Irrigation Scheduling and Water Quality for Agriculture

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1. INTRODUCTION

Water is considered as the most critical resource for sustainable development in most Mediterranean countries. It is essential not only for agriculture, industry and economic growth, but also it is the most important component of the environment, with significant impact on health and nature conservation. Currently, the rapid growth of population, together with the extension of irrigation and industrial development, are stressing the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a "use and discard" methodology either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident.

Global irrigated area has increased more than six fold over the last century, from approximately 40 million hectares in 1900 to more than 260 million hectares (Postel, 1999; FAO, 1999). Today 40% of the world's food comes from the 18% of the cropland that is irrigated. Irrigated areas increase almost 1% per year (Jensen, 1993) and the irrigation water demand will increase by 13.6% by 2025 (Rosegrant and Cai, 2002). On the other hand 8-15% of fresh water supplies will be diverted from agriculture to meet the increased demand of domestic use and industry. Furthermore the efficiency of irrigation is very low, since only 55% of the water is used by the crop (Fig. 1). To overcome water shortage for agriculture is essential to increase the water use efficiency and to use marginal waters (reclaimed, saline, drainage) for irrigation.

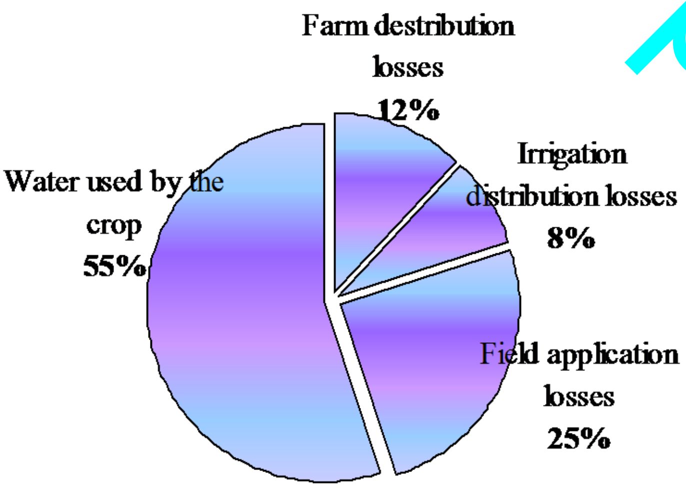

Figure 1. Water losses in agriculture

Under scarcity conditions considerable effort has been devoted over time to introduce policies aiming to increase water efficiency based on the assertion that more can be achieved with less water through better management. Better management usually refers to improvement of allocative and/or irrigation water efficiency. The former is closely related to adequate pricing, while the latter depends on the type of irrigation technology, environmental conditions and on scheduling of water application. It is well known that crop yield increases with water availability in the root zone, until *saturation level*, above which there is little effect (Hillel, 1997). The yield response curve (Fig. 2) of specific crops depend on various factors, such as weather conditions and soil type as well as the reduction of the agricultural inputs like fertilizers and pesticides. Therefore it is difficult for a farmer to tell at any given moment whether there is a water deficit or not. Since overabundant water usually does not cause harm, farmers tend to "play safe" and increase irrigation amount, especially when associated costs are low. Efficient irrigation management can be achieved through reduction of losses from water conveyance systems, obligatory use of localized (drip) irrigation systems by the farmers (with or without subsidies), proper irrigation scheduling and the application of salinity management techniques. The aim of this work is to review to existing methodologies of irrigation scheduling and discuss the water quality issues for using marginal waters for irrigation.

2. IRRIGATION SCHEDULING

Irrigation scheduling is the decision making process for determining when to irrigate the crops and how much water to apply. It forms the sole means for optimizing agricultural production and for conserving water and it is the key to improving performance and sustainability of the irrigation systems. It requires good knowledge of the crops' water requirements and of the soil water characteristics that determine when to irrigate, while the adequacy of the irrigation method determines the accuracy of how much water to apply. In most cases, the skill of the farmer determines the effectiveness of the irrigation scheduling at field level. With appropriate irrigation scheduling deep percolation and transport of fertilizers and agro-chemicals out of the root-zone is controlled, water-logging is avoided, less water is used (water and energy saving), optimum soil water conditions are created for plant growth, higher yields and better quality are obtained and rising of saline water table is avoided. In water scarce regions, irrigation scheduling is more important than under conditions of abundant water, since any excess in water use is a potential cause for deficit for other users or uses.

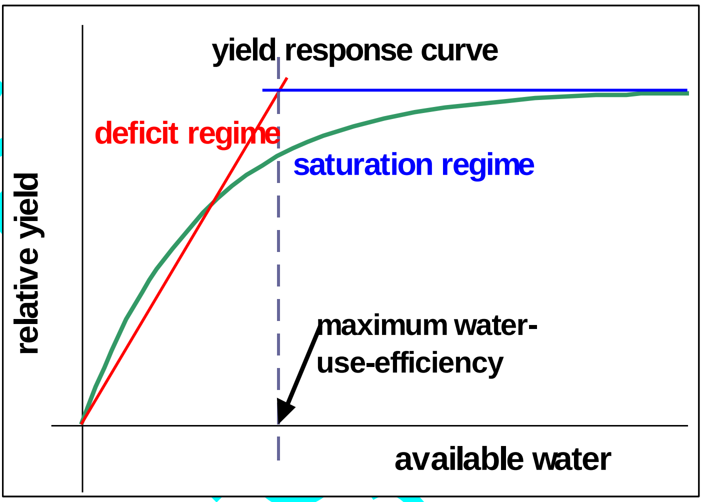

Figure 2. Plant yield response to water

Irrigation scheduling techniques and tools are quite varied and have different characteristics relative to their applicability and effectiveness Timing and depth criteria for irrigation scheduling (Huygen *et al.*, 1995) can be established by using several approaches based on soil water measurements, soil water balance estimates and plant stress indicators, in combination with simple rules or very sophisticated models. Many of them are still applicable in research or need further developments before they can be used in practice. Most of them require technical support by extension officers, extension programmes and/or technological expertise of the farmers. However, in most countries these programmes do not exist because they are expensive, trained extension officers are lacking, farmers awareness of water saving in irrigation is not enough and the institutional mechanisms developed for irrigation management give low priority to farm systems. Therefore, in general, large limitations occur for their use in the farmers practice. A brief description of irrigation scheduling techniques with reference to their applicability and effectiveness are reported below.

2.1 Soil water estimates and measurements

Soil water affects plant growth directly through its controlling effect on plant water status. There are two ways to assess the availability of soil water for plant growth: by measuring the soil water content, and by measuring how strongly that water is retained in the soil (soil water potential). The accuracy of the information relates to the sampling methods adopted and to the selection of locations where point observations are performed due to the soil water variability both in space and depth (Peymorte and Chol, 1992). Soil water estimates and measurements used for irrigation scheduling include:

a. *Soil appearance and feel.* Assessment of the soil water status by feeling how dry is the soil using the hands or a shovel. It is applicable mainly to field crops than to fruit trees and its effectiveness depends on farmer’s experience in sensing the changes in the soil moisture by hand touching the soil.

b. *Soil water content measurement.* It can be done through soil sampling for laboratory analysis, or using neutron probe or time-domain reflectometer (TDR). Neutron probes use the property of scattering and slowing down neutrons by the hydrogen nuclei of the water molecules. The TDR measures the propagation of an electromagnetic wave through the soil (Topp *et al.*, 1980). The characteristics of this propagation depend on the soil water content through the dielectric properties of the soil. The main advantages are that non-destructive and direct measurements can be performed without disturbing the soil allowing one to follow water content changes with time. The main limitation for neutron probe relates to safety rules, which have to be followed to operate, transport and store the probe, while for TDR seem to be due to gaps and cracks which may arise during installation of the rods or as a result of shrinking of the soil during drying. Assessment of the soil water content can be done using porous blocks or electrode probes by sensing the changes in the electrical resistance in the soil due to variations in soil moisture. The above mentioned techniques are precise, their applicability is large but are expensive and require calibration and expertise and/or external support to farmers. Their effectiveness depends upon the selected irrigation thresholds.

c. *Soil water potential measurement.* Tensiometers, soil psychrometers and pressure transducers are highly precise instruments for measuring soil water potential. Tensiometers, which assure low cost, simple operation and provide information for precisely determining the irrigation timing and depths when irrigation thresholds are well established, are widely used for the irrigation of horticultural crops. There should be at least one, and preferably two, tensiometer locations (two or more tensiometers at one location being a station) for each area of the field that differs in the soil type and depth (Fig. 3). The depth of tensiometer installation in the soil varies with the crop type (Tab. 1), while advise to framers is desirable. The only limitation is that they not operate beyond their sensing ability (0-80 kPa). Soil spectrometers and pressure transducers are complex, expensive and

Table 1. Depth of tensiometer installation for various crops

Plant type	Effective root depth (cm)
Grasses	15
Vegetables	15-30
Shrubs	30-45
Tree crops	30-60

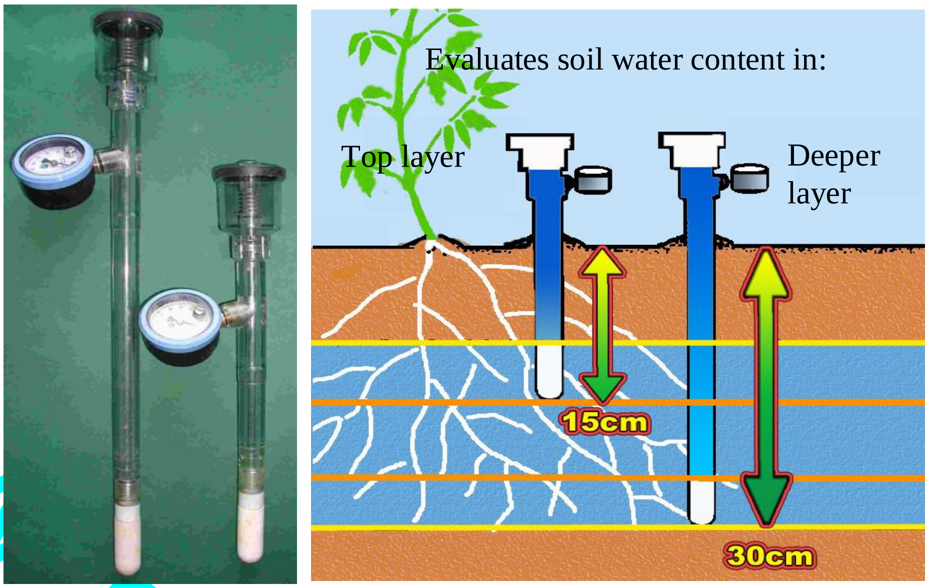

Figure 3. Tensiometers and schematic representation of their proper installation in the field.

require highly qualified farmers, so their farm application is very limited. However, a combination of devices measuring soil water content (i.e. TDR) and soil water potential is applicable to highly advanced technological farms and in research experimentation.

d. *Remotely sensed soil moisture*. Data on soil moisture, mainly for sallow soil layer, are performed with an airborne thermal infrared scanner, and usually refers to large areas. Its applicability is very limited and further development is required.

2.2. Crop stress parameters

Instead of measuring or estimating the soil water parameters, it is possible to get messages from the plant itself indicating the time of irrigation but not defining the irrigation depths. This message can either come from individual plant tissues, then it will be necessary to have a correct sampling, or from the canopy as a whole. Therefore, crop stress parameters are useful when irrigation depths are predefined and kept constant during the irrigation season. Crop water stress parameters include:

a. *Plant appearance*. Leaf rolling, changes in leaf orientation or colour are signs in plants developing water stress, so can be used for determining the time of irrigation. However, this technique is applicable to crops/plants that give detectable signs of water stress prior to wilting and its effectiveness depends upon farmer's experience.

b. *Leaf water content and leaf water potential*. The main interest of these measurements lies in the possibility of linking values of pre-dawn leaf water potential and/or leaf water content to relative evapotranspiration. However, both have limitations such as representative sampling; require relatively sophisticated equipment (pressure chamber, psychrometer), timeliness for observations and expertise in interpretation of the results. Thus, they are mainly used for research purposes.

c. *Changes in stem or fruit diameter*. Trend in diameter growth and diurnal changes of stems or fruits are measured using micrometric sensors (Deumier et al., 1996). They are not difficult to install, mainly on tree branches, and are connected to a logging system. The main problem encountered is that, sometimes, the same response is obtained with an excess and a lack of water. Furthermore, this technique is expensive, requires expertise and well-selected thresholds, so that its use by farmers is limited.

d. *Sap flow measurement.* Sap flow measurements using appropriate electronic sensors are sometimes included among the plant water stress criteria for irrigation scheduling (Valancogne and Nasr, 1989). In fact, one can obtain relative ET values by measuring sap flow along the trunk and comparing trees under water shortage to well irrigated trees. The techniques available are the sap flux density technique (Cohen *et al.*, 1981) and the mass flux technique (Sakuratani, 1981). The former is limited by the need to determine the cross-sectional area of the water conducting tissue. The latter is restricted to estimation of small trees' transpiration. Both techniques need tree sampling, require expertise, well defined thresholds and mainly used for research.

e. *Canopy temperature.* This technique is applicable to field crops for large areas. It is based on the fact that the surface temperature of a well-watered crop is some degrees lower than the air temperature, while the surface temperature of a stressed crop is close to the air temperature. Surface temperature measurements are performed using infrared thermometers, while the determination of crop water stress index (CWSI) is necessary (Idso *et al.*, 1981; Jackson *et al.*, 1981). Despite efforts to simplify calculations (Itier *et al.*, 1993), and the continually decreasing price of infrared thermometers, its use seems to be limited to industrial farms or farm advisers. Furthermore, CWSI can be used only if weather conditions are not rapidly changing (wind and radiation) and only for fully developed crops (in order to avoid soil surface temperature influence on measurements).

f. *Remote sensing of crop stress.* Airborne and satellite scanners sensing several wavelengths including the thermal infrared are used. Information may be made available through a spatially distributed format with geographical information system (GIS). The accuracy of the technique is higher when it is applied to large cropped areas with big fields and small crop variety. It is useful to support regional irrigation programmes, while good expertise in interpreting and transmitting information to farmers is required.

2.3. Climatic parameters

Climatic parameters are widely used for local or regional irrigation schemes. Weather data and empirical equations that, once they are locally calibrated, provide accurate estimates of reference evapotranspiration (ET_o) for a given area are used. Then, crop evapotranspiration (ET_c) is estimated using appropriate coefficients. Information may be processed in real time or, more often, using historical data. These techniques include:

a. *Evaporation measurements*. Evaporation is used to calculate the ET_o by the formula ETo =Kp Epan. The coefficient (Kp) depends on the type and size of the pan and the state of upwind buffer zone. The crop evapotranspiration (ET_c) is estimated using appropriate coefficients that relate evaporation to ET_o. Pan evaporation data should be averaged to 7 or 10 days. Its effectiveness depends upon the reliability of evaporation measurements, accuracy on computing ET_o and how the information reaches to the farmers. Usually this information is given on weekly base through bulletins or broadcasting.

b. *Assessment of crop evapotranspiration.* The ET_o is estimated using climatic data (air temperature, RH, wind speed, sunshine hours) through specific equations, while crop evapotranspiration (ET_c) is calculated by the formula ETc=Kc ET_o, where Kc is the crop coefficient (Allen *et al.*, 1998). Factors determining Kc are the crop type, climate, soil evaporation and crop growth stage. The effectiveness of this procedure depends upon the accuracy of data collection and calculation procedures, and on the way the information is given to farmers. This technique is applicable to regional irrigation scheduling programmes, while advice to farmers is desirable.

c. *Remote sensed ET.* Can be done using thermal infrared and multi-spectral scanners combined with surface weather data. It is applicable to large areas, so useful for regional irrigation scheduling programmes. However, there are some limitations in the application and further progress is required.

2.4 Soil-water balance

The aim of soil water balance approach is to predict the water content in the rooted soil by means of a water conservation equation: Δ (AWC $\times$ Root depth) = Balance of entering + outgoing water fluxes, where AWC is the available water content. Soil water holding characteristics, crop and climate data are used by sophisticated models to produce typical irrigation calendars. This approach can be applied from individual farms to large regional irrigation schemes. However, it needs expertise, support by strong extension services or links with information systems. Its effectiveness is very high, but depends on farm technological development and/or support services. Examples of commercial software for irrigation scheduling based on soil-water balance approach are:

IMS-Real time irrigation scheduling (Hess, 1996) Institute for Water and Environment, Grandfield University, UK.

MARKVAND: An Irrigation scheduling system for use under limited irrigation capacity. Danish Institute of Plant and Soil Science, Denmark.

SALTMED: A computer model for generic applications that illustrates the effect of all the parameters affecting crop growth and yield (Ragab, 2002), Institute of Hydrology, Wallingford, UK.

SIMIS: A decision support system that processes information about the system soil-water-plant to provide crop water requirements and estimate irrigation needs at farm and canal level (FAO, 1999b)

3. EFFECTIVE IRRIGATION SCHEDULING

It is recognized that appropriate irrigation scheduling should lead to improvements in irrigation management performance, especially at farm level. The farmer should be able to control the timing and the depth or volume of irrigation. However, the practical application of the techniques and methods has been far below expectations. The dependence on a collective system implies social, cultural and policy constraints. The main constrains are the lack of flexibility, either due to rigid schedules or the system limitations, the non-economic pricing of water (price covers less than 30% of the total cost), the high cost of irrigation scheduling (either for technology and/or labour), the lack of education and training of the framers, the institutional problems, the behavioural adaptation, the lack of interactive communication between research, extension and farmers and finally the lack of demonstration and technology transfer.

The effective application of any irrigation scheduling method and effective implementation of the corresponding delivery schedule are subject to the physical capability of the collective system for delivering water according to this schedule and to the capacity of the management for operating the system properly. One of the major obstacles to effective implementation of crop-based and water-saving irrigation scheduling is the inability of most conveyance and delivery systems to deliver water at the farm gates with the reliability and flexibility required. In surface irrigated areas supplied from collective irrigation canals discharge and duration impose constrains to farm irrigation scheduling. In case that the time interval between successive irrigations is too long, the farmers usually apply all water that is made available and over-irrigation is practised. In modern pressurised irrigation networks water is available on demand, although discharges may be limited due to technical or economic reasons. The farmers are free to select and adopt the irrigation schedules they consider more appropriate to their crops and farming practices. However, in case of drought or limited water supply, managers can enforce restrictions to volumes delivered and/or price penalties for excess water use.

Finally, all agencies involved in efficient irrigation water management should make every effort to disseminate knowledge, improve education and training at all levels, transfer technology, incite decision-makers to changes, involve the farmers in the decision process and urge the funding agencies and governments to set up the financial means required.

4. QUALITY OF IRRIGATION WATER

Water scarcity in the Mediterranean basin appears as one of the main factors limiting agricultural development, particularly in the 2000-2025 period. During the next 25 years, although irrigated areas will increase, sustainable quantities of fresh water supplies will be diverted from agriculture to meet the growing water demand in the municipal and industrial sectors in the region (Correia, 1999). To overcome water shortages and to satisfy the increasing water demand for agricultural development, the use of marginal quality waters (brackish, reclaimed, drainage) will become necessary in many countries. However, the use of saline water for irrigation requires an adequate understanding of how salts affect soil characteristics and plant performance.

The importance of water quality issues for irrigation was only recognized during the last century. Water quality refers to the characteristics that influence its suitability for use and is defined by certain physical, chemical and biological characteristics. Irrigation water quality depends on the type and quality of dissolved salts. The type and quality of salts is influenced by the geological and chemical form of petri-fraction at which water penetrates or is stored, the climatic conditions (rainfall, evaporation, etc), the type of vegetation, the infiltration rate and run-off. The laboratory analyses required for irrigation water evaluation is given on Table 2. Fresh water is considered to have a total dissolved solids (TDS) concentration of less than 500 mg/l (EC < 0.6 dS/m), brackish between water 500 to 2,000 mg/l (EC 0.6 to 3.0 dS/m), moderately saline water 2,000–5,000 mg/l (EC 3.0-8.0 dS/m), saline water 5,000 to 10,000 mg/l (EC 8-15 dS/m), highly saline water 10,000-30;000 mg/l (EC 15-40 dS/m), while sea water has TDS averaging 35,000 mg/l (EC 49 dS/m). Low quality water for agriculture is considered the brackish and saline waters (naturally or due to human activities), the drainage waters and the reclaimed waters (Maas, 1990; Hillel, 2000).

5. WATER QUALITY RELATED PROBLEMS

Irrigation enriches the soil with salts. Even good quality water (EC 0.4 dS/m) contains 250 ppm of salts, so irrigation with 500 mm of this water introduces 125 Kg of salts in 1000 m^2 of soil. Furthermore, water logging and related problems have arisen in many irrigated areas. Such problems could arise even more quickly and more severely when saline water is used.

The main problems associated with the use of saline irrigation water are:

a. Reduced soil water availability: – The salts in the soil solution retain part of soil water causing a significant reduction of water available to the crop as salinity increases osmotic effect). To withdraw water from the soil plant must overcome in addition to soil water potential the osmotic potential.

Figure 4. Salt toxicity symptoms

b. Toxicity hazards: – Certain ions (sodium, chloride, boron) accumulate in excess in the plant tissues causing crop damage (specific ion effect). The toxicity symptoms appear as burning of the outer edge of the leaf, progressing inwards between the veins and finally leaf drop and necrosis of the stem or plant (Fig. 4). The degree of the damage depends on the time of exposure, the concentration of salts, the crop sensitivity and the crop water use. Toxicity symptoms appears in salt sensitive crops when leaf Cl exceeds 0.30-0.50 % (d.w), Na exceeds 0.25-050 % (d.w.) and boron 250-300 mg/kg (d.w).

c. Nutrient imbalances: - Caused by excess concentration of certain ions or the prevention of crop uptake of others due to ion antagonism (limited Ca and K, excess NO_3, phosphate).

d. Soil degradation: - Improper use of saline water results in salt accumulation in the root zone and soil surface, so the soil becomes saline. When its sodium content is relatively high compared to other cations (Ca and K, high SAR) the soil becomes sodic with reduced infiltration rate and permeability. Both are linked to the structural stability of soil surface. Related problems are soil crusting, reduced availability of water to plants,

Table 2. Laboratory determinations needed to evaluate irrigation water quality

Water parameter		Symbol	Unit	Usual range in irrigation water
SALINITY Salt Content	Electrical conductivity	EC_w	dS/m	0 – 3
	Total Dissolved Solids	TDS	mg/l	0 – 20
SALINITY Cations & Anions	Calcium	Ca^{++}	me/l	0 – 20
	Magnesium	Mg^{++}	me/l	0 – 5
	Sodium	Na^{++}	me/l	0 – 40
	Carbonate	CO_3^{--}	me/l	0 – 0.1
	Bicarbonate	HCO_3^-	me/l	0 – 10
	Chloride	Cl^-	me/l	0 – 30
	Sulphate	SO_4^-	me/l	0 – 20
NUTRIENT	Nitrate – Nitrogen	NO3-	mg/l	0 – 10
	Ammonium – Nitrogen	NH_4^-	mg/l	0 – 5
	Phosphate – Phosphorus	PO_4-P	mg/l	0 – 2
	Potassium	K^+	mg/l	0 – 2
MISCELLANEOUS	Boron	B	mg/l	0 – 2
	Acid/Basicity	pH	1 – 14	6 – 8.5
	Sodium Absorption Ratio	SAR	me/l	0 – 15

poor seedling emergence, lack of aeration, root and plant disease development. Guidelines on the use of saline water for irrigation are given in Table 3 (Ayers and Westcot, 1985).

6. CONDITIONS AFFECTING SALINE WATER SUITABILITY FOR IRRIGATION

The suitability of water for irrigation is based on the kind and amount of salt content, the management capability of the user and the specific conditions of use. The conditions affecting the suitability of saline water for irrigation are:

6.1 Climatic conditions

The amount and distribution of rainfall influences the leaching of salts in the root zone. Temperature influences the water amount and the interval between irrigations. In regions with high precipitation and sufficient drainage, low quality water can be used without damaging crops and soils. In arid or semi-arid regions with low precipitation great attention must be paid to the quality of water.

6.2. Physical properties of soil

Soil texture, structure and permeability define the situation in which the root system of the plant lives after irrigation. High sodium content in water reduces infiltration in heavy soils (high salt content). Therefore, the use of saline water should be avoided.

Table 3. Water quality for irrigation and required restrictions in its use (Ayers and Westcot, 1985.

Problems	Water characteristic	No restrictions	Slight to moderate restrictions	Severe restrictions
Salinity effects on water availability	EC (dS/m)	< 0.7	0.7 - 0.30	> 3.0
	TDS (mg/l)	< 450	450 - 2000	> 2000
Salinity effects on soil infiltration	SAR <3	EC >0.7 dS/m	EC: 0.7-0.2 dS/m	EC <0.2 dS/m
	3 to 6	>1.2	1.2 to 0.3	<0.3
	6 to 12	>1.9	1.9 to 0.5	<0.5
	12 to 20	>2.9	2.9 to 1.3	<1.3
	20 to 40	>5.0	5.0 to 2.9	<2.9
Toxicity	Sodium			
	Surface irrigation: SAR	<3	3 to 9	>9
	Sprinkle/spray (meq/l)	<3	>3	
	Chloride concentration			
	Surface irrigation (meq/l)	<4	4 to 10	>10
	Sprinkle/spray (meq/l)	<3	>3	
	Boron (mg/l)	< 0.7	0.7 to 3.0	>3.0
	Trace elements	Variable		
Sprinkle/spray irrigation	Bicarbonate (meq/l)	<1.5	1.5 to 8.5	>8.5
Plant nutrition	pH	Normal 6.5 to 8.5		

6.3. Drainage conditions

If drainage is not adequate (water table less than 2 m), the use of low quality water may cause severe problems. Water rises up to the active root zone by capillary and if the water table contains salts it becomes a continual source of salts to plant root zone. In semi-arid regions water table must be below 2 m depth, if saline water is used for irrigation.

6.4. Irrigation method

In basin and border irrigation salt accumulation in the root zone is not likely to occur if water table is below 2 m. However, both require abundant water and adequate land leveling. In furrow irrigation salts tend to be accumulated on the top of the ridges, so leaching is required prior to planting. Salt accumulation in the root zone under sprinkler irrigation is not likely to occur, while severe leaf damage may occur from the salt accumulating on the external leaf surface. In sub-surface irrigation there is no accumulation of salts in the root zone, although limitations for use is the clogging of porous medium by salts contained in the water. Under drip irrigation salt accumulation in the root zone is not likely to occur, except in wetted fronts. Due to frequent irrigation, high water content below the dripper is ensured diluting the salts, providing control of stress and toxicity and yield losses are minimized.

6.5. Crop tolerance

Crops and different cultivars of the same crop vary considerably in their tolerance to salinity (Maas, 1990). Maas and Hoffman (1977) concluded that crop yield is not reduced until a threshold of salinity is exceeded, according to the following equation:

$$Y_r = 100 - (EC_e - t)\cdot s$$

where, Y_r is the relative yield, t is the threshold value of salinity where yield begin to decline, s is the rate of yield decline and EC_e the soil saturation extract salinity. Beyond the threshold level yield decreases linearly with rising salinity. The salinity values at zero yield provide an estimate of maximum salinity that plants can tolerate, and is used to calculate the leaching requirements. Salt tolerance is characterized by the values of both the threshold and slope (Fig. 5). Using this model Maas (1990) classified the crops according to their salt tolerance into four groups (sensitive, moderately sensitive, moderately tolerant, tolerant).

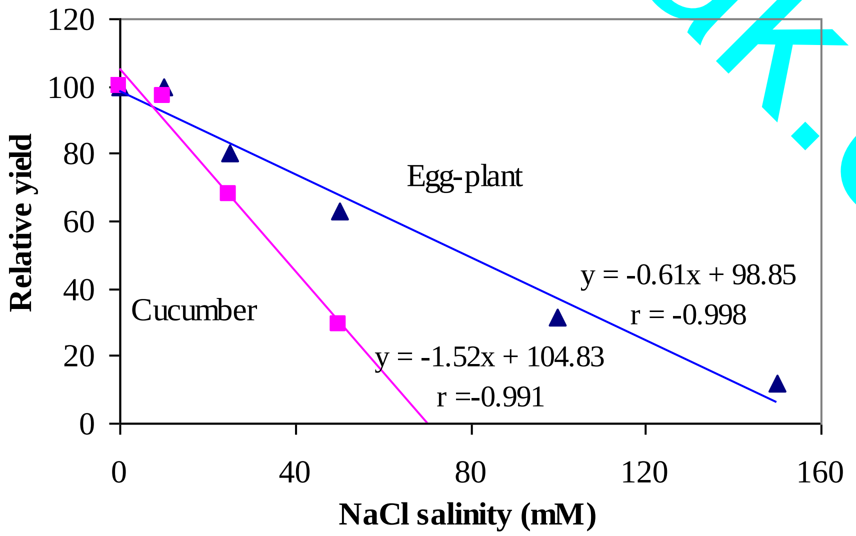

Figure 5. Relative yield response of eggplant and cucumber to salinity (Chartzoulakis and Loupassaki, 1997)

Salt tolerance of the crops is affected by plant factors (stage of growth, root system development, cultivar, rootstock), soil factors (soil water content, fertility, aeration, water table) and climatic conditions (drought, humidity, etc). The germination and seedling stages are the most sensitive to saline water irrigation. Any adverse effects at these stages will lead to a reduction in crop production proportional to the degree of plant loss during germination and establishment. Another growth stage sensitive to salinity is the reproductive phase, while critical stages vary from crop to crop.

7. MANAGEMENT PRACTICES USING SALINE IRRIGATION

The management practices must prevent excessive salt and sodicity accumulation in the soil surface and root zone and control the salt balance in the soil-water system. Irrigation practices for using saline water include the proper irrigation scheduling (amount of water and interval), efficient leaching (amount and timing), proper irrigation method, management of multi-source irrigation water of different quality, establishment of artificial drainage, use of water or soil amendments and crop selection.

7.1 Irrigation Scheduling

Under saline application the set up of an appropriate irrigation scheduling is much more complicated than when fresh water is applied. When saline water is used for irrigation the plant growth is a function of the salinity and matrix potential of the soil. The question that arises is to narrow the watering intervals to keep soil solution concentration low (diminishing the harmful effects of salts) or to lengthen the interval and to apply large amount of water. In the literature, evidence exists supporting both cases. So, exact irrigation interval depend, among others, on salt concentration level in the irrigation water, soil type as well as the prevailing climatic conditions. However, more frequent irrigation is practiced because salts are diluted ensuring higher water availability to plants and lower SAR, since dilution favor the absorption of Ca and Mg over sodium.

7.2. Irrigation Method

The method of application of saline water for irrigation may have large influence on crop production and salt accumulation and distribution in the soil profile. Drip irrigation is recommended as it keeps soil moisture continuously high, at least in part of the root zone, maintaining a low salt concentration level, besides avoiding leaf injury. The problems rising are the need to remove salts that accumulate at the wetting front and to avoid the clogging of the drippers.

7.3. Leaching Requirements

The amount of water (in terms of a fraction of the applied water) that must be applied in excess to the crop to control salts is referred as '*Leaching Requirements*' (LR) and can be calculated, for drip irrigation, from the following formula (Ayers and Wescot, 1985)

$$LR = \frac{ECw}{5(ECe - ECw)}$$

where, ECw is the electrical conductivity (dS/m) of the irrigation water and ECe the average electrical conductivity (dS/m) of the saturation extract of the soil tolerated by the crop. Leaching interacts closely with crop growth, crop yield, irrigation methods and soil physical properties. Depending on the crop and the salinity of the water and soil a 15-20% leaching fraction is recommended. For efficient leaching management, when low quality is used, the EC value of leaching water must be lower than that of the soil, and if possible lower than the irrigation water, frequent tests should be performed on soils under leaching (keeping the soil salinity equivalent to that of water), the leaching should be periodically applied when salts become more excessive rather than at each irrigation and finally to be applied during the cool season when evaporation losses are lower and, if possible, on periods of low water use.

7.4. Management of Multi-Quality Waters

The simplest solution to the problem of high EC is to change the water supply. Frequently this is not possible. Where water sources of different quality are available, blending will increase the total quantity available for irrigation and at the same time it will improve quality (dilution of salts). If blending is not possible, the cyclic use of water of low and high salinity prevents the soil from becoming highly saline while permitting, over a long period, the substitution of brackish water for a substantial fraction of the irrigation needs.

7.5. Establishing Artificial Drainage

When saline water is used for irrigation, existing drainage problems greatly complicate water management for salinity control. Temporary or permanent high water tables (1.8 m or less) make the control of salts difficult because leaching may be ineffective. A more effective way for controlling the salinity problems associated with a high water table is to establish artificial drainage with open or covered drains.

7.6. Using Water or Soil Amendments

Soil permeability problems related to water quality can often be prevented or corrected using soil or water amendments. Improved soil permeability will result if either the sodium in the irrigation water is reduced or the calcium and magnesium will be increased. At present there is no process available for removing the salts from irrigation water cheap enough for use in agriculture. Chemicals, however, can be added to the soil or irrigation water to increase calcium and improve the sodium/calcium ratio. Gypsum, sulfur, or sulfuric acid are the most commonly used soil amendments, while gypsum, sulfuric acid and sulfur dioxide are used as water amendments. Rates for application of gypsum to soil range from 2 ton/ha to 20 ton/ha, while an amount of 10 ton/ha is usually recommended. Less gypsum per hectare is required with water than with soil applications, although for water with high salinity levels, gypsum application is less effective than that in the soil. From the acid forming substances sulfur is not satisfactory for water application, while sulfuric acid is highly corrosive and dangerous to handle.

7.7. Crop Selection

The selection of crops is the practical solution to salinity. Furthermore, the dual rotation strategy with sensitive crops (lettuce, alfalfa, etc.) to be irrigated with low salinity water and the salt tolerant crops (sugar beet, cotton, etc.) with drainage water is quite effective in overcoming salinity hazards.

CONCLUSIONS

Irrigation scheduling is the technique to timely and accurately dose water to the crop and is the key for conserving water and energy, maximizing profit, improving, irrigation performance and sustainability of irrigated agriculture. Irrigation scheduling techniques and tools are quite varied and have different characteristics relative to their applicability and effectiveness for copying with water scarcity. These are based on soil water indicators, crop indicators and climatic indicators or combination of them. An efficient irrigation schedule should take into account the soil properties, soil-water relationships, type of crop and its sensitivity to drought stress, stage of crop development, availability of a water supply, and climatic factors such as rainfall and temperature. Effective irrigation scheduling should be based on the specific technology level of the farm, the irrigation method used, an interactive communication and participatory research involving researchers, system managers, extension workers and farmers. Furthermore, it requires modern pressurized irrigation networks plus rules and regulations for flexible water allocation, which are determined by a set of social, cultural and institutional conditions.

Water quality is becoming increasingly as important as quantity. Salinity is one of the most severe environmental factors limiting the productivity of the agricultural crops. Salinisation of agricultural land, associated with improper irrigation practices, soil management and increasing use of marginal waters (brackish, saline, drainage, reclaimed) for irrigation, is increasing all over the world. The major potential hazards associated with the use of such water in agriculture are: a) Yield decrease due to reduced soil water availability to the crop (osmotic effect), excessive concentration of toxic ions - mainly *Na* and/or *Cl*- in the plant tissues (specific ion effect) and/or nutrient imbalances caused by ion antagonism. b) Soil degradation due to salinisation, sodification and loss of productivity and c) Effects on the environment (pollution of aquifers, changes in plant communities). Actual response to salinity varies with other conditions of growth, including climatic and soil conditions, agronomic and irrigation management, crop variety and the sensitivity of crops at different growth stages. Consolidated standards are available for assessing the water quality and management practices allow marginal waters to be used safely for irrigation.

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