



Deliverable n.16

Handbook to be implemented in regional extension program



AL-AZHAR UNIVERSITY – GAZA – PALESTINE

AAUG

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TRAINING COURSE

**IRRIGATION AND SALINE WATER
MANAGEMENT**

AL-AZHAR UNIVERSITY – GAZA – PALESTINE

HORTIMED PROJECT

MARCH 2002

ENGLISH - PART

IRRIGATION AND SALINE WATER MANAGEMENT

Water Quality Evaluation for Irrigation Purposes

Factors govern water use for agricultural purposes:

- ? Quantity and availability of water.
- ? Economics of water.
- ? Soil type (textures and structure).
- ? Crop patterns.
- ? Irrigation Techniques.
- ? Quality of Water

The following parameters should be considered to evaluate the suitability of water for irrigation purposes:

1. Salinity

The quantity and kind of salts present in the groundwater is probably the most important single parameter for evaluating the suitability of water for irrigation. Salinity of irrigation water is usually determined by measuring its electrical conductivity and is the most important parameter in determining the suitability of water for irrigation. The electrical conductivity is expressed as mmho/cm or decisiemens per meter (dS/m). Salinity is expressed also into (TDS) which is the concentration of soluble salts in the water sample in mg/l , where:

$EC * 640 = \text{ppm (part per million) or mg/l}$

$EC * 0.36 = \text{Osmotic pressure}$

$EC * 10 = \text{meq/ L of total cations or anions.}$

$\% \text{ Salts} * 10,000 = \text{ppm}$

Potential problems are related to the total salt content, to the type of salt or to excessive concentration of one or more elements. In a long term strategy, the total quantity of salt applied in the soil with the irrigation effluent (salt added) and the rate at which salt is removed by leaching and crop uptake (salt removed) should be approximately the same.

The presence of salts affects plant growth in three ways:

- ? Osmotic effects which caused by dissolved salts concentration in the soil water.
- ? Specific ion toxicity, caused by the concentration of an individual ion ,e.g. boron, sodium, and chloride.
- ? Soil particles dispersion caused by high sodium and low salinity.

In irrigated areas, salts originate from the local ground water or from salts in the applied water. Under such conditions, good drainage is essential to allow movement of water and salt below the root zone. Salinity control is of particular concern in areas where annual rainfall is not adequate to maintain an acceptable salt balance. This concern is acute in arid and semi-arid regions throughout the world, and should be accounted for planning purposes particularly the increment of salts in the domestic water after using it in the houses as shown below in table 1.

Table 1. Typical minerals increase from domestic water use.

Constitute	Increment range mg/l
Anions	
Bicarbonate (HCO ₃)	50 – 100
Carbonate (CO ₃)	0 – 10
Chloride (Cl)	20 – 50
Nitrate (NO ₃)	20 – 40
Phosphate (PO ₄)	5 – 15
Sulphate (SO ₄)	15 – 30
Cations	
Calcium (Ca)	6 – 16
Potassium (K)	7 – 15
Sodium (Na)	40 – 70
Magnesium (Mg)	4 – 10
Total Dissolved Solids (TDS)	150 – 380

Source: Metcalf & Eddy, 1991

2. Sodictity: Sodium Adsorption Ratio(SAR)

SAR is a calculated value and used as an indicator of probable influence that the Na ion has on soil physical properties. If SAR value is high, poor aeration and low permeability is expected particularly in heavy textured soils.

SAR is calculated from this formula:

$$SAR = \frac{Na}{\sqrt{(Ca + Mg) / 2}}$$

Where:

Na, Ca, Mg, concentration are expressed in meq/liter.

Table 2. The classification of SAR based on U.S. laboratory as below:

SAR	Classification
0-7	Low Sodium
7-13	Medium Sodium
13-20	High Sodium
>20	Very high Sodium

The interaction between SAR and EC illustrated in FAO guidelines for interpretations of water quality for irrigation is shown in table 2.

Classification of Salinity and SAR

C1 - Low salinity water -- can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of slow and very slow permeability.

C2 - Medium salinity water -- can be used if a moderate amount of leaching occurs. In most cases plants with moderate salt tolerance can be grown without special practices for salinity control.

C3 - High salinity water -- cannot be used on soils with moderately slow to very slow permeability. Even with adequate permeability, special management for salinity control may be required and plants with good salt tolerance should be selected.

C4 - Very high salinity water -- not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must have rapid permeability, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt tolerant crops should be selected.

Sodium:

S1 - Low sodium water -- can be used for irrigation on almost all soils with little danger of development of harmful levels of exchangeable sodium.

S2 - Medium sodium water -- will present an appreciable sodium hazard in fine textured soils, especially under low leaching conditions. This water may be used on coarse textured soils with moderately rapid to very rapid permeability.

S3 - High sodium water -- will produce harmful levels of exchangeable sodium in most soils and requires special soil management, good drainage, high leaching, and high organic matter additions.

S4 - Very high sodium water – generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity.

Table 3. Guidelines for interpretations of water quality for irrigation (FAO, 1985)

Potential Problem	Irrigation	Units	Degree of restriction on use		
			None	Moderate	Severe
Salinity					
Ecw		dS/m	<0.7	0.7 - 3.0	> 3.0
or TDS		mg/l	450	450-2000	>2000
Infiltration					
SAR = 0-3 and EC					
3-6			> 0.7	0.7 - 0.2	< 0.2
6-12			> 1.2	1.2 - 0.3	< 0.3
12-20			> 1.9	1.9 - 0.5	< 0.5
20-40			> 2.9	2.9 - 1.3	< 1.3
			> 5.0	5.0 - 2.9	< 2.9
Specific ion Toxicity					
Sodium (Na)					
Surface Irrigation		SAR	< 3	3 - 9	> 9
Sprinkler Irrigation		me/l	< 3 > 3		
Chloride (CL)					
Surface Irrigation		SAR	< 4	4 - 10	> 10
Sprinkler Irrigation		me/l	< 4	> 3	
Boron (B)					
		mg/l	< 0.7	0.7- 3.0	> 3.
Miscellaneous effects					
Nitrogen (NO ₃ -N)		mg/l	< 5	5-30	> 30
Bicarbonate (HCO ₃)		mg/l	<1.5	1.5 - 8.5	> 8.5
PH				Normal Range 6.5 -8.4	

3. Carbonate and Bicarbonate

High carbonate (CO₃²⁻) and bicarbonate (HCO₃⁻) in water essentially increases the sodium hazard of the water to a level greater than that indicated by the SAR. High CO₃²⁻ and HCO₃⁻ tend to precipitate calcium carbonate (CaCO₃) and magnesium carbonate (MgCO₃) when the soil solution concentrates during soil drying. The concentrations of calcium and magnesium in soil solution are reduced relative to sodium and the SAR of the soil solution tends to increase.

☞ Saline and Sodic Soils

Salt affected soils are grouped according to their content of soluble salts and sodium (Table 2). Saline and Sodic soils usually occur in areas where ground water moves upward from a shallow water table close to the soil surface. The water carries salts which accumulate in the soil as the water is evaporated from the soil surface or

transpired through the plants to the atmosphere. **In general, these soils are not recommended for irrigation.**

Table 4. Soil chemistry measurements used to classify saline, sodic and saline-sodic soils.

Soil	Conductivity*	pH	SAR
Saline soil	Greater than 4	Less than 8.5	Less than 13
Sodic soil	Less than 4	8.5 to 10.0	Greater than 13
Saline-sodic	Greater than 4	Less than 8.5	Greater than 13

*Measured from a saturated soil extract

Under some conditions, *sodium* can be controlled in the upper part of the soil through the use of calcium amendments. The replacement of sodium by calcium improves the structure of the soil. Calcium soil amendments can be helpful in situations where land with a majority of unaffected irrigable soils contains pockets (inclusions) of sodium affected soils. Under irrigation, calcium soil amendments will help where surface crusting has become a problem. Special irrigation management practices may be required on these soils.

4. Boron

Boron is essential for the normal growth of all plants, but the quantity required is very small. Plants sensitive to boron, such as dry beans, require much smaller amounts than plants that are tolerant of boron, such as corn, potatoes and alfalfa. In fact, the concentration of boron that will injure the sensitive plants is often close to that required for normal growth of tolerant plants.

Boron concentration greater than 2 parts per million (ppm) may be problem for certain sensitive crops, especially in years that require large quantities of irrigation water. (See annex 2)

Minimize fresh water use in agriculture

In the arid and semi-arid areas where the fresh water is limiting factor for domestic use and agriculture irrigation; other means must be found in order to reduce the dependant on the fresh water in agriculture production. Some of these means:

1- Using salty water

- Selecting tolerance crops
- Crop management
- Saline water management
- Soil management

2- Increasing water consumption efficiency through

- Determine the crop water requirements
- Increasing irrigation system efficiency

3- Using treated wastewater

4- Rain water collection

In this training course the concentration will be on:

- Using salty water.
- Increasing water consumption efficiency.

Using Salty Water

Management for crop production

-Planting suitable tolerance crops

Where salinity cannot be kept within acceptable limits by leaching, crops should be selected that can produce satisfactory yields under the resulting saline conditions. In selecting crops for saline soils, particular attention should be given to the salt tolerance of the crop during seedling development, because poor yield frequently result from failure to obtain a satisfactory stand. Some crops that are salt tolerance during later stages of growth are quite sensitive to salinity during early growth.

-Crop tolerance to salinity

Selection of Crop patterns

The relative salt tolerance of most agricultural crops is known well enough to give general salt tolerance guidelines. Annex 1 presents a list of crops classified according to their tolerance and sensitivity to salinity.

To obtain maximum yields, water should be applied to crops before the soil moisture potential reaches a level at which the evapotranspiration rate is likely to be reduced below its potential. The relationship of actual and maximum yields to actual and potential evapotranspiration is illustrated in the following equation:

$$(1 - Y_a/Y_m) = K_y (1 - E_{Ta} / E_{Tm})$$

where:

Y_a = actual harvested yield

Y_m = maximum harvested yield

k_y = yield response factor

E_{Ta} = actual evapotranspiration

E_{Tm} = maximum evapotranspiration

The following general conclusions can be drawn from these data:

- i. Full yield potential should be achievable with nearly all crops when using a water with salinity less than 0.7 dS/m,
- ii. When using irrigation water of slight to moderate salinity (i.e. 0.7-3.0 dS/m), full yield potential is still possible but care must be taken to achieve the required leaching fraction in order to maintain soil salinity within the tolerance of the crops. Treated sewage effluent will normally fall within this group,
- iii. For higher salinity water (more than 3.0 dS/m) and sensitive crops, increasing leaching to satisfy a leaching requirement greater than 0.25 to 0.30 might not be practicable because of the excessive amount of water required.

-Factors affecting tolerance

Culture practices

Use of land preparation to increase the uniformity of water distribution and infiltration, leaching and removal of salinity. Some management practices for the soil can be done to improve the salinity control.

Land smoothing

Salinity control is difficult if the field is not sufficiently graded to permit uniform water distribution. Salts accumulate in the high spots which have too little penetration and leaching, while water accumulates in low-laying areas which cause water logging and potential drainage problems. Germination is often poor in high spots due to shortage of water and excessive salinity, while in low areas similar poor crop growth may result from water logging and soil crusting. The most difficult problems occur with flood irrigation while for sprinkler and drip irrigation require smoothing or grading only to the extent needed to prevent water accumulating excessively in low areas. Land smoothing is simply smoothing the soil surface.

Improving subsurface drainage

Subsurface drainage problems and shallow water tables greatly complicated salinity control. Shallow water tables frequently occur due to the presence of a slowly permeable layer below the soil surface such as clay barrier, hard pan or bedrock. Drainage problem caused by over irrigation but may also be caused by seepage from up slope areas or leakage from channels. The most effective control of salinity associated with a shallow water table. by lowering and stabilizing the water table with adequate drainage irrigation management can control surface soil salinity.

Deep ploughing

Stratified or layered soils are difficult to irrigate efficiently. The layers of clay and hardpans prevent deep percolation of water which essential for salinity control. So sub-soiling and chiseling can destroy these layer and make the soil more permeable to water.

Tillage

Tillage is carried out for seedbed preparation, soil permeability improvement, to break up the surface crusts and to improve water infiltration.

Placement of seed

The rate of germination of seeds is reduced by the excessive salinity, the failures are usually due to accumulation of soluble salt in raised beds. Modification of the

irrigation practices and seedbed shape should be used to reduce the salt accumulation need the seed

Fertilization

The addition of fertilizers, manure and soil amendments include many soluble salts in high concentrations closed to the germination seedling or the growing plant may cause a salinity or toxicity problem. Care in placement, timing of fertilizer and type of fertilize should be considered in fertilizer application. Salts tolerance of a crop is generally considered to be un-affected by raising the level of soil fertility above that necessary to supply needed nutrients for optimal growth. If both salinity and low fertility are limiting the yield, correction of either both will improve yield. but if the fertility is adequate and salinity is limiting the yield, the increasing in the fertility will not increasing the yield.

Sanding

Addition of sand to the surface soil is used to make a fine texture and more permeable surface. Sanding results in improving root penetration and better air and water permeability and infiltration.

Chemical amendments

Chemical amendment can be used to neutralize soil reaction. It reacts with calcium carbonate and replaces the exchangeable sodium by calcium. This decreases the ESP and should be followed by leaching for removal of salts. They also decrease the SAR of irrigation water if added to the irrigation system.

Organic and green manure

Incorporation organic matter into the soil has beneficial effects of soils irrigated with saline water with high SAR and on sodic soils. The organic manure improve the soil permeability and release of carbon dioxide; this will help in lowering the soil pH, releasing of calcium and replacement of exchangeable Na by Ca and Mg which lowering the ESP.

Mulching

Mulching to reduce evaporation from the soil surface will decrease the opportunity of soil salinization. When using saline water where the concentration of soluble salts in the soil is expected to be high in the surface, mulching can considerably help in leach salts, reduce ESP and thus facilitate the production of tolerant crop.

Management Practices for Irrigating with Saline or Sodic Water

If poor-quality water is used for irrigation, one or more of the following practices may be necessary to avoid soil problems that will limit crop yields.

- Provide adequate internal drainage.
- Meet the necessary leaching requirement (over-irrigation) depending on crop and EC_w of water. A leaching requirement can be calculated from water test results and tolerance levels for specific crops. This is necessary to avoid buildup of salt in the soil solution to levels that will limit crop yields.
- Maintain higher available water in the soil.
- Monitor salt and sodium with saline-alkali soil tests every 1 to 2 years.
- Add soluble calcium such as gypsum (calcium sulfate) to decrease the SAR to a safe value.
- Restricted use. Use only during drought periods to supplement below normal rainfall or when other sources of water are inadequate. Occasional use of practice 4 may be necessary.

The use of saline groundwater in conjunctive with fresh surface water is an important mean to mitigate salinity level in the irrigating water.

Irrigating frequency (Timing of irrigation)

In order to improve water stress when using higher salinity water timing of irrigation is very important. Timing of irrigation may include increasing the frequency of irrigation. The goal of timing of irrigation is to reduce salinity and avoid water stress between irrigation. Water stress between irrigation can often be eliminated by increasing the frequency of irrigation, thereby preventing excessive root zone depletion caused by too long intervals between irrigation. By decreasing the interval between irrigation a higher soil water availability is maintained.

Changing methods of irrigation

The method of irrigation directly affects both the efficiency of the water use and the way of salt accumulates. Surface and sprinkler irrigation applies water over the entire irrigated area. This results in most of the salts accumulating in the lower root zone. While drip irrigation apply water on a daily or near a daily basis at very low application rate. The short irrigation intervals the frequent replenish of water used by the crop, which keeps the soil moisture slightly near the field holding capacity. The irrigation should maintain a slightly by nearly continuous downward movement of moisture and salts for excellent short-term salinity control. In drip irrigation the irrigation efficiency close to 100% during the cropping period. So changing the method of irrigation from surface irrigation system to one that applies water more precisely may allow the user to approach the soil intake rate more closely.

Pre plant irrigation

Pre-plant irrigation can be relied upon to fill the rooting depth to field capacity at a time when there is little chance of causing crop damage. In some soils a pre-plant irrigation is the only opportunity to wet the deeper part of the crop root zone. It also an effective method for wetting soils with a very slow infiltration.

Extending the duration of irrigation

Extending the duration of irrigation by reducing the volume of flow to the field and holding the water on the field for greater period of time. Careful management and monitoring is needed to maintain water use efficiency and keep the runoff to minimum.

Management of sprinkler system

In order to reduce the salt accumulation by sprinkler system; the system needs management to reduce the salt effect.

-Irrigating at night

To reduce the effect of evaporation and salts accumulation irrigation at night reduces the salt accumulation at the surface of soil and at the leave edges.

-Avoid period of high wind

In order to reduce evaporation irrigation the period of high wind should be avoided.

-Increase rate of application

To reduce evaporation of the small droplet of water; the sprinkler application rate can be increased by changing the nozzles to be large enough to reach to the soil surface.

-Increase sprinkler rotation

By increasing the sprinkler rotation decrease the possibility of evaporation.

-Planting during cooler season

To reduce the evaporation from the soil surface and to reduce water consumption planting at cooler season can reduce the losses

Land and soil management

Several land and soil management practices can be adopted at the field level to overcome salinity, Sodicity, toxicity and health hazards that might be associated with the use of treated wastewater.

Land development

Typical activities include leveling of land to a given grade, establishing adequate drainage (both open and sub-surface systems), deep ploughing and leaching to reduce soil salinity.

Land grading

Land grading is important to achieve good uniformity of application from surface irrigation methods and acceptable irrigation efficiencies in general. Salts accumulate in the high spots, which have too little water infiltration and leaching, while in the low spots water accumulates, causing waterlogging, and soil crusting.

Land grading is well accepted as an important farm practice in irrigated agriculture. Several methods are available to grade land to a desired slope. The slope required will vary with the irrigation system, length of run of water flow, soil type, and the design of the field.

Deep cultivation

In certain areas, the soil is stratified, and such soils are difficult to irrigate. Layers of clay, sand or hard pan in stratified soils frequently impede or prevent free movement of water through and beyond the root zone. This will not only lead to saturation of the root zone but also to accumulation of salts in the root zone.

Salt affected soils

Salts in the soil directly influence crop yield. Also it affects certain physical and chemical properties of the soil, so it affect the suitability of the soil as a media for plant growth. The suitability of the soils for crop depends on the ability of the soils to conduct water and air (soil permeability) and on the aggregate properties which control the friability of the seedbed. Poor permeability and tilth are two major problems in irrigated lands. Contrary to saline soil and sodic soils has greatly reduced permeability and poor tilth.

Infiltration problems:

Infiltration refers to the entry of water to the soil. The rate at which the water enters is referred to as the rate of infiltration. Permeability refers to the percolation of infiltrated water into the soil. The infiltration depends on the soil physical, chemical properties and the water quality. If the infiltration rate is 3 mm/ hour it is considered low while if it is more than 12 mm/hour it is considered high. The infiltration rate increases with increasing salinity and decreases with either decreasing salinity or increasing the sodium content relative to the calcium and magnesium (SAR).

Soil infiltration problem occurs if the irrigation water does not enter the soil rapidly enough during a normal irrigation cycle. The reduced infiltration rate if due to the quality of water applied is generally a problem within the upper few centimeters of the soils but occasionally may occur at greater depths.

Management of infiltration problem:

The following management steps are directed to overcome the infiltration problem caused by the chemical quality of the water irrigation supply.

Soil and water amendments:

The chemical amendments added to the soil or water should improve a low infiltration rate caused by low salinity or by excessive sodium in the irrigation water (SAR).

Some of these amendments are Gypsum and acids

Gypsum:

Gypsum can be either a soil or water amendment. For reclamation of sodic soil gypsum in granular form is applied broadcast at the rate of 5 – 40 ton/ha. The 40

ton/ha is applied onetime for extremely sodic soil and if rapid reclamation is needed. Sense the water infiltration problem is at the surface of the soil; therefore the low application rate of gypsum to correct the surface problem is more effective. The application of gypsum to irrigation water to solve the infiltration problem usually requires fewer amounts per hectare than the soil application. Gypsum is more effective if the EC of irrigation water is less than 0.4 ds/m.

Acids forming amendments

Acid or acid forming amendments, the sulfur or sulfuric acid can be used to solve the infiltration problem but the calcium must be present in the sodic soils. Other calcium materials can be added.

Table 5. water and soil amendments and their relative effectiveness in calcium supply

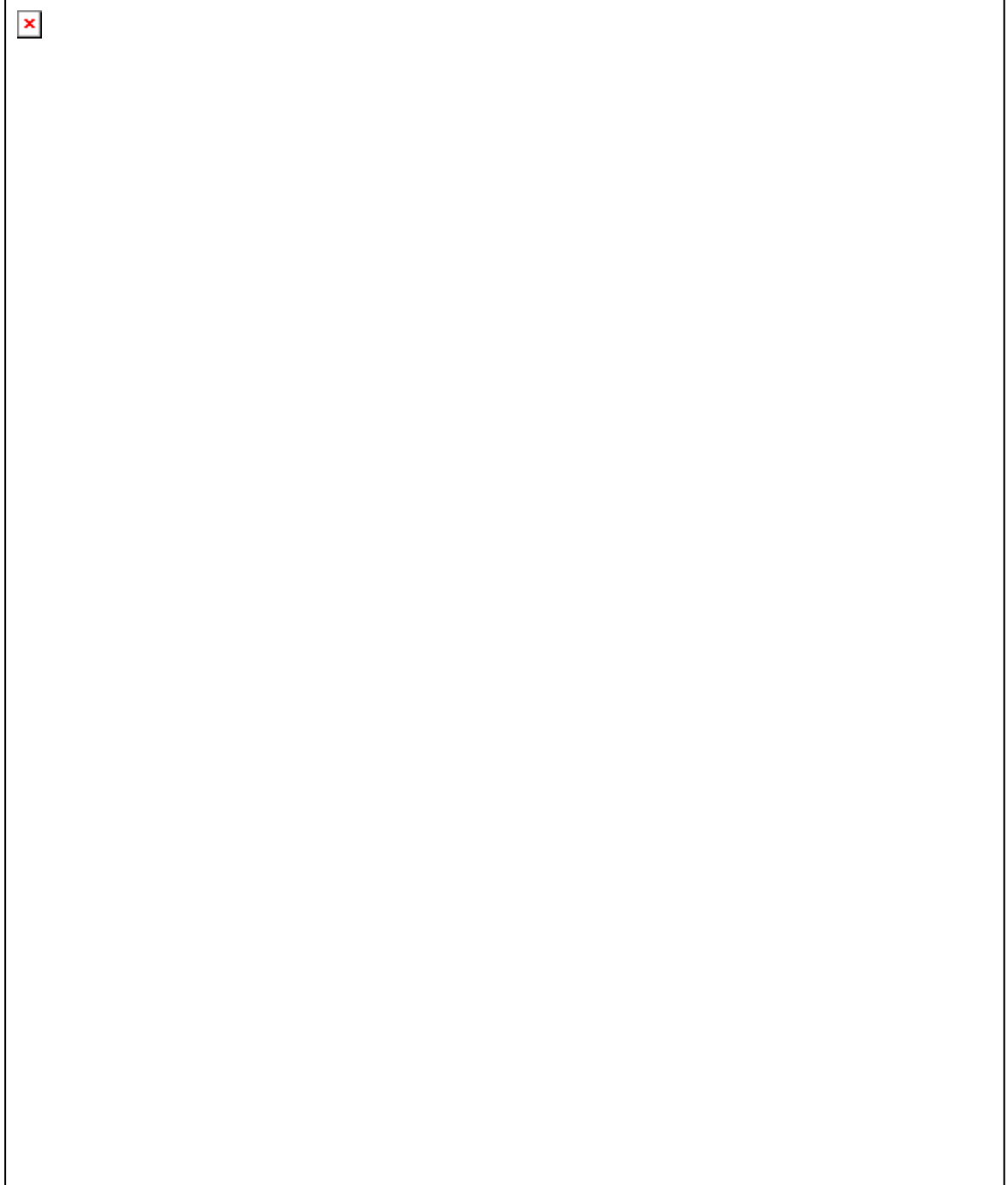
Amendment	Tons equivalent to 1 ton of 100 % gypsum
Gypsum (CaSO ₄ . 2 H ₂ O)	1.00
Sulfur (S)	0.19
Sulfuric acid (H ₂ SO ₄)	0.61
Ferric sulfate (Fe ₂ (SO ₄) ₃ . 9 H ₂ O)	1.09
Lime sulfate (9 % Ca + 24 % S)	0.78
Calcium chloride (CaCl . 2 H ₂ O)	0.86
Calcium nitrate (Ca (NO ₃) ₂ . H ₂ O)	1.06
Calcium Carbonate (Ca CO ₃)	0.58

Salt accumulation (salanization)

Salinization problem effect the irrigated area in the world about 25% of the irrigated area in the world are damaged by salanization (Postel 1989). Some claim that up to 50 % of the world's irrigated land may affected by salt (adams and Hughes 1990). Salt affected soil occur extensively under natural condition, the salt problem to the agricultural land arise when productive soils becomes salinized as a result of irrigation.

Salinization by different irrigation system

As in figure 1. the salt distribution under different irrigation systems ; surface, sprinkler and drip system



Irrigation Management

At the farm level, the following basic conditions should be met to make irrigated farming a success:

- The required amount of water should be applied
- The water should be of acceptable quality
- Water application should be properly scheduled
- Appropriate irrigation methods should be used
- Salt accumulation in the root zone should be prevented by means of leaching
- The rise of water table should be controlled by means of appropriate drainage
- Plant nutrients should be managed in an optimal way (Pescod, 1992)-

Amount of water to be applied

Traditionally, irrigation water is grouped into various quality classes in order to guide the user to the potential advantages as well as problems associated with its use and to achieve optimum crop production. The suitability of water for irrigation will greatly depend on the climatic conditions, physical and chemical properties of the soil, the salt tolerance of the crop grown and the management practices. It is possible that a farmer may have saline groundwater and if he has non-saline treated wastewater could blend the two sources to obtain blended water of acceptable salinity level.

It is commonly practiced in Gaza Governorates and in Jordan Valley. Water quality issues have plagued irrigation projects for centuries. Clearly salinity and nitrate leaching will continue to receive high research priority in irrigation agriculture, particularly in areas with known problems.

Irrigation Scheduling

Irrigation scheduling is commonly defined as determining when to irrigate and how much water to apply, or as deciding when to start and when to stop an irrigation. Successful irrigation depends upon understanding and utilizing irrigation scheduling principles to develop a management plan and then on efficiently implementing the plan. Tensiometers and electrical resistance methods are the most practical for field use and they are inexpensive instruments. Irrigation scheduling by watermark

tensiometers in an experiment carried out in citrus farm in Northern Governorate/Gaza had significant results and presents a good example of contribution of these equipments to water saving in citrus farms. For instance tensiometers help to determine the optimum irrigation needs and timing. It can contribute effectively in water saving in the field with a rate exceeds 30 %.

Selection of Irrigation Methods

The choice of irrigation method in using saline water is governed by the following technical factors:

- The choice of crops,
- The wetting of foliage, fruits and aerial parts,
- The distribution of water salts and contaminants in the soil
- The ease with which high soil water potential could be maintained,
- The efficiency of application,.

Flood irrigation - water is applied over the entire field to infiltrate into the soil (e.g. wild flooding, contour flooding, borders, basins, etc.).

ii. **Furrow irrigation** - water is applied between ridges (e.g. level and graded furrows, contour furrows, corrugations, etc.). Water reaches the ridge, where the plant roots are concentrated, by capillary action.

iii. **Sprinkler irrigation** - water is applied in the form of a spray and reaches the soil very much like rain (e.g. portable and solid set sprinklers, travelling sprinklers, spray guns, centre-pivot systems, etc.). The rate of application is adjusted so that it does not create ponding of water on the surface.

iv. **Sub-irrigation** - water is applied beneath the root zone in such a manner that it wets the root zone by capillary rise (e.g. subsurface irrigation canals, buried pipes, etc.). Deep surface canals or buried pipes are used for this purpose.

v. **Localized irrigation** - water is applied around each plant or a group of plants so as to wet locally and the root zone only (e.g. drip irrigation, bubbler, micro-sprinklers, etc.). The application rate is adjusted to meet evapotranspiration needs so that percolation losses are minimized.

vi. **Subsurface Drip Irrigation:** A highly efficient irrigation method was developed by Phene et al., (1995) to manage the soluble nitrate-N below the root zone of field

crops. The method known as deep, high frequency subsurface drip irrigation (SDI) can achieve minimum leaching if four conditions are satisfied:

- 1- Irrigation events are short and frequent and designed to replace crop water uptake as closely as possible (no leaching fraction)
- 2-Nitrogen is applied with the water through the SDI system at a rate equivalent to the uptake rate of the crop less the amount mineralised from the soil.
- 3-The crop is deep rooted.
- 4-The water table is at least 2.0 m from the soil surface.

Table 6. Evaluation of irrigation methods using saline water

Parameter of Evaluation	Furrow irrigation	Border Irrigation	Sprinklers 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 as to reduce yield	Severe leaf damage can result 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 accumulated 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 movement is 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 irrigation's	plants may be subject to stress between irrigation's	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
Suitability to handle brackish wastewater without significant yield loss	Fair to medium. With good management and drainage acceptable yields are possible	Fair to medium. Good irrigation and drainage practices can produce acceptable levels of yield	Poor to fair. Most crops suffer from leaf damage and yield is low.	Excellent to good. Almost all crops can be grown with very little reduction in yield

Source: Kandiah (1990)

Leaching for salinity management

To avoid a build up of salinity in the soil water that is harmful to the crop , it is necessary to maintain a net downward movement of water through the root zone over time. The amount of downward flow needed generally is not large and depends on the crops grown and the quality of the irrigation water.

This process of displacing the salts from the root zone is called leaching and that portion of the irrigation water, which mobilizes the excess of salts, is called the leaching requirement.

$$LR = \frac{EC_w}{5EC_e - EC_w} \quad (2.1)$$

where

EC_w : salinity of the applied irrigation water in dS/m

EC_e : average soil salinity tolerated by the crop as measured on a soil saturation extract. It is recommended that the EC_e value that can be expected to result in at least a 90% or greater yield be used in the calculation (Ayres & Westcot, 1976) .

Excess irrigation water is used in arid areas to leach salt from the root zone. This leaching fraction and any unplanned additions of extra water from over-irrigation or high rainfall contribute to ground water recharge. The leaching requirements (LR) for salinity control may be determined using the salinity of irrigated water , the tolerance of the crop, and the salinity of the irrigation water and the type of irrigation management as shown in Fig 2.

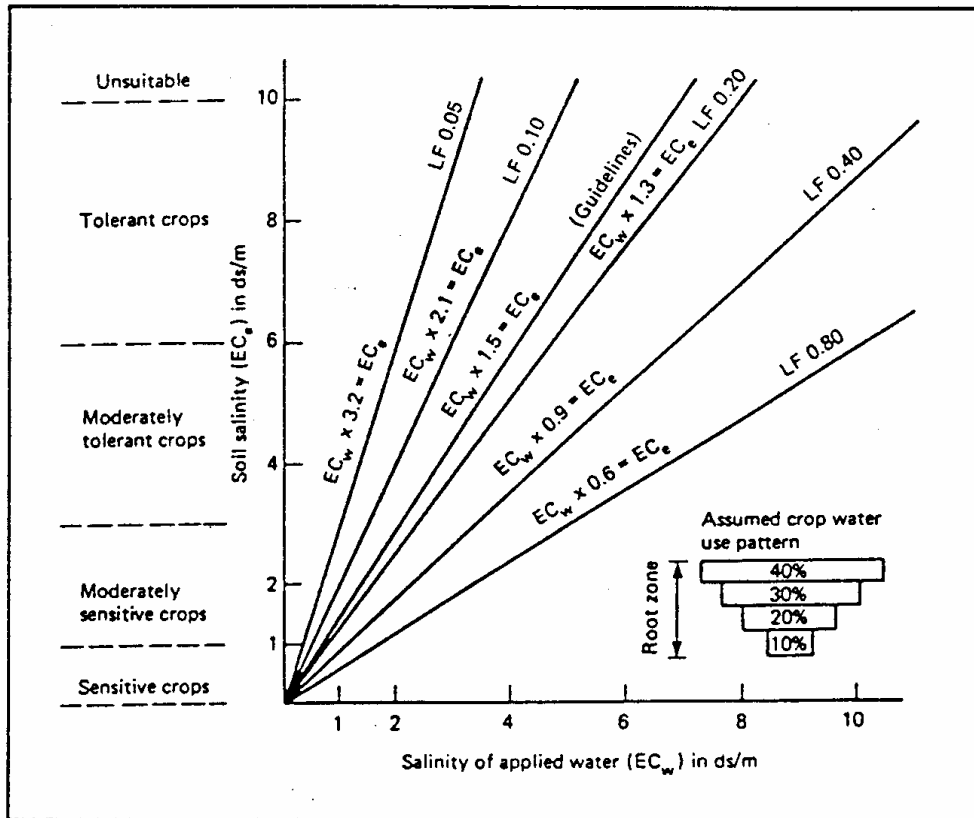


Figure 2. Relationship between applied water salinity and soil salinity at different leaching fractions

Drainage

Drainage is defined as the removal of excess water from the soil surface to below to permit optimum growth of plants. Removal of excess surface water is termed surface drainage while the removal of excess water from beneath the soil surface is termed sub-surface drainage. The importance of drainage for successful irrigated agriculture has been well demonstrated. It is particularly important in semi-arid and arid areas to prevent secondary salinization. When the water table is within a few meters of the soil surface, capillary rise of saline groundwater will transport salts to the soil surface. At the surface, water evaporates, leaving the salts behind. If this process is not arrested, salt accumulation will continue, resulting in salinization of the soil.

Increasing Water Consumption Efficiency

Crop water requirement: Water needed to cover the crop needs from evaporation, transpiration, building the plant canopies, and fruits.

Unit of water consumption:

The amount of water used by the plant expressed as a depth of water per unit time per unit area, example: mm/day/ dunum. (One Dunum = 0.1 Hectare).

Factors affect crop requirement

- Climate factors
- Crop factors
- Management factors

Climate factors:

The climate factors change with the change of time (daily, monthly, and yearly) and change with the location of the plant on the world (altitude, latitude)

Temperature:

The air temperature affect directly the water consumption of the plant (ET_{crop}) if the temperature increase the evaporation and transpiration of the plant increase under the same conditions

Humidity:

Increasing the humidity in the in the air surrounding the plant decrease the evapotranspiration of the plant. Increasing the air temperature decreasing the humidity under the same vapor pressure.

Relative humidity: (RH%) the relations between the actual vapor pressure to saturated vapor pressure

$$RH = 100 \frac{e_a}{e_s}$$

e_a : the actual vapor pressure

es: saturated vapor pressure

Radiation

The most important radiation affect the crop requirement in the net radiation (Rn) which the difference between the short wave radiation (Rns) reach to the surface and the long wave radiation (Rnl) the reflected from the different surface.

$$R_n = R_{ns} - R_{nl}$$

Wind:

The wind speed affects the evaporation of water from the surface, of the soil and plant. Increasing the wind speed increasing the evaporation under the same conditions.

Soil heat flux:

The soil heat flux depends on the soil, temperature, surface cover and the interval of calculation.

Crop factors

Plant type and variety

Each plant type has different growth characteristic and so having different crop coefficient Kc.

Plant growth

Growing seasons and development of growth of the plant; at the planting time the crop factor Kc is very small and it increasing with development of the growth

Plant canopy and density

Plant density per area and the canopy of the plant which depend on the plant

Management factor:

The management factor depends on the water quality and the agricultural operation. To contribute these factors adjusted for the ETc must be done by multiplying the ETc by the adjusted factor Ks.

Crop requirement

The relation of crop requirements

Climate + reference crop = ET_0

$ET_0 \cdot K_c = ET_c$

$ET_c \cdot K_s \cdot K_c = ET_{c \text{ adj.}}$

Methods of calculating ET

- Direct methods: one of the methods is the lysimeters
- Indirect methods
 - Using empirical equations one of them modified Penman Monteith, which depend on the climate method
 - The relation between E_{pan} and the ET crop

Irrigation schedule:

Irrigation requirement: the irrigation water requirement is the water, which must be supplied to the crop plant to ensure that it received its full water requirement or a predetermined portion of it. If the irrigation is the only source of water, the irrigation requirement will be at least equal to the water requirement and may often have to be greater to allow for possible losses in the irrigation system, such as leaching, deep percolation, or uneven distribution.

Net irrigation requirement: IR_n is the depth or volume of irrigation water required for normal crop production over the whole-cropped area excluding contributions from other sources.

Gross irrigation requirement: IR_g is the depth or volume of irrigation water required over the whole-cropped area excluding contributions from other sources, plus water losses and / or operational wastes.

The relation between IRg and IRn

$$IRg = IRn \cdot Ea + Lr.$$

Where Ea is the irrigation efficiency and Lr is the extra amount of water needed for leaching.

Peak irrigation requirement: PIR the highest water requirement for the crop during the growing season

Example for calculating PIR.

Location: Cyprus

Soil: sandy

Type of crop: Santa Rosa plum orchard spacing 5 X 5m

Data for class A pan evaporation over 15 years

Table 7. shows the calculation of PIR from the pan evaporation data

	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
E pan mm/day	1.4	2.2	3.5	4.6	6.3	8.9	8.6	7.8	6.6	4.3	2.4	1.7
Kp	0.75	0.75	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.75	0.75
Kc				0.45	0.80	1.05	1.15	1.15	1.1	0.85		
Kr	0.85											
ET crop mm/day				1.2	3.0	5.6	5.9	5.3	4.3	2.2		
Ks	1.1											
Eu	90%											
IRg mm/day				1.5	3.7	6.8	7.2	6.5	5.3	2.6		
IRg L/day/plant				37.6	91.5	169.7	179.6	162.9	131.8	66.4		

The peak irrigation requirement 179.6 L/day/plant

Irrigation schedule can be done depending on:

crop water requirement

By determination of crop requirement from the climate data by empirical equations or by using the pan evaporation data

The relation between evaporation rate and soil moisture

By knowing the relation between the pan evaporation data and the evaporation from the soil surface.

$$ET_{crop} = ET_{pan} \cdot K_{pan} \cdot K_c \cdot K_{adj}$$

According to this relation the crop water needs is calculated and used to calculate irrigation requirement.

Allowable soil moisture deficit

Each plant can tolerate certain soil moisture deficit the sensitive plant can tolerate a deficit 0.3 bar and other plant can tolerate soil deficit 0.6 bar.

Irrigation at fixed deficit

Irrigation at certain soil water deficit by

Example using the tenssiometer or neutron prop

Fixed irrigation interval

The irrigation at fixed interval depends on the soil properties

Table 8. different soils and suggested irrigation intervals for different climate

Climate	Soil		
	Very coarse, no water holding capacity	Light sandy	Heavier loams, and clayey soils
Hot and dry high transpiration rates	Pulse irrigation during the day or once a day, when plant using most water	1 day interval or 2 days when some silt or clay in the soil	2 or 3 days interval in heavy soils which have poor aeration
Moderate	Pulse irrigation during the day or once a day, when plants are using most water	2 or 3 days interval	3 or 4 days interval
Cool low transpiration rate	Pulse irrigation during the day or once a day, when plants are using most water	3 or days interval (twice a week) providing there be some water holding capacity	6 or 8 days interval (once a week)

Increasing water use efficiency

Irrigation efficiency:

In order to minimize the fresh water consumption the irrigation efficiency must be improved.

Water losses

Water loss occur at different levels:

- At the level of the plant; when applying water to the soil
- At the level of the field; after water has entered the field
- At the level of conveyance; during conveyance

These water losses are normally expressed as irrigation efficiency, whereby the concept efficiency denotes that fraction of the total amount of water, which will benefit the field respectively the crop.

There is more than one definition to the irrigation efficiency but we will use the definition Of ASCE.1978.

IE: Irrigation efficiency

$$IE = \frac{\text{Average depth of water beneficially used}}{\text{Average depth of water applied}}$$

AE: Application efficiency

$$AE = \frac{\text{Average depth of water stored in root zone}}{\text{Average depth of water applied}}$$

AELQ: application efficiency of low quarter

$$\text{AELQ} = \frac{\text{Average depth low quarter}}{\text{Average depth of water applied}}$$

DU: Distribution efficiency

$$\text{DU} = \frac{\text{Average low-quarter depth of water infiltrated}}{\text{Average depth of water infiltrated}}$$

UC: Uniformity coefficient

$$\text{UC} = [1 - (\frac{\sum X}{MN})] \cdot 100$$

X: deviation of individual observation from the mean

M: the mean value

N: number of observation

System application efficiency: the system application efficiency as defined by Hall 1960

SAE: System application efficiency

$$\text{SAE} = \frac{\text{Net volume of useful water applied to the soil in the field}}{\text{Gross volume of water delivered to the field}}$$

EIE: Economic irrigation efficiency (Hall, 1960)

$$\text{EIE} = \frac{\text{Total production with the actual irrigation}}{\text{Total production expected under the ideal conditions}}$$

Factors affects the system efficiency

System design:

If there is some problem in the design it causing non uniformity in the distribution of water in the field

Water losses:

Losses by seepage and evaporation

Losses by seepage from the pipes or channels

Losses by evaporation from the open channels or the soil surface

Clogging and partially clogging of outlets:

For drip irrigation system the emission point (drippers) some times are completely or partially clogged by the different means:

- Physical clogging

Physical suspension material

Soil particles

- Biological clogging

Algae

Slime

Bacteria

- Chemical clogging

Water salts

Fertilizers

Table 9. chemical, Physical, and Biological materials tan can clogging of drip irrigation

Physical	Chemical	Biological
sand	calcium or magnesium	filaments
silt	carbonate	slime
clay	calcium sulfate	microbial deposition:
organic matter	heavy metal hydroxide, oxides, carbonate, silicates, and sulfate	iron
	fertilizers	sulfur
	phosphate	manganese
	aqueous ammonia	bacteria
	iron, zinc, copper,	small aquatic
	manganese	organisms:
		snail egg
		larva

--	--	--

In order to reduce the effect of system clogging or partially clogging which affect the uniformity distribution in the field for the following step can be done.

For physical clogging: filter of different type (sand, screen, hydro-cyclon, disk filters) can be used to reduce closing or partially closing of the outlet.

For biological clogging: some chemicals can be used (acids) to reduce the growth of biological slimes and Bacteria

For chemical clogging: some acids (HCL) can be used to dissolve the clogging og the outlets

Table 11. chloride dosage to reduce the biological growth

Problem	Dosage
Algae	0.5- 1.0 mg/l continuous or 20 mg/L for 20 minutes
Hydrogen sulphaide	3.5- 9.0 times the hydrogen sulphide content (mg/L)
Iron bacteria	1.0 mg/L but varies with bacterial content
Slime	0.5 mg/L continuous

Soilless culture and hydroponic:

Definition: according to FAO (1990)

Soilless culture: any system of crop production not based on the soil as the rooting medium.

Hydroponic: all forms of water culture and culture in inert substrates.

Advantages of changing from the soil to soilless culture

increasing in the yield

reducing sterilization by methyl bromide

energy saving

growth control

avoiding hazardous amount of harmful compound in vegetables

improving labor condition

Closed soilless culture: in the closed system, the solution water with the nutrient is reused by the plant after adjusting the nutrient concentration and the EC. In this case where the solution passes along many plants, make it as transportation means for plant disease. So in reuse system the solution must be disinfected.

Disinfection: disinfection can be done by:

Heating

Ozonisation

UV-radiation

Ultrafiltration

Microfiltration

These methods of disinfection are very expensive so some farmers check the solution from the disease.

Substrates used for soilless culture:

Rockwool

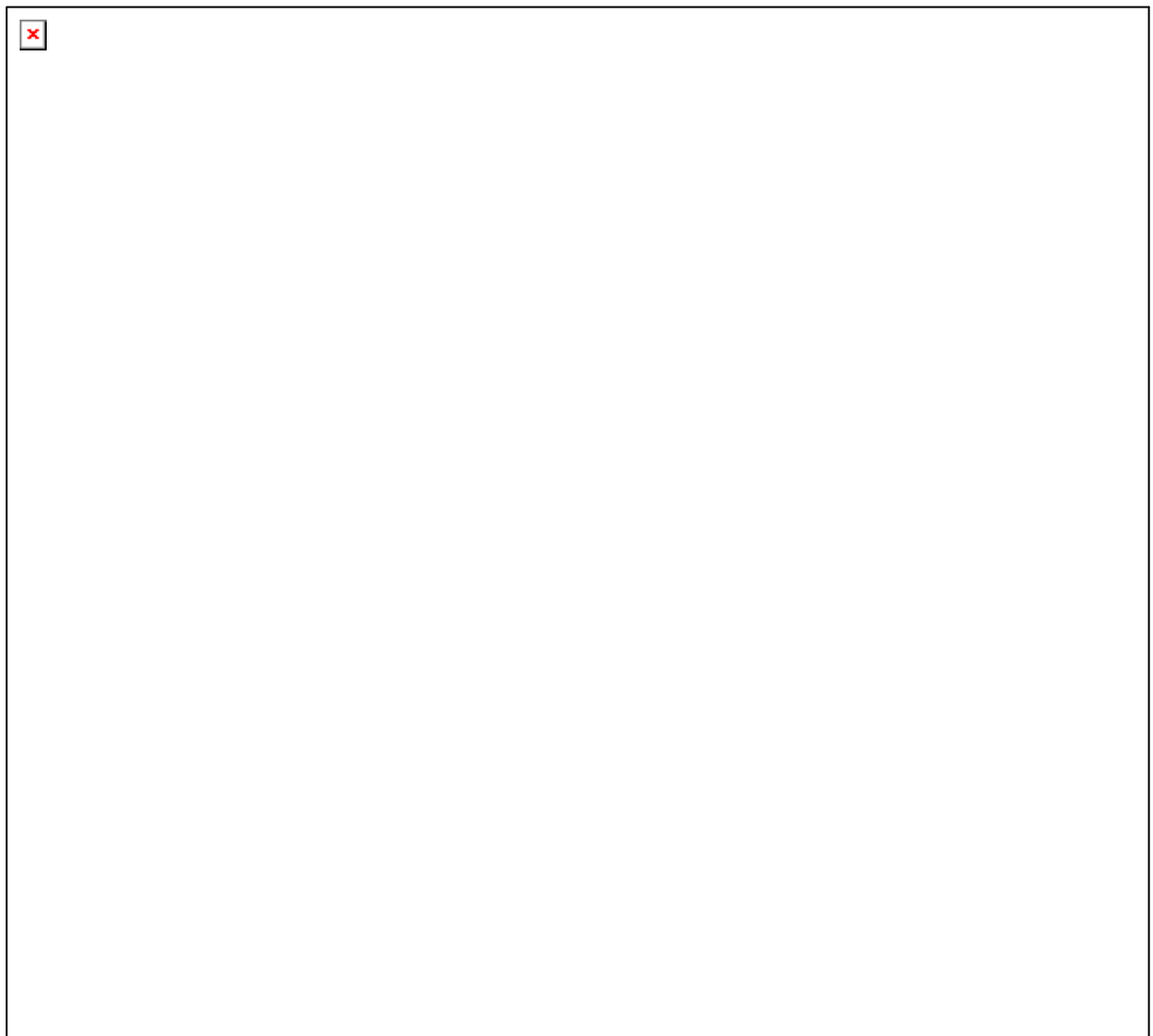
Glasswool

Poly-urethane

Poly-phenol

Perlite
Vermiculite
Clay granulates
Lava
Pomice stone
Sand
Peat
Cocos
Organic substrates

Table 12. Characteristics of various substrates.



System layout for soilless culture:

Troughs

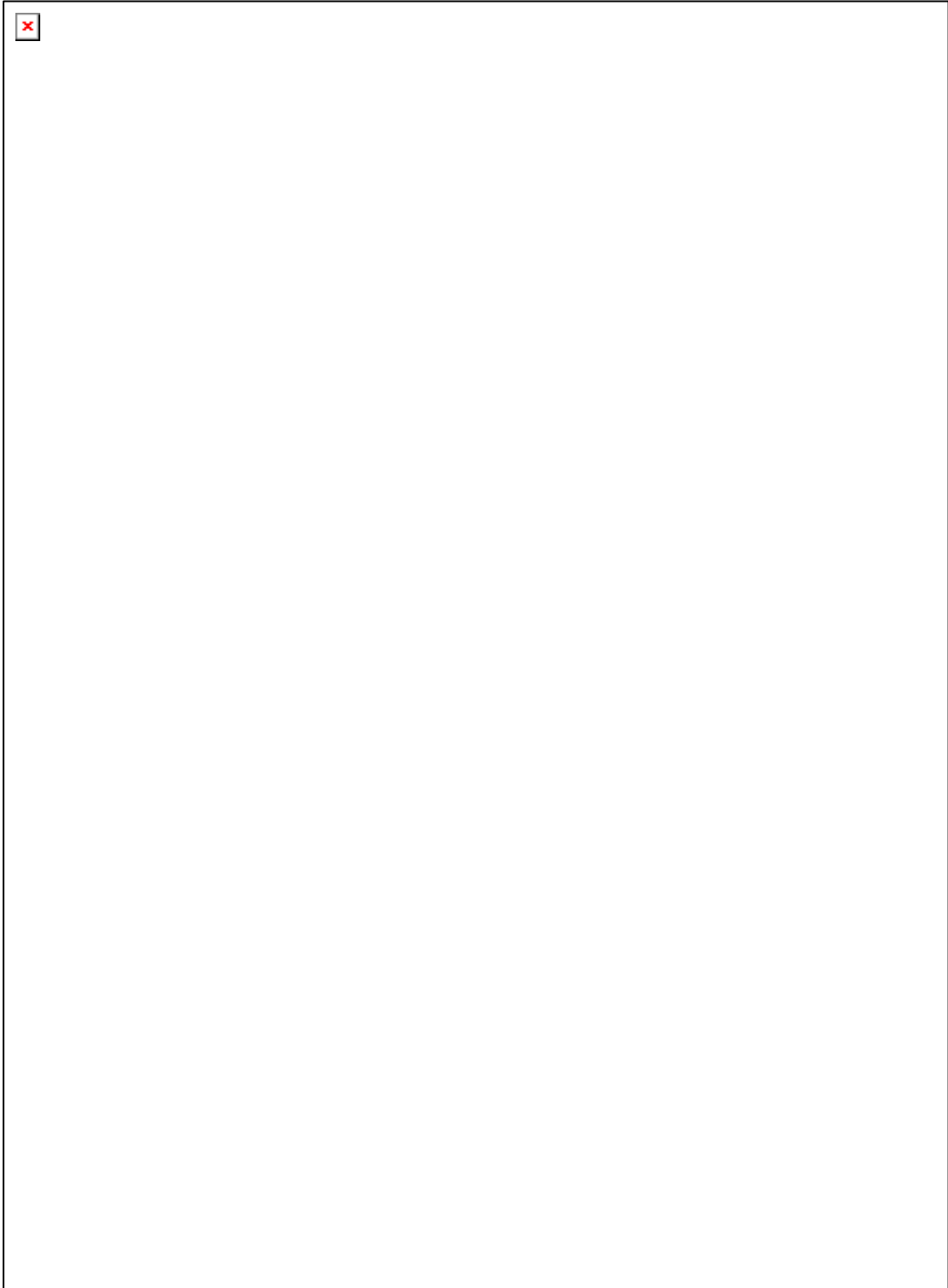
Drain profiles

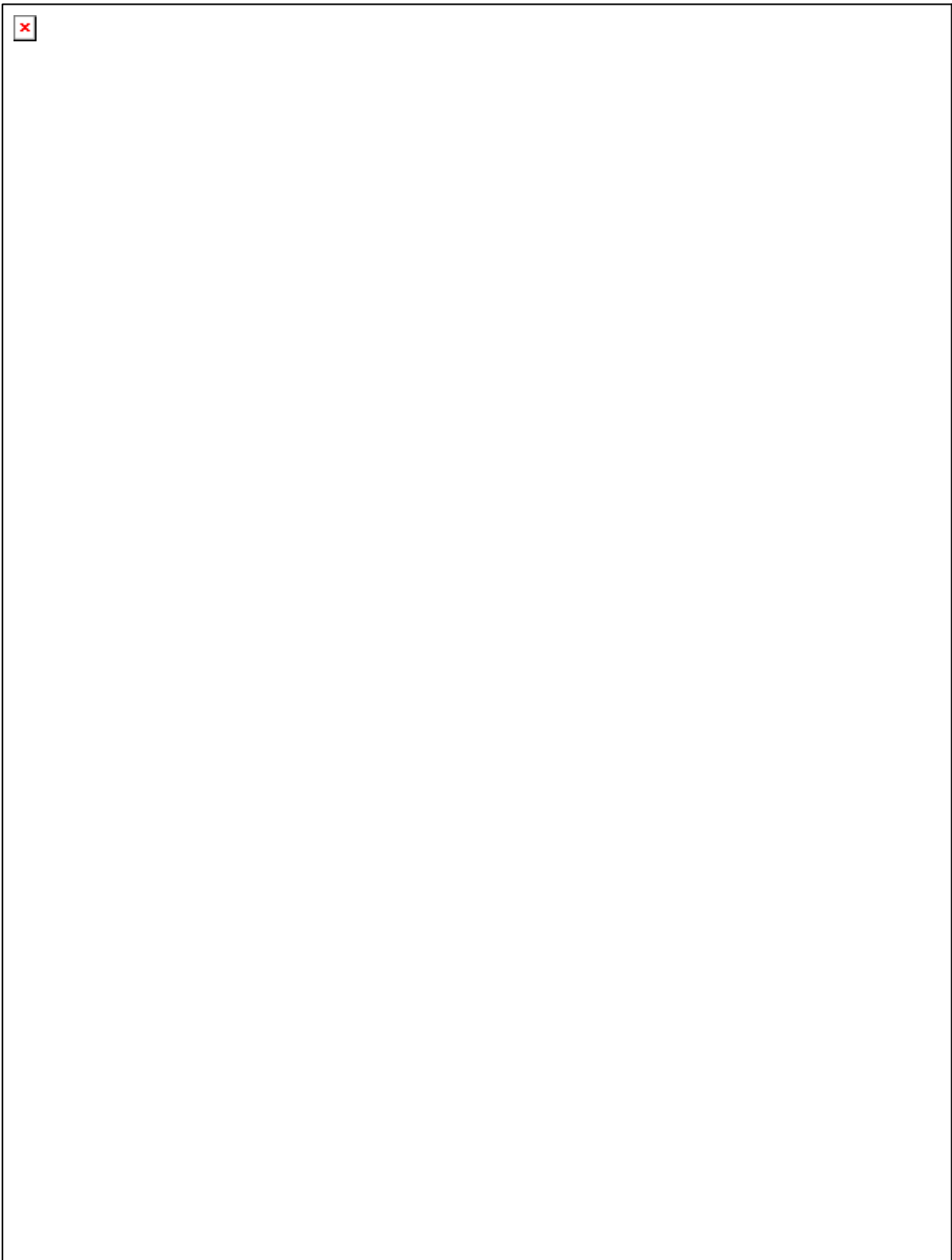
Trays and crates

Beds

Fullfield system

Figures 3. the different layout systems.





Which system for which crop types?

Different crop may need different systems. To indicate available system for the various crops the crops are divided into eight groups. Within this groups the crops have comparable growth characteristic and the same system can be used

Crop groups:

A: Fruit- vegetable crop, like tomato, cucumber, sweet pepper, egg plant, fresh bean and melon.

B: one harvest vegetable; green vegetable, like cabbage-lettuce, iceberg lettuce, turnip cabbage, and endive

C: one harvest crop; seed crops, like radish, rettich and spinach.

D: frequently harvested cut flower, like rose, carnation, bouvardia and baby's breath.

E: one harvested cut flower, like chrysanthemum and michaelmas daisy.

F: flowering bulb, corm, rootstock crops, like freesia, cut hyppastrum, peruvia lily, lily, tulip and iris.

G: remaining cut flowers, like painter's palette, transval daisy, and orchid.

H: strawberry

Each group have certain system and some systems can be used to more than one group.

Waste products:

The soilless culture can be a solution to reduce the loss of nutrient and harmful component to the environment.

Recommended system

In selecting any soilless culture several aspect should be considered; annual cost, risk of disease, the yield and the pollution to the environment.

- No leakage during installation
- No damaging volatilization of damp or substance
- Resistance to sterlization
- Can be recycled
- Lower cost
- No decrease of physical properties during use
- Not creating a new waste
- Having a life at least three years.

Annex 1

RELATIVE SALT TOLERANCE OF AGRICULTURAL CROPS

TOLERANT	
<u>Fibre, Seed and Sugar Crops</u>	
Barley	<i>Hordeum vulgare</i>
Cotton	<i>Gossypium hirsutum</i>
Jajoba	<i>Simmondsia chinensis</i>
Sugarbeet	<i>Beta vulgaris</i>
<u>Grasses and Forage Crops</u>	
Alkali grass	<i>Puccinellia airoides</i>
Alkali sacaton	<i>Sporobolus airoides</i>
Bermuda grass	<i>Cynodon dactylon</i>
Kallar grass	<i>Diplachne fusca</i>
Saltgrass, desert	<i>Distichlis stricta</i>
Wheatgrass, fairway crested	<i>Agropyron cristatum</i>
Wheatgrass, tall	<i>Agropyron elongatum</i>
Wildrye, Altai	<i>Elymus angustus</i>
Wildrye, Russian	<i>Elymus junceus</i>
<u>Vegetable Crops</u>	
Asparagus	<i>Asparagus officinalis</i>
<u>Fruit and Nut Crops</u>	
Date palm	<i>Phoenix dactylifera</i>
MODERATELY TOLERANT	
<u>Fibre, Seed and Sugar Crops</u>	
Cowpea	<i>Vigna unguiculata</i>
Oats	<i>Avena sativa</i>
Rye	<i>Secale cereale</i>
Safflower	<i>Carthamus tinctorius</i>
Sorghum	<i>Sorghum bicolor</i>
Soybean	<i>Glycine max</i>
Triticale	<i>X Triticosecale</i>
Wheat	<i>Triticum aestivum</i>
Wheat, Durum	<i>Triticum turgidum</i>
<u>Grasses and Forage Crops</u>	
Barley (forage)	<i>Hordeum vulgare</i>
Brome, mountain	<i>Bromus marginatus</i>
Canary grass, reed	<i>Phalaris, arundinacea</i>
Clover, Hubam	<i>Melilotus alba</i>
Clover, sweet	<i>Melilotus</i>
Fescue, meadow	<i>Festuca pratensis</i>
Fescue, tall	<i>Festuca elatior</i>
Harding grass	<i>Phalaris tuberosa</i>
Panic grass, blue	<i>Panicum antidotale</i>
Rape	<i>Brassica napus</i>
Rescue grass	<i>Bromus unioloides</i>
Rhodes grass	<i>Chloris gayana</i>
<u>Grasses and Forage Crops</u>	
Ryegrass, Italian	<i>Lolium italicum multiflorum</i>
Ryegrass, perennial	<i>Lolium perenne</i>

Sudan grass	<i>Sorghum sudanense</i>
Trefoil, narrowleaf birdsfoot	<i>Lotus corniculatus tenuifolium</i>
Trefoil, broadleaf	<i>L. corniculatus arvenis</i>
Wheat (forage)	<i>Triticum aestivum</i>
Wheatgrass, standard crested	<i>Agropyron sibiricum</i>
Wheatgrass, intermediate	<i>Agropyron intermedium</i>
Wheatgrass, slender	<i>Agropyron trachycaulum</i>
Wheatgrass, western	<i>Agropyron smithii</i>
Wildrye, beardless	<i>Elymus triticoides</i>
Wildrye, Canadian	<i>Elymus canadensis</i>
<u>Vegetable Crops</u>	
Artichoke	<i>Helianthus tuberosus</i>
Beet, red	<i>Beta vulgaris</i>
Squash, zucchini	<i>Cucurbita pepo melopepo</i>
<u>Fruit and Nut Crops</u>	
Fig	<i>Ficus carica</i>
Jujube	<i>Ziziphys jujuba</i>
Olive	<i>Olea europaea</i>
Papaya	<i>Carica papaya</i>
Pineapple	<i>Ananas comosus</i>
Pomegranate	<i>Punica granatum</i>
MODERATELY SENSITIVE	
<u>Fibre, Seed and Sugar Crops</u>	
Broadbean	<i>Vicia faba</i>
Castorbean	<i>Ricinus communis</i>
Maize	<i>Zea mays</i>
Flax	<i>Linum usitatissimum</i>
Millet, foxtail	<i>Setaria italica</i>
Groundnut/peanut	<i>Arachis hypogaea</i>
Rice, paddy	<i>Oryza sativa</i>
Sugarcane	<i>Saccarum officinarum</i>
Sunflower	<i>Helianthus annuus palustris</i>
<u>Grasses and Forage Crops</u>	
Alfalfa	<i>Medicago sativa</i>
Bentgrass	<i>Agrostisstoloniferapalustris</i>
Bluestem, Angleton	<i>Dichanthium aristatum</i>
Brome, smooth	<i>Bromus inermis</i>
Buffelgrass	<i>Cenchrus ciliaris</i>
Burnet	<i>Poterium sanguisorba</i>
Clover, alsike	<i>Trifolium hybridum</i>
<u>Grasses and Forage Crops</u>	
Clover, Berseem	<i>Trifolium alexandrinum</i>
Clover, ladino	<i>Trifolium repens</i>
Clover, red	<i>Trifolium pratense</i>
Clover, strawberry	<i>Trifolium fragiferum</i>
Clover, white Dutch	<i>Trifolium repens</i>
Corn (forage) (maize)	<i>Zea mays</i>
Cowpea (forage)	<i>Vigna unguiculata</i>
Dallis grass	<i>Paspalum dilatatum</i>
Foxtail, meadow	<i>Alopecurus pratensis</i>

Gramma, vlu	<i>Bouteloua gracilis</i>
Lovegrass	<i>Eragrostis sp.</i>
Milkvetch, Cicer	<i>Astragalus deer</i>
Oatgrass, tall	<i>Arrhenatherum, Danthonia</i>
Oats (forage)	<i>Avena saliva</i>
Orchard grass	<i>Dactylis glomerata</i>
Rye (forage)	<i>Secale cereale</i>
Sesbania	<i>Sesbania exaltata</i>
Sirat	<i>Macroptilium atropurpureum</i>
Sphaerophysa	<i>Sphaerophysa salsula</i>
Timothy	<i>Phleum pratense</i>
Vetch, common	<i>Vicia angustifolia</i>
Vegetable Crops	
Broccoli	<i>Brassica oleracea botrytis</i>
Brussel sprouts	<i>B. oleracea gemmifera</i>
Cabbage	<i>B. oleracea capitata</i>
Cauliflower	<i>B. oleracea botrytis</i>
Celery	<i>Apium graveolens</i>
Corn, sweet	<i>Zea mays</i>
Cucumber	<i>Cucumis sativus</i>
Eggplant	<i>Solanum melongena esculentum</i>
Kale	<i>Brassica oleracea acephala</i>
Kohlrabi	<i>B. oleracea gongylode</i>
Lettuce	<i>Latuca sativa</i>
Muskmelon	<i>Cucumis melon</i>
Pepper	<i>Capsicum annum</i>
Potato	<i>Solanum tuberosum</i>
Pumpkin	<i>Cucurbita pepo pepo</i>
Radish	<i>Raphanus sativus</i>
Spinach	<i>Spinacia oleracea</i>
Squash, scallop	<i>C. pepo melopepo</i>
Sweet potato	<i>Ipomoea batatas</i>
Tomato	<i>Lycopersicon lycopersicum</i>
Turnip	<i>Brassica rapa</i>
Watermelon	<i>Citrullus lanatus</i>
Fruit and Nut Crops	
Grape	<i>Vitis sp.</i>
SENSITIVE	
Fibre, Seed and Sugar Crops	
Bean	<i>Phaseolus vulgaris</i>
Guayule	<i>Parthenium argentatum</i>
Sesame	<i>Sesamum indicum</i>
Vegetable Crops	
Bean	<i>Phaseolus vulgaris</i>
Carrot	<i>Daucus carota</i>
Okra	<i>Abelmoschus esculentus</i>
Onion	<i>Allium cepa</i>
Parsnip	<i>Pastinaca sativa</i>
Fruit and Nut Crops	
Almond	<i>Prunus dulcis</i>

Apple	<i>Malus sylvestris</i>
Apricot	<i>Prunus armeniaca</i>
Avocado	<i>Persea americana</i>
Blackberry	<i>Rubus sp.</i>
Boysenberry	<i>Rubus ursinus</i>
Cherimoya	<i>Annona cherimola</i>
Cherry, sweet	<i>Prunus avium</i>
Cherry, sand	<i>Prunus besseyi</i>
Currant	<i>Ribes sp.</i>
Gooseberry	<i>Ribes sp.</i>
Grapefruit	<i>Citrus paradisi</i>
Lemon	<i>Citrus limon</i>
Lime	<i>Citrus aurantifolia</i>
Loquat	<i>Eriobotrya japonica</i>
Mango	<i>Mangifera indica</i>
Orange	<i>Citrus sinensis</i>
Passion fruit	<i>Passiflora edulis</i>
Peach	<i>Prunus persica</i>
Pear	<i>Pyrus communis</i>
Persimmon	<i>Diospyros virginiana</i>
Plum: Prune	<i>Prunus domestica</i>
Pummelo	<i>Citrus maxima</i>
Raspberry	<i>Rubus idaeus</i>
Rose apple	<i>Syzygium jambos</i>
Sapote, white	<i>Casimiroa edulis</i>
Strawberry	<i>Fragaria sp.</i>
Tangerine	<i>Citrus reticulata</i>

Source: FAO (1985)

Annex 2.**RELATIVE BORON TOLERANCE OF AGRICULTURAL CROPS¹**

VERY SENSITIVE (<0.5 mg/l)	
Lemon	<i>Citrus limon</i>
Blackberry	<i>Rubus spp.</i>
SENSITIVE (0.5-0.75 mg/l)	
Avocado	<i>Persea americana</i>
Grapefruit	<i>Citrus X paradisi</i>
Orange	<i>Citrus sinensis</i>
Apricot	<i>Prunus armeniaca</i>
Peach	<i>Prunus persica</i>
Cherry	<i>Prunus avium</i>
Plum	<i>Prunus domestica</i>
Persimmon	<i>Diospyros kaki</i>
Fig, kadota	<i>Ficus carica</i>
Grape	<i>Vitis vinifera</i>
Walnut	<i>Juglans regia</i>
Pecan	<i>Carya illinoensis</i>
Cowpea	<i>Vigna unguiculata</i>
Onion	<i>Allium cepa</i>
SENSITIVE (0.75-1.0 mg/l)	
Garlic	<i>Allium sativum</i>
Sweet potato	<i>Ipomoea batatas</i>
Wheat	<i>Triticum eastivum</i>
Barley	<i>Hordeum vulgare</i>
Sunflower	<i>Helianthus annuus</i>
Bean, mung	<i>Vigna radiata</i>
Sesame	<i>Sesamum indicum</i>
Lupine	<i>Lupinus hartwegii</i>
Strawberry	<i>Fragaria spp.</i>
Artichoke, Jerusalem	<i>Helianthus tuberosus</i>
Bean, kidney	<i>Phaseolus vulgaris</i>
Bean, lima	<i>Phaseolus lunatus</i>
Groundnut/Peanut	<i>Arachis hypogaea</i>
MODERATELY SENSITIVE (1.0-2.0 mg/l)	
Pepper, red	<i>Capsicum annum</i>
Pea	<i>Pisum sativa</i>
Carrot	<i>Daucus carota</i>
Radish	<i>Raphanus sativus</i>
Potato	<i>Solanum tuberosum</i>
Cucumber	<i>Cucumis sativus</i>
MODERATELY TOLERANT (2.0-4.0 mg/l)	
Lettuce	<i>Lactuca sativa</i>
Cabbage	<i>B. oleracea capitata</i>
Celery	<i>Apium graveolens</i>
Turnip	<i>Brassica rapa</i>
Bluegrass, Kentucky	<i>Poa pratensis</i>
Oats	<i>Avena sativa</i>
Maize	<i>Zea mays</i>

Artichoke	<i>Cynara scolymus</i>
Tobacco	<i>Nicotiana tabacum</i>
Mustard	<i>Brassica juncea</i>
Clover, sweet	<i>Melilotus indica</i>
Squash	<i>Cucurbita pepo</i>
Muskmelon	<i>Cucumis melo</i>
TOLERANT (4.0-6.0 mg/l)	
Sorghum	<i>Sorghum bicolor</i>
Tomato	<i>L. lycopersicum</i>
Alfalfa	<i>Medicago sativa</i>
Vetch, purple	<i>Vicia benghalensis</i>
Parsley	<i>Petroselinum crispum</i>
Beet, red	<i>Beta vulgaris</i>
Sugarbeet	<i>Beta vulgaris</i>
VERY TOLERANT (6.0-15.0 mg/l)	
Cotton	<i>Gossypium hirsutum</i>
Asparagus	<i>Asparagus officinalis</i>

