

## 2. SUITABILITY OF TREATED WASTEWATER FOR IRRIGATION

Wastewater is unique in composition. Physical, chemical and biological constituents which occur in this water must be taken into consideration. In this chapter the problems are shortly presented and more emphasis is attached to the solutions and some integrated management approaches are presented in order to alleviate and/or overcome these problems.

### 2.1 Chemical and physical characteristics of wastewater

The constituents of concern in wastewater are given in Appendix I.

However, for proper management approaches, the main constituents of concern to farmers in Near East countries are:

- 1- **Suspended solids** since filtration may be needed particularly with micro-irrigation systems;
- 2- **Nutrients** in order to adjust fertilization;
- 3- **Salinity** in order to estimate leaching fraction and select appropriate cropping pattern; and
- 4- **Pathogens** for precautionary measures, selecting cropping pattern and choosing the appropriate irrigation system.

## ***Wastewater quality criteria for irrigation***

The chemical and physical quality characteristics are the same as applied to any irrigation water. In this respect, the general guidelines presented in (Table 2) can be used to evaluate treated wastewater for irrigation purposes in terms of the chemical constituents such as the dissolved salts, relative sodium content and toxic ions. The procedure remains the same as with other waters.

### **Salinity**

In most countries the water used for municipal supply is the best water quality available and it is usually of low salinity. However, under water scarcity conditions salinity may be a problem. The quantity and kind of salts present are important to assess the suitability of treated wastewater for irrigation. Potential problems are related to the total salt content, to the type of salt or to excessive concentration of one or more elements (Ayers and Westcot, 1985).

Table 2.

Guidelines for interpretation of water quality for irrigation (FAO 1985)

Potential Irrigation		Degree of restriction on use		
		None	Slight to Moderate	Severe
Problems	Units			
<b>Salinity</b>				
EC <sub>w</sub> <sup>1</sup>	dS/m	< 0.7	0.7 - 3.0	> 3.0
or				
TDS	mg/l	< 450	450 - 2000	> 2000
<b>Infiltration</b>				
SAR <sup>2</sup> = 0 - 3	and EC <sub>w</sub> =	> 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

## Specific ion Toxicity

### Sodium (Na)

Surface Irrigation	SAR	< 3	3 – 9	> 9
Sprinkler Irrigation	meq/l	< 3	> 3	

### Chloride (Cl)

Surface Irrigation	meq/l	< 4	4 – 10	> 10
Sprinkler Irrigation	meq/l	< 3	> 3	

### Boron (B)

mg/l	< 0.7	0.7 - 3.0	> 3.0
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### Miscellaneous effects

Nitrogen (NO <sub>3</sub> -N) <sup>3</sup>	mg/l	< 5	5 – 30	> 30
Bicarbonate (HCO <sub>3</sub> )	meq/l	< 1.5	1.5 – 8.5	> 8.5

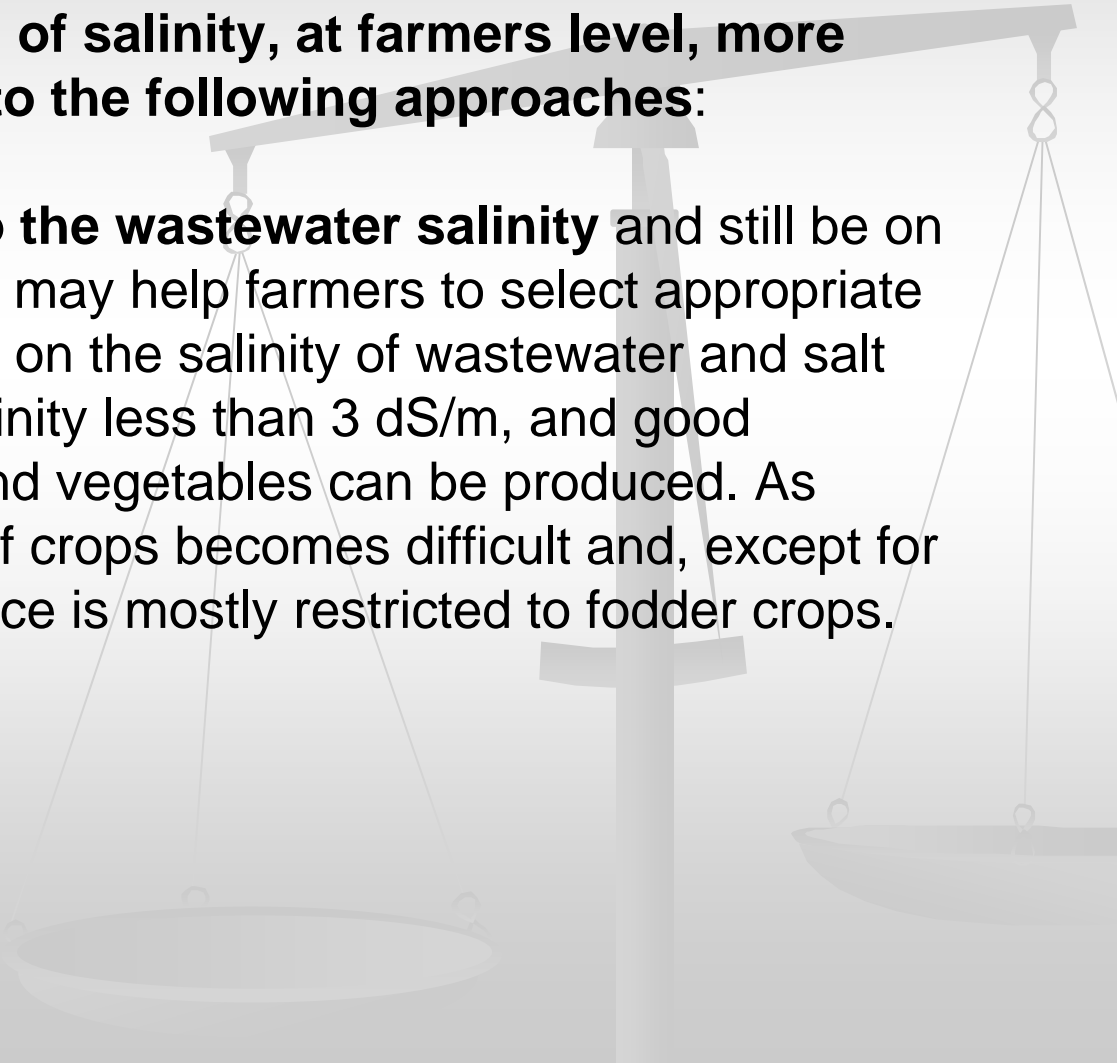
### pH

Normal range 6.5 - 8.4

<sup>1</sup> EC<sub>w</sub> means electrical conductivity in deciSiemens per meter at 25° C.

<sup>2</sup> SAR means sodium adsorption ratio.

<sup>3</sup> NO<sub>3</sub> - N means nitrate nitrogen reported in terms of elemental nitrogen. NH<sub>4</sub>-N and organic-N should be also tested with wastewater.

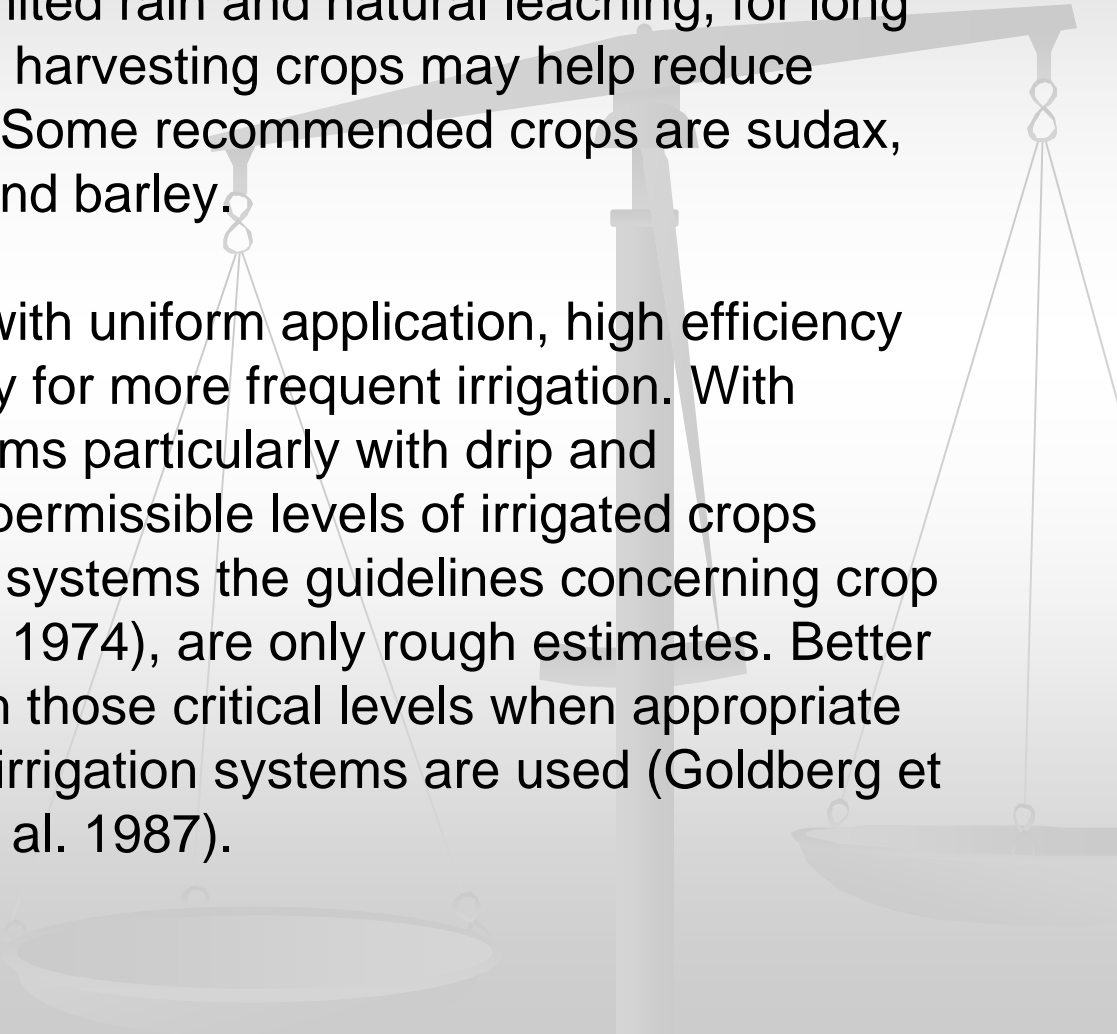


**To overcome the problem of salinity, at farmers level, more emphasis must be given to the following approaches:**

**a) Select crops tolerant to the wastewater salinity** and still be on the profitable site. (Table 3) may help farmers to select appropriate cropping pattern depending on the salinity of wastewater and salt tolerance of crops. With salinity less than 3 dS/m, and good management, most fruits and vegetables can be produced. As salinity rises the selection of crops becomes difficult and, except for certain vegetables, the choice is mostly restricted to fodder crops.

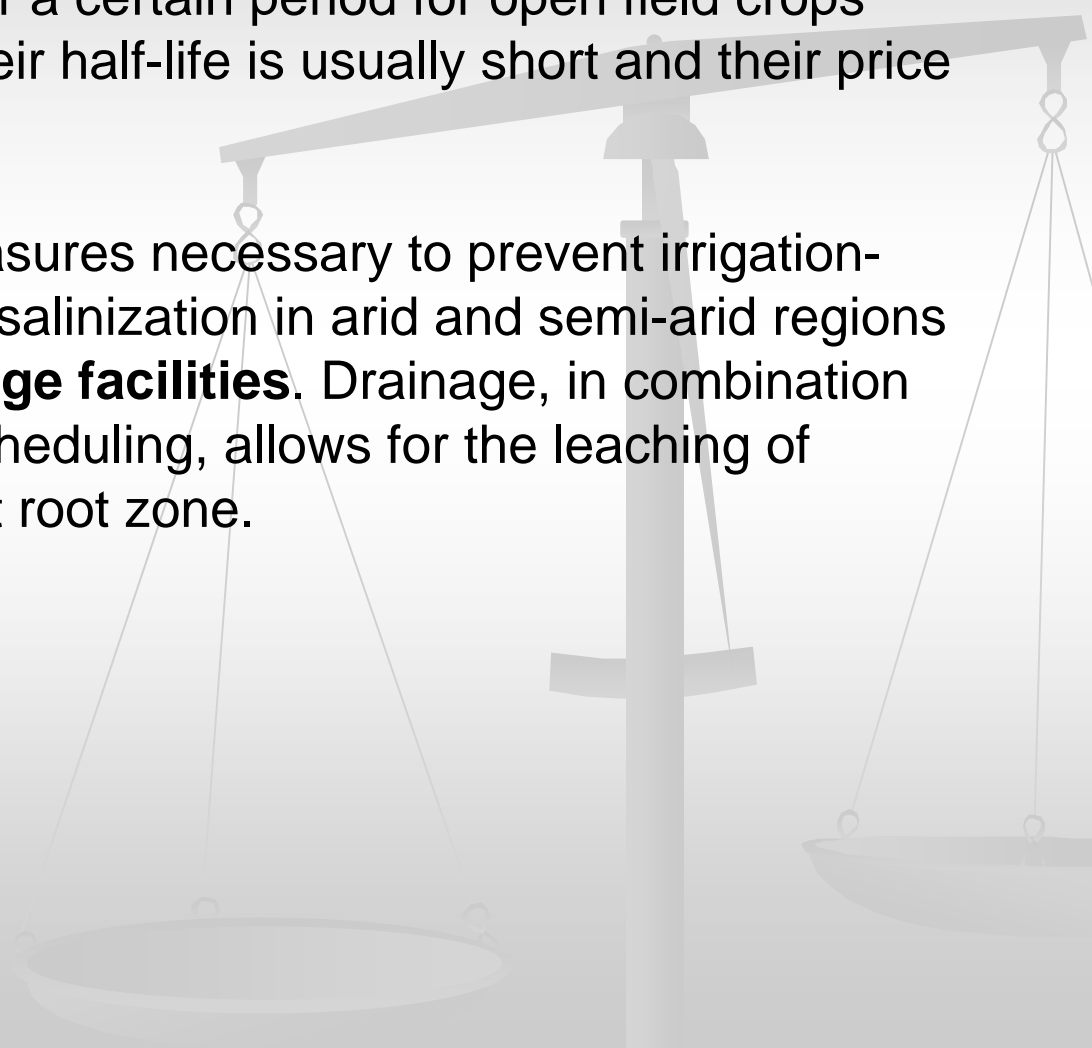
•Table 3. Tolerance to salinity of some cultivated crops (Adapted from FAO, 1985)

Electrical Conductivity of irrigation water (dS/m, and mg/l) *					
<2 <1280	2-3 1280-1920	3-4 1920-2560	4-5 2560-3200	5-7 3200-4480	>7 >4480
Citrus	Fig	Sorghum	Soybean	Safflower	Cotton
Apples	Olives**	Groundnut	Date palm***	Wheat	Barley
Peach	Broccoli	Rice	Harding grass	Sugar beet	Wheat grass
Grapes	Tomato	Beets	Trefoil	Rye grass	
Strawberry	Cucumber	Tall fescue	Artichokes	Barley grass	
Potato	Cantaloupe			Bermuda grass	
Pepper	Watermelon			Sudax	
Carrot	Spinach				
Onion	Vetch				
Beans	Sudan grass				
Corn	Alfalfa				

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- b) Select salt tolerant crops with the ability to absorb high amounts of salts** without particular toxicity effects (salt harvesting crops). In case of irrigation with treated wastewater of high salinity, particularly in areas with limited rain and natural leaching, for long term sustainable reuse salt harvesting crops may help reduce salinity build-up in the soil. Some recommended crops are sudax, sorghum, bermuda grass and barley.
- c) Select irrigation system** with uniform application, high efficiency and providing the possibility for more frequent irrigation. With pressurised irrigation systems particularly with drip and minisprinklers, the salinity permissible levels of irrigated crops could be higher. With such systems the guidelines concerning crop tolerance to salinity (Maas, 1974), are only rough estimates. Better yields can be achieved with those critical levels when appropriate management with modern irrigation systems are used (Goldberg et al., 1971; Papadopoulos et al. 1987).

**d) Scheduling of irrigation.** The amount of irrigation water and the frequency of water application are crucial factors to control salinity. With micro-irrigation systems, irrigation could be more frequent and soil salinity in the vicinity of the irrigated plant could be maintained at a lower level.

**e) Leaching** is a common approach by farmers but not the best probable solution in the case of water scarcity, inadequate drainage or shallow water table. In a long term the total quantity of salt applied in the soil with the wastewater (salt in) and the rate at which salt is removed by leaching and crop uptake (salt out) should be approximately the same. Which approach is to be accepted for the “salt out” is very important in selecting cropping pattern and management for the effective use of wastewater for irrigation (Papadopoulos, 1991). Salt harvesting crops of economical value like sudax and sorghum give good results. Cultivating a salt harvesting-crop every year or periodically is recommended.

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- f) **Soil polymers and/or other soil conditioners** although effective under certain conditions for a certain period for open field crops are not recommended. Their half-life is usually short and their price is high.
- g) **Drainage.** One of the measures necessary to prevent irrigation-induced waterlogging and salinization in arid and semi-arid regions is the installation of **drainage facilities**. Drainage, in combination with adequate irrigation scheduling, allows for the leaching of excess salts from the plant root zone.

## **Alkalinity**

Dispersion of soil colloidal phase, stability of aggregates, soil structure and permeability for water, are very sensitive to the type of exchangeable ions present in irrigation water. The increase in soil alkalinity, which may occur with treated wastewater due to high Na concentration even though leaching is allowed, reduces soil permeability for water, particularly at the soil surface, since soil clays tend to disperse and swell from the increased level of exchangeable Na. However, at certain sodium adsorption ratio (SAR) the infiltration rate increases or decreases with the salinity level. Therefore, SAR and  $EC_w$  should be used in combination to evaluate eventual potential problems (Rhoades, 1977).

**The following management solutions are recommended:**

**a) Chemical amendments.** The use of calcium source amendment such as gypsum is widely accepted for amelioration of soils with high percentage of Na in the Cation Exchange Capacity (CEC) or whenever water high in SAR is used for irrigation. Na in soil is exchanged by Ca from gypsum and dispersion of the colloidal phase is reduced. Application of gypsum should be repeated periodically depending on the Na content in water and the CEC of the soil. The farmers are advised to seek professional help to estimate the amount and frequency of the gypsum application required.

**b) Adapted Irrigation system.** Crust formation at the soil surface is the result of irrigating with water high in SAR. The degree of the problem, however, is not the same with all irrigation systems. In general, *the surface irrigation systems* with water high in SAR create thick surface crust. Similar results are obtained with sprinklers of high discharge capacity. This way, the soil permeability for water as well as soil aeration and emergence of the seeds are affected. With low capacity minisprinklers and drippers of low discharge rate the formation of surface soil crusting is reduced, the duration of irrigation is extended and sufficient time is allowed for water penetration into the soil (Papadopoulos and Stylianou, 1988a).

**c) Organic matter.** The alkalinity problem could also be solved by addition of organic matter like straw, other plant materials and organic manure.

## **Measures recommended to overcome ion-toxicity:**

1- With sensitive crops, B-toxicity is difficult to correct without changing the crop or the

water supply (Ayers, 1977). For water with certain level of boron, one should select crops which can tolerate that concentration.

2- Leaching may help to maintain boron concentration in the soil at levels comparable to those of the water used for irrigation (Bernstein and Francois, 1973). Depending on the soil, a certain additional amount of irrigation water is usually added to the estimated irrigation requirement.

3- The frequent irrigation dilutes boron in the soil solution.

4- With the use of micro-irrigation systems, water application could be more uniform and frequency of irrigation could also be controlled.

**Table 4. Relative tolerances of plants to boron in irrigation water (Adapted from Ayers, 1977)**

<b>Sensitive (1mg/l)</b>	<b>Semitolerant (2 mg/l)</b>	<b>Tolerant (3 mg/l)</b>
Citrus	Bean	Carrot
Avocado	Bell pepper	Lettuce
Apricot	Tomato	Cabbage
Peach	Corn	Onion
Cherry	Olives	Sugar beet
Grapes	Radish	Date palm
Apple	Pumpkin	Asparagus
Pear	Wheat	Turnip
Plum	Potato	
Strawberries	Sunflower	

Chloride (Cl) and sodium (Na) are less toxic than boron. In arid and semiarid regions due to the relatively high Na and Cl contents of the domestic water, treated wastewater may have high concentration of these elements. With proper irrigation management, (irrigation system, frequency of irrigation, leaching) toxicity effects can be reduced significantly, presenting no real constraint for reuse.

## **T race elements and heavy metals**

They are the main problem with treated wastewater reuse in countries with heavy industry. The metals that may be present in sewage {Cadmium (Cd), copper (Cu), molybdenum (Mo), nickel (Ni) and zinc (Zn)} can pose significant health hazards to humans and animals and also may affect the irrigated crops. These metals in most cases are accumulated in the crop, and could adversely affect humans or domestic animals, feeding on these crops. Because of this, many developed countries have set maximum permissible cumulative loading of metals to agricultural lands. Heavy metals are discussed in more details in connection with sludge. Biswas (1987) reported permissible heavy metal loading in some European countries

Therefore:

1- Heavy metals in treated wastewater under calcareous soil conditions should not be considered, as real problem and no particular management is required.

2- Under acid conditions (few cases in the Region :pH<7) heavy metals could be a problem and the following measures at farmers level are recommended:

- \* Liming (use of calcium carbonate). In this way soil pH is increased and thus the solubility of heavy metals is reduced.
- \* Avoid using acid fertilizers.
- \* Select crops tolerant to certain heavy metals.
- Select crops having no biomagnification characteristics (accumulation of certain heavy metals by specific crops and/or parts of the crop).

Farmers should be encouraged to consult professionals before making the final decision on the measures needed.

## **Control of the problem of eventual excess N in wastewater**

**a) Estimate the concentration of N.** The chemical analysis for elemental N is required. Based on this analysis the farmer could calculate the amount of N added to the soil through the quantity of wastewater used. This amount should be subtracted from the fertilizer amount needed by crops. For easy estimations the farmer should remember that:

**1 ppm (part per million) = 1 mg/l = 1 g/m<sup>3</sup> in irrigation water**

Therefore, the amount of N and other nutrients applied to the soil with wastewater depends on the amount of irrigation water. The farmers should be aware how to irrigate.

## **b) Select the crop based on the N level.**

Selection of crop depending on N in treated wastewater is needed for two purposes:

- **Making the best possible use of N from wastewater.**

If nitrogen present in wastewater is not adequate, supplemental fertilizer nitrogen is needed for satisfactory crop yields. From the standpoint of long-term application of wastewater, N input levels should be adjusted to compensate for N removal by the harvested portion of the crop plus expected losses from the system by volatilization and leaching. The N, P, K requirement of main crops is given in the following chapters.

- **Avoiding nitrate pollution.**

Some crops are highly effective in removing nitrogen from soil, which may eventually move down in the form of  $\text{NO}_3\text{-N}$  deeper in soil and contaminate underground water. Grasses such as Sudan grass, Bermuda grass, Sudax, and Rhodes grass remove N efficiently from the soil. These crops are effective in removing nitrates for the following reasons:

- they have abilities to accumulate nitrate;
- several cuts are possible in one season so that more growth of the crop can be achieved;
- their nitrate content does not decrease with age; and
- they are deep-rooted crops

**c) Scheduling of irrigation.** Since nutrients are always present in treated wastewater, then any amount of irrigation water above the crop water requirement may create a problem. The problem could be an environmental or an agronomic one or both. The farmer should remember that with wastewater irrigation it is even more important to follow proper scheduling of irrigation than that with water of good quality.

- **Amount of water.**

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- **Frequency of irrigation.**

**d) Irrigation system.** To avoid pollution from nitrates the irrigation system should provide a uniform water application. Evidently, the higher the efficiency of irrigation system, the higher N uptake efficiency by crops is obtained and the less is the potential for nitrate losses and pollution. Proper designed, installed, and managed drip and micro-irrigation systems give higher irrigation efficiency. With furrow irrigation the farmers are advised to create short furrows especially if laser leveling is unavailable.

- **e) Mixing treated wastewater with fresh water, if available.**

## Irrigation system (method) and efficiency of N, P, K uptake.

Table 14. Fertilizer (NPK) uptake in % as influenced by the irrigation system (FAO/RNEA, 1992).

Irrigation system*	Nitrogen	Phosphorus	Potassium
Furrow	40-60	10-20	60-75
Sprinkler	60-70	15-25	70-80
Microirrigation	75-85	25-35	80-90

\*The values refer to good designed and operated irrigation systems

With surface irrigation methods, the fertilizer use efficiency is the lowest. In particular, due to leaching, the N use efficiency can be considerably low. Therefore, in order to estimate the overall amount of nutrients, which must be present in soil to meet crop nutrient requirements for certain yield, the efficiency of the fertilizer nutrient uptake by the crop is needed.

### **Nitrogen, Phosphorus and Potassium requirement of different crops**

Taking into account the nutrient requirement for certain yield, the nutrient capacity of soil and wastewater, and the efficiency of nutrient uptake by crop under different irrigation systems, the following formula can be used to estimate the amount of N, P and K required being readily available in soil:

## Irrigation methods

- **Surface (traditional) methods**

Flood irrigation (by border or basin), wetting almost all the land surface

Hose-basin irrigation. The water is delivered by hose

Furrow irrigation, wetting only part of the ground surface.

- **Pressurised irrigation methods**

**Sprinklers** (Sprinklers of high capacity, ordinary mini-sprinklers, and sprayers). Crops and soil are wetted the same way as rain.

**Drip** (point or localized irrigation system). The main characteristics of the system are:

1- High application efficiency. It is probably, if it is used properly, the best method for irrigation in places where scarcity of water is a problem.

2- Appropriate method to cope with problems associated with saline irrigation water and soil alkalinity.

3- This method is safe and in general might be the most promising for irrigation with wastewater, particularly if purification is such to prevent extensive clogging.

4- Contact of wastewater with both the farmers and the irrigated crops is minimized.

5- No aerosols are formed and, therefore, no pollution of the atmosphere and of the area nearby to the irrigated fields occurs.

Evaluation of Common Irrigation Methods for their Suitability to Use Brackish Water (Kandiah, 1990)

Parameters of Evaluation	Furrow Irrigation	Border Irrigation	Sprinkler Irrigation	Drip Irrigation
Foliar wetting and consequent leaf damage resulting in poor yield	No foliar injury as the crop is planted on the ridge	Some bottom leaves may be affected, but the damage is not so serious to reduce yield	Severe leaf damage can occur resulting in significant yield loss	No foliar injury occurs under this method of irrigation
Salt accumulation in the root zone with repeated applications	Salts tend to accumulate in the ridge which could harm the crop	Salts move vertically downwards and are not likely to accumulate in the root zone	Salt movement is downwards and root zone is not likely to accumulate salts	Salt movements are radial along the direction of water movement. A salt wedge is formed between drip points
Ability to maintain high soil water potential	Plants may be subject to stress between irrigations	Plants may be subject to water stress between irrigations	Not possible to maintain high soil water potential throughout the growing season	Possible to maintain high soil water potential throughout the growing season and minimise the effect of salinity

## **Strategy to protect human health and environment**

Human health and environment could be protected through four groups of measures (Mara and Cairncross, 1987):

Wastewater treatment level

Restriction of the crops grown

Irrigation methods and

Control human exposure to the waste, and hygiene.

Full treatment prevents excreted pathogens from reaching the field.

However, the farmers in most of the cases have to cope with wastewater of a certain quality. Because of this, for the farmers crop restriction, irrigation system and human exposure control which act later in the pathway, are more important. A combination of agro-technical measures to be selected, depending on the local socio-cultural, institutional and economic conditions may provide health protection.

### ***Crop selection for health protection***

Wastewater which has been treated to the WHO quality guidelines for unrestricted use (<1000 faecal coliforms per 100 ml and < 1 nematode egg per l) can be used to irrigate all crops, without further health protection measures. If the WHO quality guidelines are not fully met, it may still be possible to irrigate selected crops without risk to the consumer (Fig. 1).

Crops can be grouped into three broad categories with regard to the degree to which health protection measures are required (Shuval et. al., 1986).

## **Category A      Protection needed only for field workers:**

- Crops not for human consumption (cotton, sisal)
- Crops normally processed by heat or drying before human consumption (grains, oilseeds, sugar beet)
- Vegetables and fruits grown exclusively for canning or other processing that effectively destroys pathogens
- Fodder crops sun-dried and harvested before consumption by animals
- Landscape irrigation in fenced areas without public access (nurseries, forests, and greenbelts).

## **Category B      Further measures may be needed:**

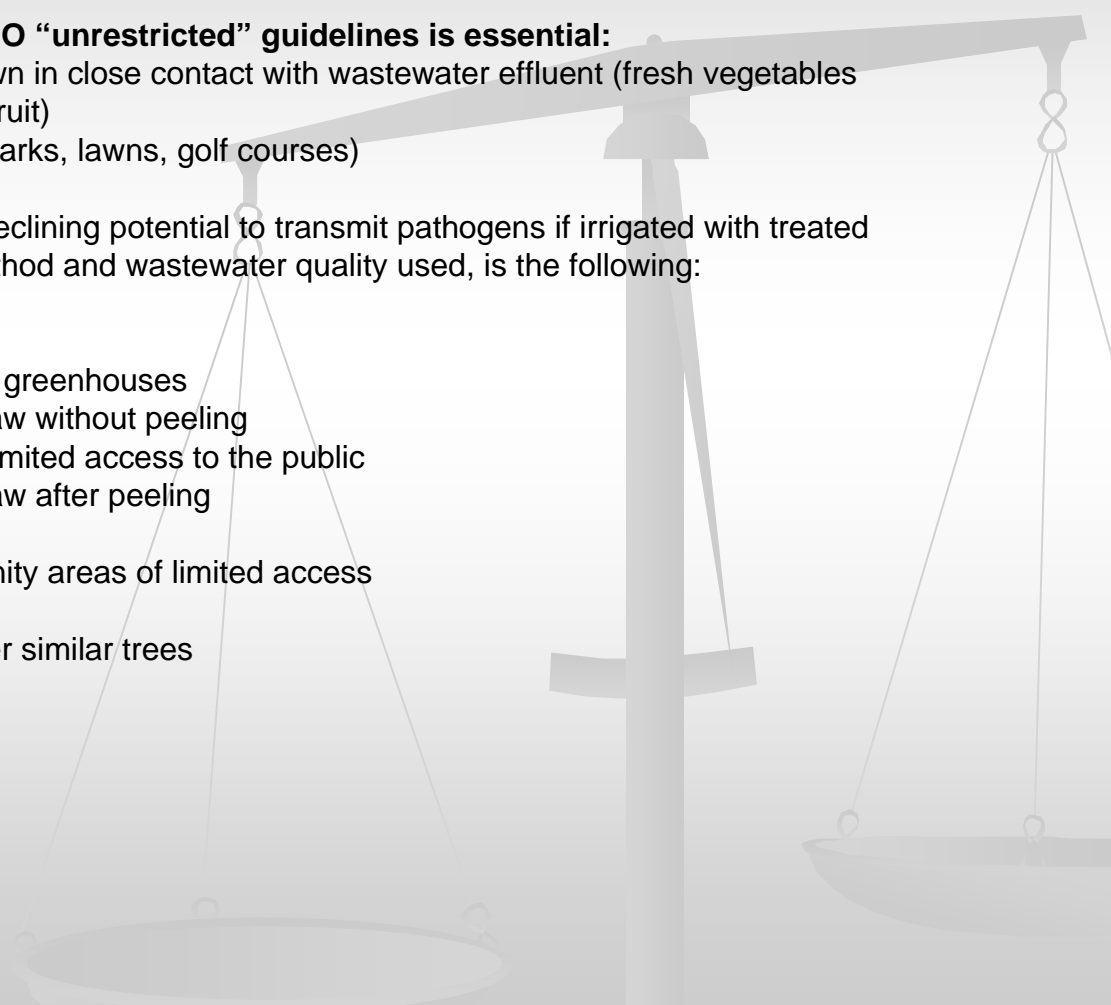
- Pasturelands, green fodder crops
- Crops for human consumption that do not come into direct contact with wastewater, on condition that none must be picked off the ground and that spray irrigation must not be used (tree crops, vineyards, etc.)
- Crops for human consumption normally eaten only after cooking (potatoes, eggplant, beetroots)
- Crops for human consumption, the peel of which is not eaten (melons, watermelons, citrus, bananas, nuts, groundnuts)
- Any crop if sprinkler irrigation is used.

**Category C Treatment to WHO “unrestricted” guidelines is essential:**

- Any crops often eaten uncooked and grown in close contact with wastewater effluent (fresh vegetables such as lettuce or carrots, or spray-irrigated fruit)
- Landscape irrigation with public access (parks, lawns, golf courses)

A useful arrangement of crops with declining potential to transmit pathogens if irrigated with treated wastewater, irrespective of the irrigation method and wastewater quality used, is the following:

- 1) Vegetables eaten raw
- 2) Vegetables eaten cooked
- 3) Ornamentals raised for sale in greenhouses
- 4) Trees producing fruits eaten raw without peeling
- 5) Lawns in amenity areas of unlimited access to the public
- 6) Trees producing fruits eaten raw after peeling
- 7) Table grapes
- 8) Lawns and other trees in amenity areas of limited access
- 9) Fodder crops
- 10) Trees producing nuts and other similar trees
- 11) Industrial crops



## ENVIRONMENTAL ASPECTS ASSOCIATED WITH WASTEWATER USE FOR IRRIGATION

When wastewater is used properly for agricultural purposes, than being disposed in any other way, improvement of the environment could be achieved. The following are some of the environmental benefits:

- Avoidance of discharge to surface waters, preventing occurrence of unpleasant esthetic situations, anaerobic conditions in rivers and eutrophication of lakes and reservoirs.
- Saving groundwater resources
- Possibility of soil conservation and its improvement by humus build-up on agricultural land and the prevention of land erosion.

### **Potential negative environmental effects**

Wastewater use for irrigation may have also negative effects on the environment and human health. The principal environmental hazards associated with wastewater are:

- The introduction of chemicals into susceptible ecosystems (mainly soil, water and plants) and
- The spread of pathogens.

## Effects on soil

These effects are of particular importance for the farmers since they may reduce soil productivity, fertility and yield. Soil should remain at a good level of chemical and physical characteristics in order to enable long term sustainable use and profitable agriculture. The expected soil problems are:

Salinization

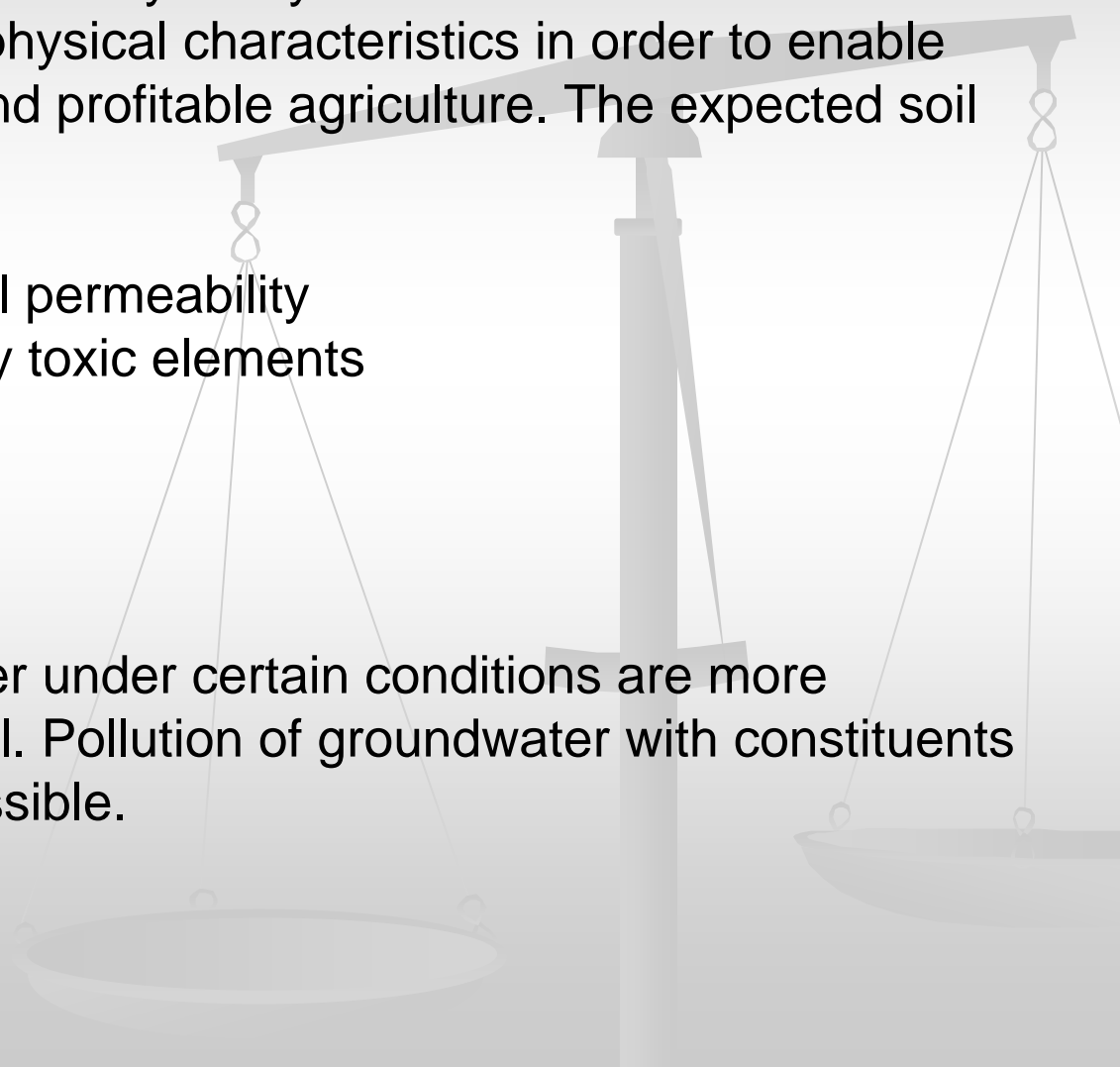
Alkalinity and reduced soil permeability

Accumulation of potentially toxic elements

Accumulation of nutrients.

## Effects on groundwater

The effects on groundwater under certain conditions are more important than effects on soil. Pollution of groundwater with constituents present in wastewater is possible.



## **The following management aspects to reduce and/or overcome the problem are recommended:**

- Irrigation (amount of water) based on crop water requirement with minimum leaching if needed.
- Scheduling of irrigation based on crop water requirement, soil water holding capacity and wastewater quality.
- Select crops, which may absorb potentially hazardous constituents present in wastewater.
- In case of saline waters introduce in the cropping pattern salt harvesting crops.
- To avoid contamination by  $\text{NO}_3\text{-N}$  the amount of water could be restricted to that amount which supplies the N required by the crop and if N exceeds crop requirement then:
  - \* Select crop with higher N requirement.
  - \* Select the irrigation system that provides the highest possible application uniformity.
  - \* Blending of water with fresh water
  - \* Keep operation and maintenance of irrigation systems at acceptable level.

## **Effects on surface water bodies**

***Eutrophication, growth of algae***