-out of the kernels and bird damage.

One FU shown in Fig. 89 achieved an average yield of 260 kg/du cultivating three plots, with sowing on three different dates and harvesting on the same date. This resulted in growing periods of 93, 119, and 137 days. The rationale behind this practice is a risk minimizing strategy with regard to the rainfall pattern. Unfortunately the plots were harvested at the same time and the yields for technical/labor-saving reasons could not be separated. It would have been interesting to find out if length of the cultivation period and the duration between maturity and harvest had an influence on the yield.

The general conclusion is that the appropriate growing season for wheat in the Jordan Valley stretches from December to June because of mild temperatures in the early stages of plant development combined with good chances for rains, and because of the warm temperatures after April, which is good for the ripening stage and the harvesting.

Planting Density and Seed Rate

The common sowing technique for wheat is broadcasting. Fig. 90 depicts the quantities of seeds sown per dunum, ranging from 13.5 to 18 kg/du. The highest yield was achieved with the highest amount of seeds. The fact that also the lowest yield was achieved with a relatively high seed rate was mainly due to the low water quantity applied and the general low input management on this FU.

[19] The left dot of the line graph marks the sowing date, the middle dot the beginning of the harvest and the right dot the end of the harvest.

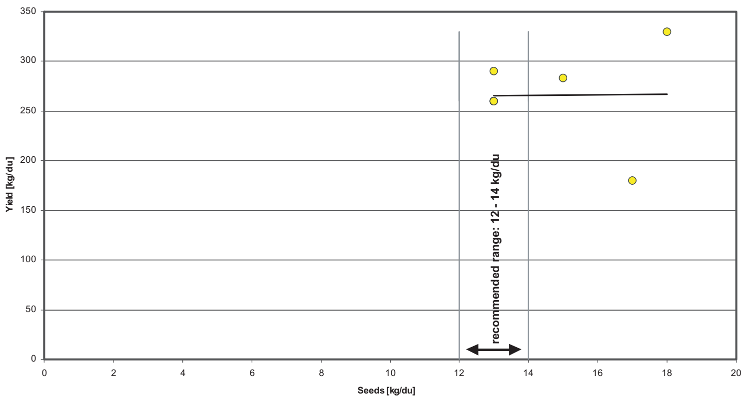


Fig. 90: Wheat yields and planting density

Wheat should be sown at a seed rate of at least 12 - 14 kg/du

The general impression from Fig. 90 is that the seed rates applied on the monitored FU are higher than the international rates. Since the yields on the monitored FUs are on a relatively good national and local level it is assumed that seed rates of about 12 - 14 kg/du are necessary to compensate to a certain extent for adverse effects of brackish irrigation water.

Fertilization

In Fig. 91 the yields obtained and the nitrogen (N) application rates are displayed. The extreme cases need detailed discussion: The highest application rate of 20 kg/du is based on the application of 1,000 kg/du of sheep manure, assuming 2 % of N in the manure. The fact that the yield is still low is - besides the relatively high EC_{iw} - mainly due to the slow availability of the N in manure compared to mineral fertilizer and the low water application contributing to the slow decomposition of the manure.

The two FUs with no fertilizer application followed a deliberate low-input strategy, except for the seed rates, which were standard and contributed to the good yields. With regard to the highest yield it is worthwhile to mention that the water source of this FU is a spring that presumably has influx from neighboring drains and contains 25.9 ppm of NO_3-N. So the wheat received possibly about 2.4 kg/du of N with the irrigation water.

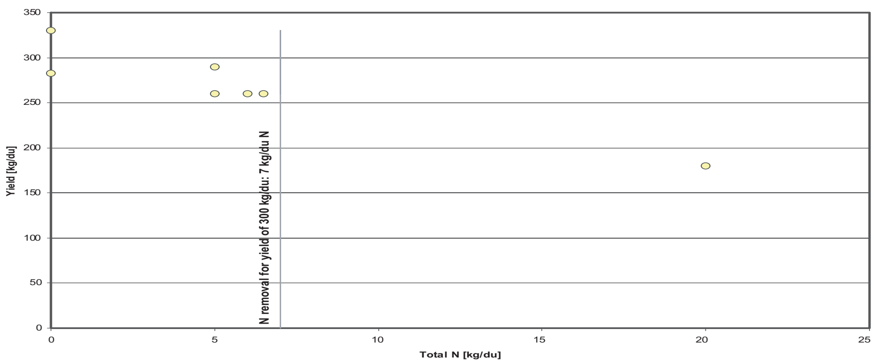


Fig. 91: Wheat yields and N application

Farmers using brackish water for irrigation should consider nitrogen (N) application rates above 7 kg/du

With regard to the other FUs applying between 5 to 7 kg/du, their N application rates came close to the amount that is removed by a yield of 300 kg/du of wheat (Euroconsult, 1989) and resulted in satisfying yields. This indicates that around 7 kg/du of N should be applied for wheat irrigated with brackish water in the Jordan Valley.

General Agricultural Practices

The usual **tillage** practice on the monitored FUs is one plowing (20 - 30 cm) and one harrowing. Occasionally there are two plowings.

Only one FU applied sheep manure as **organic fertilizer** (see also chapter 'Fertilization').

Weeding was practiced on all monitored FUs, one FU with the smallest plot weeded manually, the others applied herbicides. No special effects of particular practices with regard to salinity were observed.

With regard to **disease and pest management** only one FU sprayed a pesticide. Smut *(Ustilago ssp.)* and rust *(Puccinia ssp.)* are widespread, but significant infestation was not observed on the monitored FUs.

Barley

(Hordeum vulgare L.*)*

BARLEY IS the most salt tolerant cereal is sometimes used for reclamation of saline soils (*UC SAREP Online*, without year). However, its importance is marginal in the Jordan Valley due to low prices, and because it is mainly used as fodder.

Fig. 92: Barley in DA 52

Between 2000 and 2003 barley was grown only on three monitored FUs. Available data are restricted to two FUs because other monitored FUs were flooded by the Jordan River in March 2003 and the crops, completely destroyed.

The data from the monitored plots are compiled in Tab. 24.

Barley

	monitored FUs		References
Yield [kg/du]	range: average:	130 - 179 155	157 (*Mahadin 1999*), 430 (Germany)
EC_{iw} [dS/m]	range: averages:	4.9 - 5.8 5.4	5.3 *(FAO, 1985)*
Soil texture	L, SL		
Total water [mm]	277 - 365		438 *(IAS, 2000)*
Growing period	January - June		
Seed rate [kg/du]	7 - 15		
N [kg/du]	0 - 7		6 (India)

Tab. 24: Barley production data as compared to international data

With appropriate agricultural and irrigation practices the cultivation of barley is possible up to EC_{iw} = 7 dS/m with yields of 155 kg/du and more

The average yield on the monitored FUs was 155 kg/du; *Mahadin (1999)* reports 157 kg/du, mainly under freshwater irrigation. International yields are higher, like 430 kg/du in Germany.

According to *FAO (1985),* the threshold value for irrigation water (100 % yield) is 5.3 dS/m. The highest average EC_{iw} on the monitored FUs was 5.4 dS/m, which underlines the salt tolerance of barley. Considering that the irrigation water threshold value for wheat was assessed about 2 dS/m higher than the international threshold leads to the assumption that the threshold for barley is also higher than the international value. Accordingly the assessment for the Jordan Valley is that barley can be irrigated with brackish water of up to EC_{iw} = 7 dS/m, provided similar agricultural and irrigation practices and inputs are applied as for wheat.

With regard to soils, barley is less demanding than wheat and can be grown on most soils of the Jordan Valley.

The crop water requirements of barley are similar to those of wheat *(FAO, 1985 b)*. For the cultivation with brackish water, the total seasonal field water requirement reaches up to 690 mm (see chapters 'Water Requirement' and 'Wheat'). Since pre-irrigation is recommended for wheat in dry areas, it is surely also a recommendable practice for barley in the Jordan Valley.

The preferable cultivation period is from January to June in order to make best use of the natural rainfall. The appropriate seed rate is in the range from 12 - 14 kg/du.

The application of total N for barley should be around 7 kg/du as for wheat.

Leaf Crops

Parsley *(Petroselinum sativum)*, Rocket *(Eruca sativa)*, Malva *(Malva parviflora)*, Chicory *(Chicorium intybus)*, Coriander *(Coriandrum sativum)*, White Beet *(Beta cicla)*, Cress *(Lepidium sativum)*, Dill *(Anethum graveolens)*

THE TERM LEAF CROPS refers to a variety of different plants which are especially cultivated for their leaves. The leaves are either prepared as salads, used as herbs, or they are cooked. The main production area for such leaf crops in the Jordan Valley is around the village of Karamah.

Fig. 93: Leaf crops cultivated in basins around Karamah

The farmers of Karamah have a long tradition and good experience in cultivating leaf crops with brackish water. They have found a remarkably economical niche and have therefore acquired a relatively reliable source of income. Several of these plants, like rocket (jarjir) and malva (khubese) are also growing wild in the Jordan Valley and are collected by housewives for cooking.

The economic value of these leaf crops should not be underestimated because they are popular and especially appreciated during Ramadan, when the prices are attractive for the farmers.

Tab. 25 provides an overview of the species that are growing well under brackish water irrigation and lists their dominant use.

Common name	Local name	Botanical name	Main use
White beet	siliq	Beta cicla	cooking
Chicory	hindbeh	Chicorium intybus	cooking
Coriander	cuzbara	Coriandrum sativum	cooking, herb, spice
Cress	rashad	Lepidium sativum	salad
Dill	shabat	Anethum graveolens	herb
Malva	khubese	Malva parviflora	cooking
Parsley	bagdunis	Petroselinum sativum	salad, herb
Rocket	jarjir	Eruca sativa	salad

Tab. 25: Salt tolerant leaf crops cultivated in the Jordan Valley, and their use

The leaf crops described above are a very special segment within the irrigated agriculture, not only in the Jordan Valley but also internationally. As literature does not provide values for comparison of salinity tolerance and yields, the following description is limited to the Jordan Valley.

The following charts and tables compile the observations made on monitored FUs around Karamah village. As an orientation, the observed production factors for all of the leaf crops given in Tab. 25 are mentioned. When more than one plot was monitored (rocket and parsley) ranges of the factors are given.

Yields

The leaf crops cultivated around Karamah village belong to various botanical families and species with different properties and ecological requirements. Cultivation periods, seed rates, harvest periods, number of cuts, and the biomass (the whole above-ground part of the plant) produced vary considerably and give rise to different water requirements and other farm practices. Therefore the monitoring of production details was restricted and focused on the two most economically important species, parsley and rocket.

The yields of the different leaf crops are displayed in Fig. 94. The chart shows clearly the wide differences in biomass production of the various species and thereby gives an indication of the different requirements of the leaf crops with regard to soil, climate and water. The highest biomass (about 18,000 kg/du) was produced by the leaves of white beet, the lowest (about 2,600 kg/du) by cress.

Leaf crops are well adapted to irrigation with brackish water in the Jordan Valley and provide a good source of income for the farmers who specialized in their cultivation

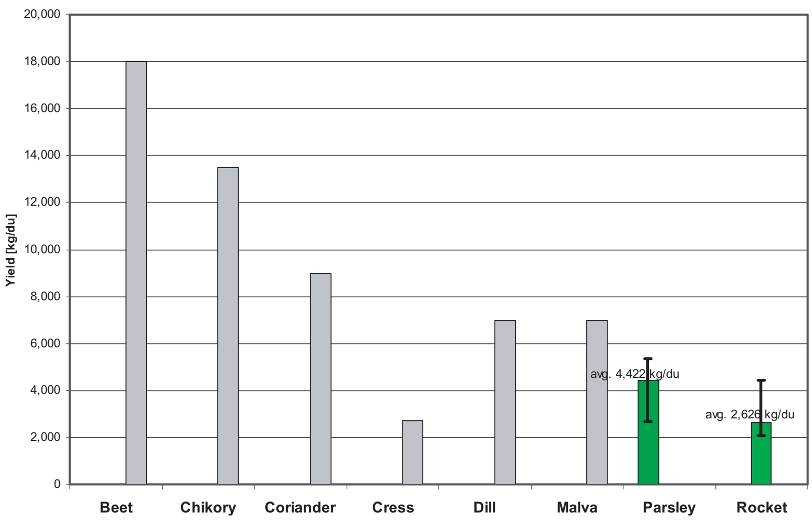


Fig. 94: Leaf crop yields

With regard to parsley and rocket, grown on 3 and 4 plots respectively, the maximum and minimum deviations are given in addition to the average yields of the 2001/2 and 2002/3 seasons. For the other 6 species the yields of single plots from the 2001/2 season are shown.

Varieties

Normally, local varieties are used and the seeds are produced by the farmers themselves, except for parsley. Farmers say that it is too hot for parsley seed production and that the second generation is of low quality with fewer cuts and yields. Therefore some farmers buy a special parsley variety ('Cham') from Damascus, which performs well under the given conditions and meets customers' demands best.

Irrigation Water Salinity

Most of the farmers cultivating leaf crop around Karamah village are members of the Karamah well association and irrigate their crops with water of that particular well. During the past three years the salinity of this well water ranged between EC_{iw} = 6.8 - 7.2 dS/m.

One monitored FU has irrigated its leaf crops with pure brackish water for about 5 years, whereas the other monitored FUs blended water from the well with KAC water resulting in an average value of EC_{iw} = 6.7 dS/m, which is only slightly lower than the EC_{iw} of the well.

According to the farmers, they have observed that brackish water irrigation delays the harvest of the leaf crops. As a rule of thumb this results in three cuts per crop during a given period under brackish water irrigation as compared to five cuts under freshwater irrigation. Accordingly the total yield with brackish irrigation water is lower than under fresh water irrigation.

Leaf crops in the Jordan Valley tolerate irrigation water salinity of up to 7.2 dS/m

When irrigating leaf crops with brackish water the number of cuts per season is reduced as compared to freshwater irrigation

Soil Texture

All plots with monitored leaf crops have loamy soils. With regard to the good results achieved, the general assessment is that these loamy soils are suitable for leaf crop cultivation with brackish water irrigation.

Irrigation Practices and Total Water Supply

The prevailing irrigation method for leaf crops is basin irrigation. This appears appropriate because it allows the cultivation of relatively small plots (8 m^2 as common size) successively and thus enables the farmers to split the harvest period according to market demands. One farmer tried drip irrigation for parsley and rocket, but so far no advantage can be concluded from this practice. Surprisingly this FU also had a remarkably high water application rate.

Basin irrigation is an appropriate irrigation method for leaf crops. FWR in the range of 620 - 780 mm for parsley and 140 - 470 mm for rocket help to compensate for adverse effects of brackish irrigation water

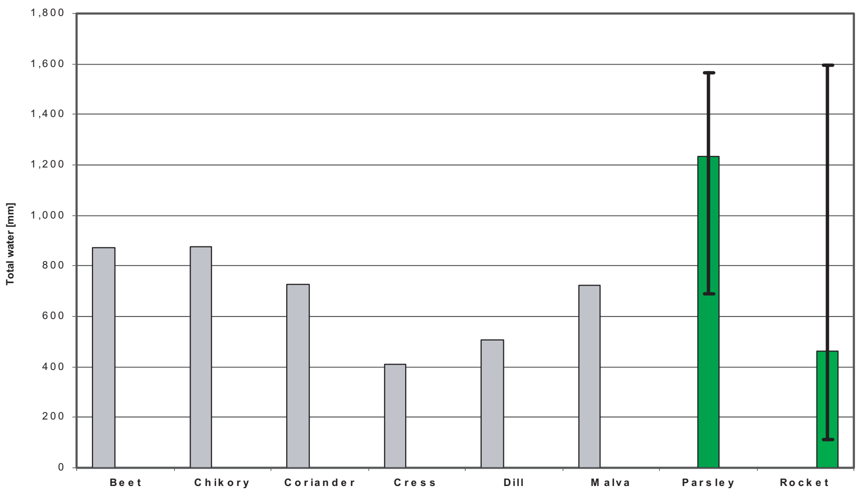


Fig. 95: Leaf crops and TWA

The total amount of water applied (TWA) to the leaf crops, which is sometimes extremely high, is shown in Fig. 95. It is clear that in cases of high biomass production and irrigation with water of high salinity (EC_{iw} = 6.1 - 7.2 dS/m) over a long cultivation period, high water application rates are appropriate. However it is felt that in some cases the application rates exceeded the crop water requirements by far.

A rough orientation can be obtained from Tab. 27 displaying the weekly crop water requirement values (ET_c) for spinach[20] based on climatic data from the Karamah Agricultural Station, located

[20] Since no particular leaf crop coefficients are available in the literature, the values for spinach were taken.

close by. The effective rainfall should be deducted - if relevant - and the leaching fraction and a supplement for technical losses in the on-farm irrigation system should be added. The leaching fraction for spinach on gypsiferous soils under basin irrigation with water of 7 dS/m is assessed at 0.54. The efficiency of basin irrigation is estimated at 60 % (see chapter 'Water Requirement').

The values for parsley range between 620 and 780 mm. For rocket the FWR ranges between 140 and 470 mm, depending on the months when the crop is cultivated and on the duration of the harvest period.

Comparing the values for the FWR with reality discloses astonishing practices on some of the monitored FUs. For example rocket has a relatively low biomass production as compared to other leaf crops and a short cultivation season, but the water application rate ranged from 138 - 1,595 mm. The highest irrigation application rates occurred in the 2002/3 season, but also the amounts applied in the previous season were far higher than needed. In general the LF applied on these FUs were extremely high, resulting in deep percolation of water and nutrients.

One explanation for this practice is probably the rotational and on-demand distribution mode for the irrigation water: the discharge of the well is about 150 m^3/h. This amount in combination with the flooding of the basins makes it difficult to manage the application rate precisely. Another reason for the high application rates is that a significant decrease of the water price per hour in the Karamah well association in the 2002 season caused the high water application. (In previous years such outstanding application rates were not observed.)

Middle Jordan Valley	**Weekly crop water requirement [mm]**			
	k_{c1} (20 days)	**k_{c2} (20 days)**	**k_{c3} (20 days)**	**k_{c4}**
January	5.9	8.1	10.2	9.8
February	7.6	10.6	13.4	12.7
March	13.0	17.9	22.7	21.6
April	14.9	20.6	26.1	24.8
May	19.2	26.5	33.6	32.0
June	22.3	30.9	39.1	37.2
July	22.2	30.6	38.8	36.9
August	19.5	27.0	34.1	32.5
September	16.8	23.2	29.3	27.9
October	12.3	17.0	21.5	20.4
November	10.2	14.2	17.9	17.1
December	5.5	7.6	9.6	9.1

Tab. 26: Weekly crop water requirement ET_c for leaf crops in the middle Jordan Valley (DA 21 - DA 26)

Southern Jordan Valley	**Weekly crop water requirement [mm]**			
	k_{c1} (20 days)	**k_{c2} (20 days)**	**k_{c3} (20 days)**	**k_{c4}**
January	**4.6**	**6.4**	**8.1**	**7.7**
February	6.4	8.8	11.2	10.6
March	10.7	14.8	18.8	17.9
April	13.0	18.0	22.8	21.7
May	16.7	23.1	29.2	27.8
June	19.3	26.8	33.8	32.2
July	19.0	26.3	33.3	31.7
August	16.7	23.0	29.2	27.8
September	14.0	19.3	24.4	23.3
October	10.0	13.9	17.6	16.7
November	7.3	10.1	12.8	12.2
December	4.5	6.2	7.8	7.4

Tab. 27: Weekly crop water requirement ET_c for leaf crops in the southern Jordan Valley (DA 27 - DA 52)

Pre-irrigation is a common practice for all leaf crops monitored (see Fig. 96). Only when rocket was cultivated directly after rocket on the same plot no pre-irrigation was applied and the first irrigation took place right after sowing.

Pre-irrigation is a recommendable practice for leaf crops irrigated with brackish water in the Jordan Valley

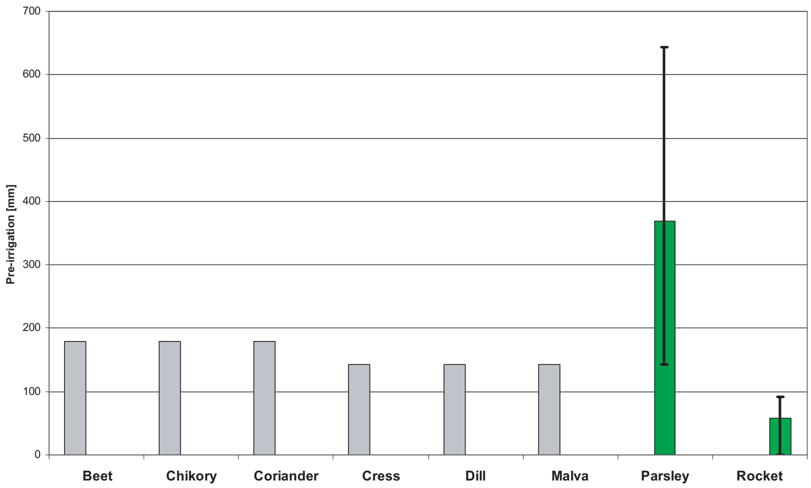


Fig. 96: Pre-irrigation rates of leaf crops

A general depth for pre-irrigation of 100 - 150 mm is recommended in the literature *(Euroconsult. 1989)*. This implies that most of the farmers could reduce the application rate of the pre-irrigation.

Growing Season

In Fig. 97 the growing seasons of the different leaf crops are shown[21]. Normally the season starts at the beginning of October. This is a reasonable practice, because the main growing stages of the plants will fall into cooler periods and may benefit from rainfalls. There was an exception to this planting date: one farmer planted his rocket in August, but the yield was lower as compared to the farmers planting later.

The favorable growing season for leaf crops in the Jordan Valley is from October to end of February

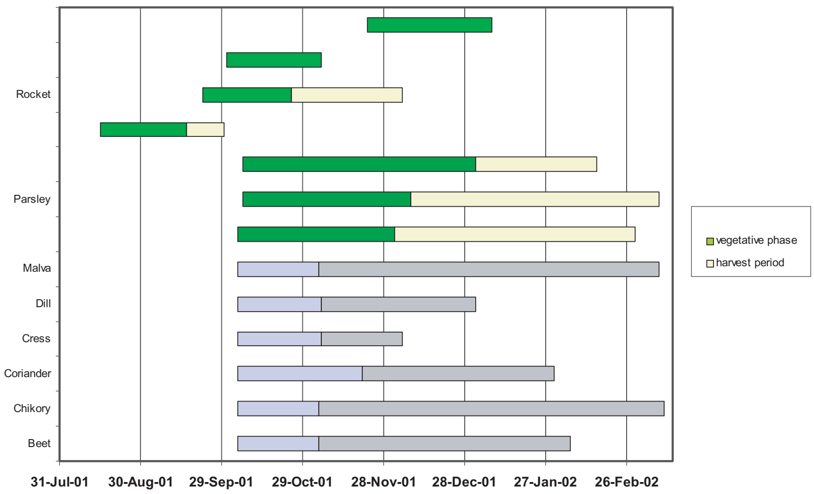


Fig. 97: Leaf crops and growing periods

Rocket and cress have the shortest period. Rocket is normally harvested only once for quality reasons. Because of the short cultivation period it is occasionally also cultivated twice in a season on the same plot, depending on the market situation.

For most leaf crops the harvest period is longer than the vegetative period as can be seen in Fig. 97. This explains the high biomass production of some of the crops. Harvesting normally stops when it becomes hot. Most of the crops, except parsley, are left on the field in order to harvest the seeds for the following season.

[21] The left part of the bar marks the period from sowing to harvest, the right part the harvest period.

Tab. 28 summarizes the duration of the cultivation period, the number of usual cuts and the days between the cuts according to farmers' experiences.

Common name	Local name	Cultivation period (days)	No. of cuts	Days between cuts
Parsley	bagdunis	130 - 154	3	45
Rocket	jarjir	35 - 75	1 - 2	17
Malva	chubese	170 - 190	7 - 8	20
Chicory	hindbeh	170 - 190	7 - 8	20
Coriander	cuzbara	120	5 - 6	15
White beet	siliq	120	4	20
Cress	shabat	60 - 120	1 - 3	30
Dill	rashad	90	4	20

Tab. 28: Leaf crops and the number of possible cuts

The table explains that leaf crops - when harvested with several cuts over a long period - have high demands with regard to water and nutrient supply.

Seed Rates

Leaf crops are normally broadcast in basins of 8 m^2 and larger. Seed rates range between 5 - 10 kg/du.

Leaf crops are broadcast in basins with seed rates between 5 - 10 kg/du

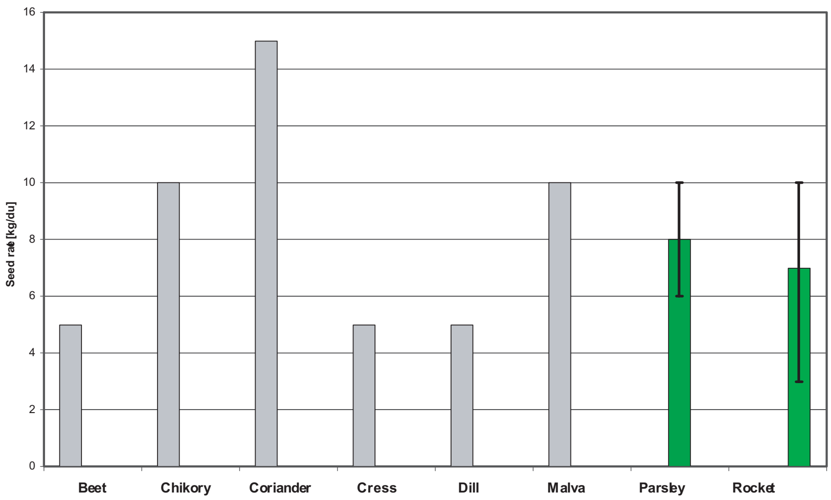


Fig. 98: Leaf crops and seed densities

Compared with the small sizes of the seeds the rates applied appear relatively high, but the practice of broadcasting, the possible losses caused by the brackish water irrigation at the germination and emergence stage, and the flooding of the basins after sowing require seed rates that compensate for losses during the early development stage of the crops.

Fertilization

Leaf crops produce high amounts of biomass (up to 18,000 kg/du as shown in Fig. 94) and accordingly remove high amounts of nutrients from the soil. Particular figures were not found in the literature, but spinach may serve as a rough orientation. A yield of about 2,100 kg/du removes about 13.1 kg/du of N (*IFA, 1992*). With regard to the yields observed, this means a range of about 13 - 113 kg/du of N removed by the different leaf crops on the monitored FUs.

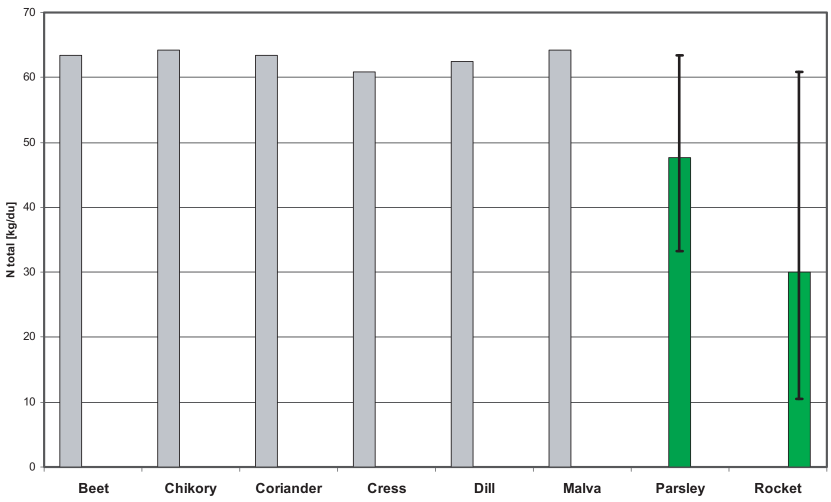


Fig. 99: Leaf crop yields and N application

Farmers using brackish water for irrigation of leaf crops should consider high nitrogen (N) application rates of up to 65 kg/du including manure

The total N applied to the leaf crops is displayed in Fig. 99. The usual practice is one manure application of about 1,300 - 3,000 kg/du before planting, which provides between 26 - 60 kg/du of N. During the cultivation period mainly ammonium sulfate in the range of 1 - 13 kg/du is added. The main part of N, except for parsley and rocket, comes from manure. Since the fertilization practice is quite similar for all monitored leaf crops although they have very different yields, part of the N is probably wasted, at least for the low yielding species.

The high deviations for parsley and rocket are due to the fact that less manure and more mineral fertilizer with different application rates were used in the 2002/3 season as compared to the 2001/2 season.

General Agricultural Practices

The **tillage** practice on the monitored FUs is one or two plowings and one harrowing, which appears appropriate.

Manure should be applied at a rate of 1,300 - 3,000 kg/du before planting

The application of chicken manure as **organic fertilizer** before planting is a recommendable practice, because the application of organic matter improves the structure and physical condition of the soil, improves soil microbial activity, and increases the level of nutrients as well as the nutrient and water holding capacity *(GTZ, 2000 and 2001 a)*. With regard to these benefits, it is recommended to apply manure before planting at a rate of 1,300 - 3,000 kg/du.

Since leaf crops are broadcast, they form a dense canopy and cover the soil well. Thus the need for **weeding** is moderate and farmers normally do not apply herbicides.

With regard to **disease and pest management**, 'Lanate' was the main insecticide applied against sucking insects like aphides and trips, and against caterpillars.

Spraying leaf crops is a critical issue because the leaves are directly consumed, sometimes even raw. Therefore it is of utmost importance that prescriptions with regard to waiting periods are respected. As mentioned above, spraying of pesticides is very moderate on the monitored FUs and probably no health risk is involved for the consumers.

Alfalfa

(Medicago sativa L.*)*

ALFALFA OR LUCERNE is the 'queen of forages' because it is high yielding with substantial protein, mineral and energy content. It is also an excellent pasture, often mixed with grasses. In combination with supplemental grain, alfalfa is a valuable fodder for dairy cows, fattening cattle, and sheep.

In addition alfalfa is a positive component in crop rotations because of its ability to fix nitrogen with a range of 8.3 - 59.4 kg N/du/year (*Duke, 1983, unpublished*). Therefore it can increase yields of successive crops, improve the soil structure and tilth with its deep root system, and reduce water runoff and soil erosion.

Alfalfa, often wrongly named 'berseem' in Jordan, is perennial. Berseem (*Trifolium alexandrinum* L.), an annual, has lower yields, but is supposed to be more salt tolerant. In Egypt berseem is used in reclamation of salty lands (*Graves et al.*, without year).

Fig. 100: Alfalfa in small and large-scale cultivation

Despite its positive properties and a certain tolerance for brackish irrigation water, alfalfa is only occasionally found in the Jordan Valley. It is normally cultivated on relatively small plots as supplemental fodder for cattle and sheep.

One of the monitored FUs is cultivating alfalfa successfully on a large scale. Detailed and continuous monitoring was possible on this farm resulting in a data set of two plots. With regard to its relatively good performance on the monitored farm and its beneficial effects on soils and excellent forage value, it is felt that alfalfa should receive more attention when brackish water is an irrigation source. The fact that the entire alfalfa harvest could be sold for satisfying prices shows that there is a certain demand for alfalfa, even though there are cheap imports from Saudi Arabia on the market.

Yields

The monitored FU cultivated alfalfa on one plot over a period of four years on an area of 33 du, irrigating mainly with water of Wadi Zarqa. The monitoring commenced in January 2000. In June 2002 this plot was ploughed and wheat was sown to benefit from the accumulated nitrogen collected by the legume alfalfa. From April 2002 onward the farmer cultivated another FU of 36 du nearby with alfalfa.

Alfalfa achieves an annual average yield of 2,300 kg/du in the Jordan Valley when irrigated with brackish water

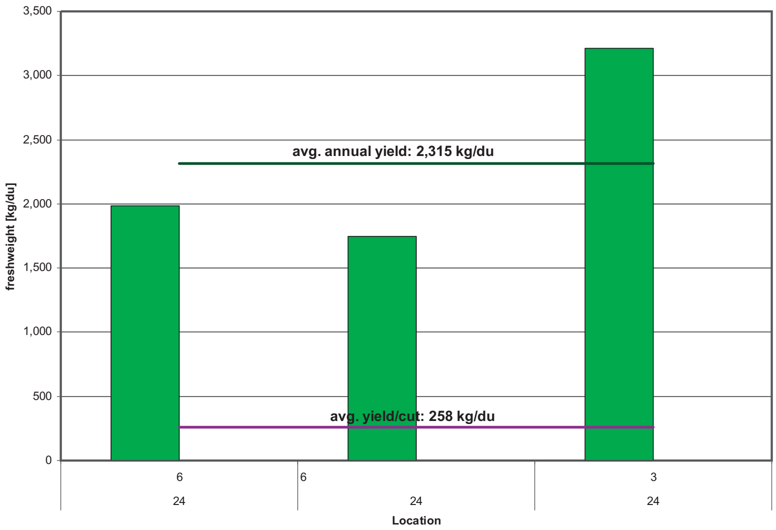


Fig. 101: Alfalfa freshweight yields

The freshweight yields shown in Fig. 101 ranged from 1,749 to 3,212 kg/du/year with an average of 2,315 kg/du/year. There was an average of 9 cuts per year. The average yield per cut was 258 kg/du with a variation between 194 kg/du and 321 kg/du.

For comparison *NCARTT (1997)* reports average yields of 2,500 - 3,500 kg/du freshweight under irrigation with freshwater. *Duke (1983)* reports forage yields of 500 - 7,500 kg/du per year from California with 8 - 12 cuttings per year.

After cutting, the alfalfa was directly pressed to bales and sold.

Varieties

The monitored FU cultivated 'Hijazi' which is the main variety in Jordan.

Irrigation Water Salinity

The irrigation water supply for both plots differed according to freshwater availability and growth stage of the alfalfa. In Fig. 102 cluster A shows the alfalfa stand in the 2000/1 season when, due to freshwater shortage, the plot was purely irrigated with brackish water with an average EC_{iw} = 8 dS/m. Cluster B presents the situation in 2001/2 when irrigation was alternated: KTR (average EC_{iw} = 2.2 dS/m) water from October to May and Wadi Zarqa water from May onward with an average EC_{iw} = 8.2 dS/m. The yield was slightly lower than in the previous year perhaps due to the fact that nitrogen was applied, which is normally not recommended for legumes because it can cause over-fertilization and thus reduce yields (see also chapter 'Fertilization').

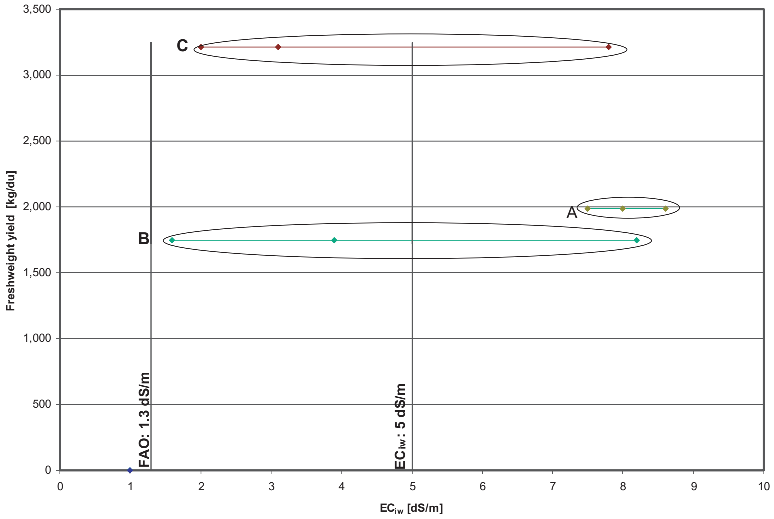


Fig. 102: Alfalfa fresh weight yields and irrigation water salinity

In the Jordan Valley alfalfa can be cultivated with brackish irrigation water up to an average EC_{iw} = 5 dS/m with yields around 2,300 kg/du

Cluster C represents the newly planted plot in 2002/3. Since alfalfa is salinity sensitive in the germination and emergence stage, and since freshwater was available in larger quantities during this period, the farmer used KTR water (average EC_{iw} = 2.3 dS/m) for irrigation till the alfalfa stand was fully developed, and changed to Wadi Zarqa water about one year after planting. The difference in yield is significant as shown in Fig. 102.

According to *FAO (1985),* the threshold for irrigation water is 1.3 dS/m. This classifies alfalfa as a relatively salt-sensitive crop whereas in the Jordan Valley the data available suggest that alfalfa can be irrigated with average water salinities up to EC_{iw} = 5 dS/m still achieving satisfying yields.

Soil Texture

The monitored alfalfa was cultivated on a sandy loam. This soil provided good leaching properties and therefore helped to reduce adverse effects of brackish irrigation water.

Irrigation Practices and Total Water Supply

On the monitored FU, alfalfa is irrigated with sprinklers. When grown on other FUs on a small scale it is mostly cultivated in basins providing irrigation water by flooding the basins.

The irrigation of the newly planted plot was monitored with two water meters. The values were averaged and summarized each month. Fig. 103 displays the irrigation applications (blue), rainfall (light blue), total water applied (red), and field water requirement (dark line).

Sprinkler irrigation is an appropriate irrigation method for alfalfa. Up to 1,800 mm of field water requirement helps to compensate for adverse effects of brackish irrigation water

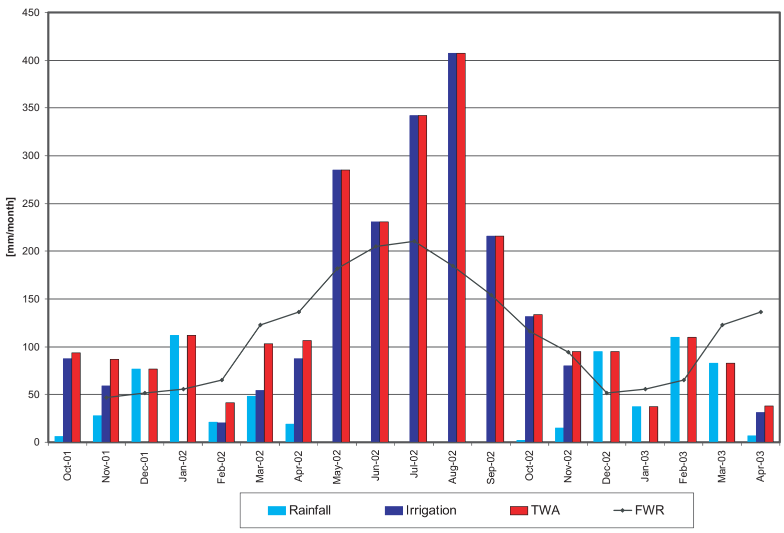


Fig. 103: Alfalfa crop water requirement and total water applied

Tab. 29 and Tab. 30 provide weekly crop water requirement values for the middle and southern Jordan Valley. To calculate the field water requirement, an irrigation system efficiency for sprinkler equipment of 70 % (i.e. 30 % loss) is assumed. Because of the relatively light soil, it is also assumed that the supplement of 30 % for the losses covers the leaching requirement and therefore no leaching fraction is added. With these assumptions and applying the values of Tab. 29, the yearly water requirement for the middle Jordan Valley is around 1,800 mm per year.

On the monitored FU, a pre-irrigation of about 94 mm was applied before sowing in November 2001. The applied irrigation water exceeded the field water requirement mainly in the hot months. In total about 14 % more water was applied than required, which is moderate.

Middle Jordan Valley	**Weekly crop water requirement [mm]**			
	k_{c1} (10 days)	**k_{c2} (20 days)**	**k_{c3} (90 days)**	**k_{c4}**
January	5.9	8.1	9.8	9.8
February	7.6	10.6	13.4	12.7
March	13.0	17.9	22.7	21.6
April	14.9	20.6	26.1	24.8
May	19.2	26.5	33.6	32.0
June	22.3	30.9	39.1	37.2
July	22.2	30.6	38.8	36.9
August	19.5	27.0	34.1	32.5
September	16.8	23.2	29.3	27.9
October	12.3	17.0	21.5	20.4
November	10.2	14.2	17.9	17.1
December	5.5	7.6	9.6	9.1

Tab. 29: Weekly crop water requirement ET_c for alfalfa in the middle Jordan Valley (DA 21 - DA 26)

Southern Jordan Valley	**Weekly crop water requirement [mm]**			
	k_{c1} (10 days)	**k_{c2} (20 days)**	**k_{c3} (90 days)**	**k_{c4}**
January	4.6	6.4	8.1	7.7
February	6.4	8.8	11.2	10.6
March	10.7	14.8	18.8	17.9
April	13.0	18.0	22.8	21.7
May	16.7	23.1	29.2	27.8
June	19.3	26.8	33.8	32.2
July	19.0	26.3	33.3	31.7
August	16.7	23.0	29.2	27.8
September	14.0	19.3	24.4	23.3
October	10.0	13.9	17.6	16.7
November	7.3	10.1	12.8	12.2
December	4.5	6.2	7.8	7.4

Tab. 30: Weekly crop water requirement ET_c for alfalfa in the southern Jordan Valley (DA 27 - DA 52)

Growing Season and Seed Densities

Alfalfa is a perennial crop and can be grown for several years. Sowing in the cooler autumn period is recommended. During the sensitive growth stages (germination and emergence) irrigation with freshwater is recommended to achieve fast and dense ground coverage. An appropriate amount of seeds applied is 6 kg/du.

Fertilization

On the first plot 4.3 kg/du of nitrogen was added in 2001 as urea and compound fertilizer. The new plot was supplied with 10 kg/du of N as ammonium sulfate, urea and compound fertilizers, the latter with emphasis on potassium content.

Legumes have the ability to fix atmospheric nitrogen with the support of bacteria *(Rhizobium)* and normally do not require additional application of nitrogen. Furthermore, application of N supports non-legume weeds, particularly grasses, which might reduce the alfalfa yield and decrease the longevity of the alfalfa stand.

Legumes like alfalfa generally do not require nitrogen fertilization, even if irrigated with brackish water

Applying potassium and phosphorus supports legumes if there are deficiencies in the soil. However, soil analyses indicate that the levels of available P (around 50 ppm) and K (more than 200 ppm) are medium to high *(GTZ, 2001)*.

Summarizing this suggests that there is no need for fertilizer application to alfalfa and other legumes in the Jordan Valley, even in case of brackish water irrigation.

General Agricultural Practices

The **tillage** practice of one plowing and one harrowing appears to be appropriate.

The application of manure as **organic fertilizer** before planting is a recommendable practice because organic matter improves the structure and the physical conditions of the soil. Organic matter furthers soil microbial activities, increasing the level of nutrients as well as the nutrient and water holding capacity of the soil *(GTZ, 2000 and 2001 a)*.

Manure can be applied at a rate of about 1,500 kg/du before sowing

With regard to these benefits, it is recommended to apply manure before planting at a rate of about 1,300 kg/du. It is also possible to apply manure after cutting, but since it cannot be incorporated into the soil at this stage, there will be high losses of nitrogen to due to volatilization.

Since alfalfa is broadcasted and forms a dense cover there is low need for **weeding**. If still required this is usually done by application of herbicides.

No particular **diseases and pests** were observed on the alfalfa plots.

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Annexes

Ministry of Water and Irrigation
Jordan Valley Authority
Irrigation Advisory Service - Irrigation Directorate Karamah Office
Crop Water Requirements in Southern Jordan Valley (1999 - 2000)
Monthly Average [m^3/du]

Selected data

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Date Palm	40	50	60	80	120	170	175	170	165	80	50	40	1,200
Onion	46	62	57	58	32				45	84	83	54	475
Tomato, autumn								121	109	168	112	55	565
Tomato, winter	32	73	117	120	22							53	417
Tomato, summer		41	76	146	133	55							451
Squash, autumn 1	23							15	89	96	77	50	350
Squash, autumn 2									89	77	83	33	282
Squash, winter	37	46	2								61	20	166
Squash, summer		20	69	134	169	46							438
Beans, autumn									119	112	99		330
Beans, winter	47	7									95	45	194
Beans, spring l	10	54	95	58									217
Beans, spring 2		21	74	140	24								259
Potato, autumn									108	126	107	62	403
Potato, spring	7	55	100	144	74								380
Pepper, autumn	1							121	105	161	106	62	556
Pepper, winter	46	71	96	65							93	37	408
Pepper, spring	10	46	92	147	182	125							602
Eggplant, autumn								121	103	146	95	53	518
Eggplant, winter	42	71	96	65							93	35	402
Eggplant, spring	10	43	86	147	182	125							593
Cabbage, autumn									74	92	83	33	282
Cabbage, winter	37	46	2								46	35	166
Cabbage, spring		21	69	143	184	123							540
Cauliflower, winter	49	70	29								78	55	281
Cauliflower, autumn									74	92	83	33	282
Broad beans, winter	22								47	74	47	28	218
Lettuce, winter	46	45									93	39	223
Water Melon		41	64	103	175	209	173						765
Sweet Melon		41	64	103	175	209	173						765
Other Vegetables	32	15						15	92	103	93	60	410
Okra			113	95	105	122	120	125	110				790
Jew's Mallow				131	139	147	150	120					687
Maize				25	89	126	185	180	133	66			804
Wheat	37	77	111	129								84	438
Barley	37	77	111	129								84	438
Clover Trefoil	113	67	67	54	73	105	33						512

Ministry of Water and Irrigation
Monthly Net Irrigation Requirement per Crop Group Zone 2- Surface Water Irrigation

Selected data

DESCRIPTION	AC ZONE	1	2	3	4	5	6	7	8	9	10	11	12	Total
BBeans_Peas_Aut1	2							40	167	202	159	52		620
BBeans_Peas_Aut2	2								40	154	143	102	7	447
BBeans_Peas_Wntr	2	43	69	49							40	72	42	315
Carrot_Aut1	2								40	149	126	93	34	442
Carrot_Aut2	2	25								40	106	80	47	297
Carrot_Wntr	2	37	49								40	72	43	241
Carrot_Spr	2	27	56	96	158								40	377
Crucifers_Aut1	2								41	138	123	93	5	400
Crucifers_Aut2	2	-5								41	108	81	47	271
Crucifers_Wntr	2	37	20								41	72	41	210
Crucifers_Spr	2	41	47	83	170	222	203							766
Crucifers_Smr	2				41	153	237	211						641
Cucmbr_Aut1	2							50	145	169	138	32		534
Cucmbr_Aut1_Plstc	2								50	16	82	71	-8	210
Cucmbr_Aut2	2								50	135	120	88	-10	384
Cucmbr_Aut2_Plstc	2	-7								50	11	56	45	155
Cucmbr_Wntr	2							50	145	172	138	31		535
Cucmbr_Wntr_Plstc	2	47	1								50	6	36	140
Cucmbr_Spr_Plstc	2	3	36	81	126	89							50	385
Cucmbr_Smr	2				50	150	229	180						609
Cucmbr_Smr_Plstc	2	3	34	81	126	90							50	385
EggP_Aut1	2	-15						47	148	136	122	92	47	577
EggP_Aut2	2	35	61	96	113					47	109	69	37	567
EggP_Aut2_Plstc	2	-1								47	7	46	48	147
EggP_Wntr	2	30	61	96	115						47	69	32	450
EggP_Wntr_Plstc	2	29	58	85	132	104					47	5	6	467
EggP_Spr	2	47	47	80	169	222	186							750
EggP_Smr	2				47	148	233	199						626
G_Beans_Aut1	2							41	150	189	101			480
G_Beans_Aut2	2								41	139	134	50		364
G_Beans_Aut2_Plstc	2									41	16	66	6	129
G_Beans_Wntr	2	-5									41	72	43	151
G_Beans_Wntr_Plstc	2	38	59	85	85						41	5	10	322
G_Beans_Spr	2	41	47	84	173	175								519
G_Beans_Spr_Plstc	2	4	38	85	87								41	254
G_Beans_Smr	2			41	123	210	201							575
G_Beans_Smr_Plstc	2	4	41	85	87								41	258
J_Mallow_Spr	2		40	76	140	130								387
J_Mallow_Spr_Plstc	2	40	16	69	71									196
J_Mallow_Smr	2				40	162	201	155						559
Lett_Spin_Aut1	2								40	149	115	86	28	419
Lett_Spin_Aut2	2	18								40	115	77	43	293
Lett_Spin_Wntr	2	28	56	74								40	37	236
Lett_Spin_Spr	2	26	51	89	149								40	355
Lett_Spin_Smr_Plstc	2				40	15	129	165						350

Melons_Spr	2	48	47	84	166	146								490
Melons_Spr_Plstc	2	48	7	63	126	96								340
Melons_Smr	2	48	47	84	166	146								490
O_Legumes_Aut1	2							50	151	199	148	13		561
O_Legumes_Spr	2	50	49	96	177	90								462
O_Legumes_Smr	2				50	167	254	137						608
O_Veg_Aut1	2							40	164	149	126	89	13	581
O_Veg_Aut2	2	3								40	107	72	43	266
O_Veg_Wntr	2	28	56	92	135							40	37	387
O_Veg_Spr	2	27	53	92	134								40	346
O_Veg_Smr	2				40	161	226	212						640
O_Veg_LongSsn_Aut1	2	31	54	85	153	143	47	50	153	134	99	77	40	1066
O_Veg_LongSsn_Aut2	2	28	54	85	157	201	219	167	43	50	105	65	30	1204
O_Veg_LongSsn_Spr	2	26	49	84	157	201	210	71					50	847
O_Veg_LongSsn_Spr_Plstc	2	3	22	77	120	151	152	38					50	612
O_Veg_LongSsn_Smr	2				50	151	225	133						559
Okra_Aut1	2							45	145	158	136	40		524
Okra_Spr_Plstc	2	45	19	35										99
Okra_Smr	2				45	148	220	191						604
Onion_Grlc_Aut1	2	35	58	67					40	151	128	89	44	613
Onion_Grlc_Aut2	2	35	59	90	135					40	107	81	44	592
Onion_Grlc_Wntr	2	31	59	92	168	211	198					40	34	834
Onion_Grlc_Spr	2	29	59	92	144								40	364
Peppr_Aut1	2							40	163	189	145	93	15	644
Peppr_Aut1_Plstc	2							40	23	139	109	74	17	403
Peppr_Aut2	2	6							40	151	134	93	47	469
Peppr_Aut2_Plstc	2	49	27							40	14	66	48	244
Peppr_Wntr	2	37	61	96	135						40	78	42	489
Peppr_Wntr_Plstc	2	49	59	85	96						40	6	36	370
Peppr_Spr	2	26	52	93	174	180							40	566
Peppr_Spr_Plstc	2	3	25	83	133	126							40	411
Peppr_Smr	2	26	52	93	174	180							40	566
Peppr_Smr_Plstc	2	3	25	83	133	126							40	411
Potato_Aut1	2								40	149	142	102	33	466
Potato_Aut2	2	23								40	106	91	53	312
Potato_Wntr	2	43	46								40	72	47	248
Potato_Spr	2	27	64	107	152								40	389
Squash_Aut1	2							50	145	159	131	26		512
Squash_Aut2	2								50	135	114	83	-14	369
Squash_Wntr	2	32	1								50	67	34	184
Squash_Spr	2	50	47	78	156	138								469
Squash_Spr_Plstc	2	50	4	40	120	88								302
Squash_Smr	2				50	146	211	170						576
Tomato_Aut1	2							50	161	174	157	102	-6	638
Tomato_Aut2	2	-15							50	149	125	101	53	462
Tomato_Aut2_Plstc	2	54	64	27						50	7	31	51	284
Tomato_Wntr	2	34	69	107	112							50	34	405
Tomato_Wntr_Plstc	2	54	64	27							50	6	38	239
Tomato_Spr	2	26	54	103	191	153							50	578
Tomato_Spr_Plstc	2	50	4	40	142	182	121							539
Tomato_Smr	2				50	163	256	209						678
Tomato_Smr_Plstc	2	50	4	40	142	182	121							539

Turn_Radi_Aut1	2							40	161	178	126			505
Turn_Radi_Aut2	2									40	106	81	33	259
Turn_Radi_Wntr	2	31	46									40	34	151
Turn_Radi_Spr	2	40	47	86	154									327
Dates	2	37	62	96	175	216	230	231	211	185	131	83	43	1699
Nurseries	2	27	49	78	147	196	229	242	222	195	138	88	80	1692
Olives	2	50	63	92	147	161	166	170	155	136	46			1187
Forage_Spr	2	50	44	70	135	184	219	231	211	184	128	29		1484
Maize_Wntr	2	34	70	109	117							50	34	414
Maize_Smr	2				50	141	182	257	261	229	75			1194
Wheat & Barley_Wntr	2	24	58	106	191	48							100	528
Wheat & Barley_Spr	2	26	50	100	191	66							100	533

Ministry of Water and Irrigation
Monthly Net Irrigation Requirement per Crop Group Zone 2 - Drip Irrigation

Selected data

DESCRIPTION	AC ZONE	1	2	3	4	5	6	7	8	9	10	11	12	Total
BBeans_Peas_Aut1	2							36	74	172	152	46		481
BBeans_Peas_Aut2	2								36	69	120	97	4	327
BBeans_Peas_Wntr	2	39	65	42							36	55	35	273
Carrot_Aut1	2								10	149	126	93	34	412
Carrot_Aut2	2	25								10	106	80	47	267
Carrot_Wntr	2	37	49								10	72	43	211
Carrot_Spr	2	27	56	96	158								10	347
Crucifers_Aut1	2								41	65	92	83	-1	280
Crucifers_Aut2	2	-11								41	58	61	40	188
Crucifers_Wntr	2	31	12								41	55	32	171
Crucifers_Spr	2	41	54	85	157	201	179							716
Crucifers_Smr	2				41	81	204	187						512
Cucmbr_Aut1	2							50	145	169	138	32		534
Cucmbr_Aut1_Plstc	2								50	16	78	67	-10	200
Cucmbr_Aut2	2								50	135	120	88	-10	384
Cucmbr_Aut2_Plstc	2	-10								50	11	53	43	148
Cucmbr_Wntr	2							50	145	172	138	31		535
Cucmbr_Wntr_Plstc	2	44	-2								50	6	34	133
Cucmbr_Spr_Plstc	2	3	34	77	120	81							50	365
Cucmbr_Smr	2				50	150	229	180						609
Cucmbr_Smr_Plstc	2	3	32	77	120	82							50	365
EggP_Aut1	2	-20						47	64	68	97	87	43	387
EggP_Aut2	2	29	58	90	99					47	63	38	24	448
EggP_Aut2_Plstc	2	-4								47	7	44	45	140
EggP_Wntr	2	26	57	90	103						47	59	27	410
EggP_Wntr_Plstc	2	28	55	81	126	91					47	5	6	439
EggP_Spr	2	47	53	86	164	211	169							730
EggP_Smr	2				47	73	206	183						510
G_Beans_Aut1	2							41	72	167	93			372
G_Beans_Aut2	2								41	67	117	45		269
G_Beans_Aut2_Plstc	2									41	16	63	3	123
G_Beans_Wntr	2	-8									41	55	38	125
G_Beans_Wntr_Plstc	2	36	56	81	76						41	5	10	304
G_Beans_Spr	2	41	54	87	165	162								508
G_Beans_Spr_Plstc	2	4	36	81	79								41	241
G_Beans_Smr	2			41	82	191	187							501
G_Beans_Smr_Plstc	2	4	39	81	78								41	244
J_Malllow_Spr	2		20	76	140	130								367
J_Malllow_Spr_Plstc	2	20	16	65	64									165
J_Mallow_Smr	2				20	162	201	155						539
Lett_Spin_Aut1	2								15	149	115	86	28	394
Lett_Spin_Aut2	2	18								15	115	77	43	268
Lett_Spin_Wntr	2	28	56	74								15	37	211
Lett_Spin_Spr	2	26	51	89	149								15	330
Lett_Spin_Smr_Plstc	2				15	15	117	148						294

Melons_Spr	2	48	54	86	161	139								488
Melons_Spr_Plstc	2	48	7	62	123	90								330
Melons_Smr	2	48	54	86	161	139								488
O_Legumes_Aut1	2							50	151	199	148	13		561
O_Legumes_Spr	2	50	49	96	177	90								462
O_Legumes_Smr	2				50	167	254	137						608
O_Veg_Aut1	2							30	164	149	126	89	13	571
O_Veg_Aut2	2	3								30	107	72	43	256
O_Veg_Wntr	2	28	56	92	135							30	37	377
O_Veg_Spr	2	27	53	92	134								30	336
O_Veg_Smr	2				30	161	226	212						630
O_Veg_LongSsn_Aut1	2	31	54	85	153	143	47	50	153	134	99	77	40	1066
O_Veg_LongSsn_Aut2	2	28	54	85	157	201	219	167	43	50	105	65	30	1204
O_Veg_LongSsn_Spr	2	26	49	84	157	201	210	71					50	847
O_Veg_LongSsn_Spr_Plstc	2	3	21	73	114	143	142	22					50	567
O_Veg_LongSsn_Smr	2				50	151	225	133						559
Okra_Aut1	2							45	145	158	136	40		524
Okra_Spr_Plstc	2	45	18	31										95
Okra_Smr	2				45	148	220	191						604
Onion_Grlc_Aut1	2	35	58	67					10	151	128	89	44	583
Onion_Grlc_Aut2	2	35	59	90	135					10	107	81	44	562
Onion_Grlc_Wntr	2	31	59	92	168	211	198					10	34	804
Onion_Grlc_Spr	2	29	59	92	144								10	334
Peppr_Aut1	2							28	67	160	138	88	11	491
Peppr_Aut1_Plstc	2							28	22	132	104	71	14	372
Peppr_Aut2	2	1							28	63	111	88	43	335
Peppr_Aut2_Plstc	2	47	23							28	14	63	45	221
Peppr_Wntr	2	34	58	90	123						28	54	33	420
Peppr_Wntr_Plstc	2	47	56	81	87						28	6	34	338
Peppr_Spr	2	32	56	90	166	166							28	537
Peppr_Spr_Plstc	2	3	24	79	126	114							28	376
Peppr_Smr	2	32	56	90	166	166							28	537
Peppr_Smr_Plstc	2	3	24	79	126	114							28	376
Potato_Aut1	2								10	149	142	102	33	436
Potato_Aut2	2	23								10	106	91	53	282
Potato_Wntr	2	43	46								10	72	47	218
Potato_Spr	2	27	64	107	152								10	359
Squash_Aut1	2							50	63	122	124	22		381
Squash_Aut2	2								50	60	85	78	-17	257
Squash_Wntr	2	28	-3								50	54	27	157
Squash_Spr	2	50	54	83	149	128								463
Squash_Spr_Plstc	2	50	4	38	114	81								286
Squash_Smr	2				50	70	181	158						459
Tomato_Aut1	2							50	63	118	149	97	-10	467
Tomato_Aut2	2	-20							50	60	82	95	50	317
Tomato_Aut2_Plstc	2	51	61	21						50	7	30	48	269
Tomato_Wntr	2	36	65	101	100							50	41	393
Tomato_Wntr_Plstc	2	51	61	21							50	6	36	226
Tomato_Spr	2	32	58	100	182	137							50	560
Tomato_Spr_Plstc	2	50	4	38	136	174	108							510
Tomato_Smr	2				50	73	228	194						545

Tomato_Smr_Plstc	2	50	4	38	136	174	108							510
Turn_Radi_Aut1	2							10	161	178	126			475
Turn_Radi_Aut2	2									10	106	81	33	229
Turn_Radi_Wntr	2	31	46									10	34	121
Turn_Radi_Spr	2	10	47	86	154									297
Dates	2	36	60	94	171	213	229	231	211	185	131	83	43	1686
Nurseries	2	27	49	78	147	196	229	242	222	195	138	88	45	1657
Forage_Spr	2	50	44	70	135	184	219	231	211	184	128	29		1484
Maize_Wntr	2	34	70	109	117							50	34	414
Maize_Smr	2				50	141	182	257	261	229	75			1194
Wheat & Barley_Wntr	2	24	58	106	191	48							100	528
Wheat & Barley_Spr	2	26	50	100	191	66							100	533

Name, abbreviation	Nutrient content (%)	Formula	Solid, liquid	Salt index	Description, main purpose	Application rate per du	Price (JD/ton)
Ammonium sulfate	21 % N	$(NH_4)_2SO_4$	Solid	69	For vegetative growth	2 - 5 kg	260
Ammonium nitrate	33 % N	NH_4NO_3	Solid	105	For vegetative growth	2 - 5 kg	280
Urea	46 % N	$CO(NH_2)_2$	Solid	75	For vegetative growth, significant N loss by volatilization can occur	2 - 5 kg	450
MAP	11:48:0, 13: 52:0	$NH_4(H_2PO_4)$	Solid	30	At planting for root system development and for flowering stage	0.5 - 1 kg	450
Magnesium sulfate		$MgSO_4$	Solid	53	For Mg deficiency (not foliar)	1 - 3 kg	200-360
Calcium nitrate	16 % N	$Ca(NO_3)_2$	Solid	65	Calcium nitrate (16% N) contains all of its N in nitrate form. It is also used as a soluble source of calcium	1 - 2 kg	260-400
Potassium nitrate	13 % K	KNO_3	Solid	74	Potassium nitrate (13 % N) is used as source for K and N. All of the N is in nitrate form and is subject to leaching and denitrification as soon as it is added to soil. It is used primarily in the fruit and vegetable industry as a readily available sources of N and K	1 - 2 kg	280-400
Di ammonium phosphate (DAP)	18:46:0	$(NH_4)_2HPO_4$	Solid	34	Release of nitrogen is very slow. It is used at planting.	3 - 5 kg	150
Super phosphate	18-20 % P_2O_5	$Ca(H_2PO_4)_2$	Solid	8	It is used at planting.	3 - 5 kg	60-120
Triple phosphate	48 % P_2O_5	$Ca(H_2PO_4)_2$	Solid	10	It is used at planting.	3 - 5 kg	160

Imprint

These guidelines were prepared by
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The guidelines reflect the experiences and findings of the Brackish Water Project in Jordan between 2000 and 2003. We are sure that additional experiences and knowledge about the use of brackish water under comparable environmental conditions exist. Therefore comments and feedback are highly appreciated. Please contact:

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Design Concept: Syntax Design