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Kirda C.

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C. Kirda
Çukurova University
Faculty of Agriculture
Adana, Turkey

SUMMARY - World wide extent of saline of water resources is briefly discussed. Sampling techniques and methods of analysis of water samples with reference to irrigation quality assessment are briefly reviewed. A chronological review of irrigation-water quality criteria is presented and its limitations are discussed. It is shown that water quality alone would not suffice to evaluate potential salinity hazard of irrigation water unless consideration is given to crop, soil, climate and existing agronomic and irrigation management practices. Importance of drainage, land preparation crop rotation, specific irrigation methods and management are discussed as regard their influence on salt balance in the plant root zone.

Key words: Irrigation water quality, irrigation, salinity, salt leaching.

RESUME *- La vaste étendue des ressources en eau salée dans le monde est brièvement discutée. Les techniques d'échantillonnage et les méthodes d'analyse des échantillons d'eau avec référence aux normes de qualité pour l'irrigation sont examinées. Une revue chronologique des critères de qualité de l'eau d'irrigation est présentée et leurs limites sont discutées. Il est montré que la qualité de l'eau seule n'est pas suffisante pour évaluer les risques de salinité potentielle de l'eau d'irrigation, moins de prendre aussi en considération les plantes, le sol, le climat, les pratiques agronomiques et la conduite de l'irrigation existantes. L'importance du drainage, la préparation du sol, la rotation des cultures, les méthodes d'irrigation spécifiques sont discutées du point de vue de leur influence sur l'équilibre en sel dans la zone racinaire de la plante.*

Mots-clés: *Qualité de l'eau d'irrigation, irrigation, salinité, lessivement.*

INTRODUCTION

Water is the most important input required for plant growth in agriculture production. Bulk weight of all living organisms consists of 80 to 90 % water. Water need for plant growth is met with soil water storage in plant root zone. Under rainfed conditions, soil water storage is continuously replenished with natural rainfall; however, irrigation is essential in arid and semi-arid climates to maintain soil water storage at an optimum level to get higher yield. Therefore, irrigation can be defined as replenishment of soilwater storage in plant root zone through methods other than natural precipitation. All water sources used in irrigation contain impurities and dissolved salts irrespective of whether they are surface or underground water. However quality of water has meaning only with respect to its particular use. Water which can be considered good quality for household use, may not be ideal for irrigation.

In agriculture, water quality is related to its effects on soils, crops and management necessary to compensate problems linked to water quality. It is very important to note that not all problems of soil degradation like salinity, soil permeability, toxicity etc. can be related to irrigation water quality.

Total salt concentration of irrigation waters should not be used as a single criteria to prevent its use in irrigation. Even water with considerably high salt concentration can still be used for irrigation without endangering soil productivity, provided selected irrigation management could take into account all other factors affecting crop production. The key point is how to maintain existing salt balance in plant root zone. Total salt concentration of field sails under good irrigation management practices is 4-5 times higher than salt concentration of irrigation water. If one applies more water than what is actually needed, ground water table starts to rise and soil-extract salt concentration becomes 40-50 times of that irrigation water. This condition can be prevented with drainage systems. In such cases, water quality has secondary importance, and the major issue to deal with is the drainage. Table 1 gives relative distribution of different irrigation water sources, in selected countries, according to their electrical conductivity measurements. If one uses USSL (1954) water quality criteria alone, 67 and 40% of the irrigation water sources should not have been used in India and Algeria, respectively. However, irrigation waters of such a high salt content are still being used in these countries and no adverse effect has been reported. Irrigation management implemented in these countries, it appears, must prevent salt accumulation. Therefore, water quality is not the only criteria to assess suitability of irrigation water.

***Table 1** - Electrical conductivity of irrigation water sources in selected countries (Arnon, 1972)*

EC×106 25 °C	USA	ALGERIA	INDIA	ISRAEL
	Number of irrigation water surveyed			
	1018	79	576	1507
250 - 750	53	5	13	36
750 - 2250	37	28	35	60
2250 - 4000	-	28	22	3
2250 - 5000	10	-	-	-
4000 - 6000	-	18	18	1
5000 - 20000	-	21	-	-

ANALYTICAL METHODS IN ANALYZING IRRIGATION WATER

Sampling

One needs approximately 2 liters of water sample for its analysis in laboratories. It is important that the sample must represent the water source and special care may be needed to ensure that. Method of sampling varies depending on different sources such as (1) rivers, (2) nonflowing ponds/lakes and (3) ground water sources. Samples from rivers must be taken from the fastest flowing part, the mid-way along the width of the river. The samples from lakes or ponds should come from the center and the deepest part of the lake. It is best if water sample from dams comes from the part where the water leaves the dam. One must never take water sample from the river mounts reaching the lakes. Samples from deep wells must be taken after 15 to 20 minutes pumping. Water samples from irrigation schemes are taken before water enters the irrigated area to ensure that no mixing takes place with tail waters or runoff from the irrigated fields. Samples are collected in 1 to 2 liter glasses or PVC bottles. Samples brought to the laboratories should be analyzed without delay to prevent biological transformation.

Methods of analysis

Methods of analysis regarding irrigation water quality are mainly of titrimetry, turbidimetry, electrical conductivity and of flame photometry. Additionally, pH measurements are routinely included, indicating whether acidity or alkalinity may be of a problem.

Electrical conductivity measurements are made very easily and routinely to assess total salt concentration of water samples. Empirical relations exist, relating electrical conductivity measurements with other concentration units such as $g.m^{-3}$, $me.lt^{-1}$ and the like.

Of major anions, carbonate (CO_3^{-1}), bicarbonate (HCO_3^{-1}) and chloride (Cl^{-1}) found in water are analyzed rather inexpensively with titration. Sulfate anion (SO_4^{-2}) is usually analyzed with turbidimetric method. Sulfate is precipitated out as barium sulfate with addition of $BaCl_2$ solution to the water sample. Intensity of barium sulfate suspension measured with either colorimeter or spectrometer is related with sulfate ion concentration in the sample. Calcium and magnesium of the major earth alkaline elements, present in irrigation water, can also be measured through titration, using versanate. The easiest and the simplest method of analysis for sodium and potassium is to use flame photometer, although some laboratories may prefer using atomic absorption spectrometer if available.

WATER QUALITY CLASSIFICATIONS

Early classifications

Scofield (1935) is among the first putting forward a criteria to assess irrigation water quality. He had recognized toxic effects of Cl^{-1} and SO_4^{-2} in irrigation waters (Table 2). Wilcox and Magistad (1943) suggested somewhat simpler classification and neglected potential toxicity of excess chloride ions (Table 3). Doneen (1954) modified the classification suggested by Wilcox and Magistad (1943) to include chloride toxicity (Table 4). Later, Doneen (1958) introduced a new concept called "effective salinity" (ES) to consider relative solubility of different salts likely to occur in irrigation water. ES can simply be calculated by subtracting concentrations of Ca and Mg carbonates from the total salt concentration since it is very likely that they can precipitate out in soil during irrigation. In a new version of water quality criteria, he also gave consideration to soil properties (Table 5).

Table 2 *- Concentration limits for irrigation water quality (Scofield, 1935).*

Class	$EC\times10^6$ 25° C	Total salt (ppm)	Na ratio %	Cl^{-1} (me/l)	SO_4^{-2} (me/l)
1. Very good	<250	<175	<20	<4	<4
2. Good	250- 750	175- 525	20- 40	4- 7	4- 7
3. Can be used	750- 2000	525- 1400	40- 60	7- 12	7- 12
4. Use with caution	2000- 3000	1400- 2100	60- 80	12- 20	12- 20
5. Harmful	3000<	2100<	80<	20<	20<

Table 3 *- Irrigation water quality standards (Wilcox and Magistad, 1943)*

Class	$EC\times10^6$ 25° C	Total salt (ppm)	Na ratio %	Boron (ppm)
1.	<1000	<700	<60	<0.5
2.	1000- 3000	700- 2000	60- 75	0.5- 2.0
3.	3000<	2000<	75<	2.0<

Table 4 *- Irrigation water classes. (Doneen, 1954)*

Criteria	Class 1 Very good - good	Class 2 Good - hazardous	Class 2 Hazardous - very hazardous
EC×10^6 25° C	<1000	1000- 3000	3000<
Boron, ppm	<0.5	0.5- 2.0	2<
% Na	<60	60- 75	75<
Cl, me/l	<5	5- 10	10<

Table 5 *- Classification of irrigation water based on ES (Doneen, 1958)*

Soil characteristics	ES	Class 1	Class 2	Class 3
Little or no leaching (Clay soils)	me/l	<3	3 - 5	5<
	ppm	<165	165 - 275	275<
Low leaching, drainage is restricted (Silty soils)	me/l	<5	5 - 10	10<
	ppm	<275	275 - 550	550<
Good drainage (Sandy soils)	me/l	<7	7 - 15	15<
	ppm	<385	385 - 825	825<

Long-time effects of irrigation water quality on physical properties of soil depend mainly on total salt, sodium, bicarbonate and carbonate concentration of irrigation waters, and on initial soil properties of soil itself. Doneen (1966) proposed a concept called "permeability index" (PI) to assess probable influence of water quality on physical properties of soils. The PI can be calculated using

$$PI = (Na^{+1} + \sqrt{HCO_3^{-1}}) / Cations \qquad [1]$$

where ion concentrations are given in me.l^{-1}. Figure 1 can be used to assess the probable long-time influence of water quality on soil permeability, which is the most important single soil physical property reflecting soil texture and soil structure, as well as chemical characteristics.

Irrigation water quality criteria developed by US Salinity Laboratory (USSL (1954) has received wide acceptance in many countries. Total salt concentration and probable sodium hazard of the irrigation water are the two major constituents of the criteria. Four classes of salinity and sodium hazard were proposed to assess irrigation water quality. Salinity hazard is based on electrical conductivity (EC) measurements. A concept called sodium adsorption ratio (SAR) is used for possible sodium hazard. The SAR value is calculated using the formula

$$SAR = Na^{+1} / \sqrt{Ca^{+2} + Mg^{+2} / 2} \qquad [2]$$

where concentrations are given in me/l. Figure 2 can be used to determine irrigation water classes in which a given quality of water can be placed using EC and SAR values.

Christiansen et al. (1977) have proposed to use a somewhat newer approach to assess irrigation water quality. They defined 6 different classes of irrigation water considering total salt concentration, sodium ratio, SAR value, sodium carbonate, chloride, effective salinity and boron concentration of the irrigation water (Table 6).

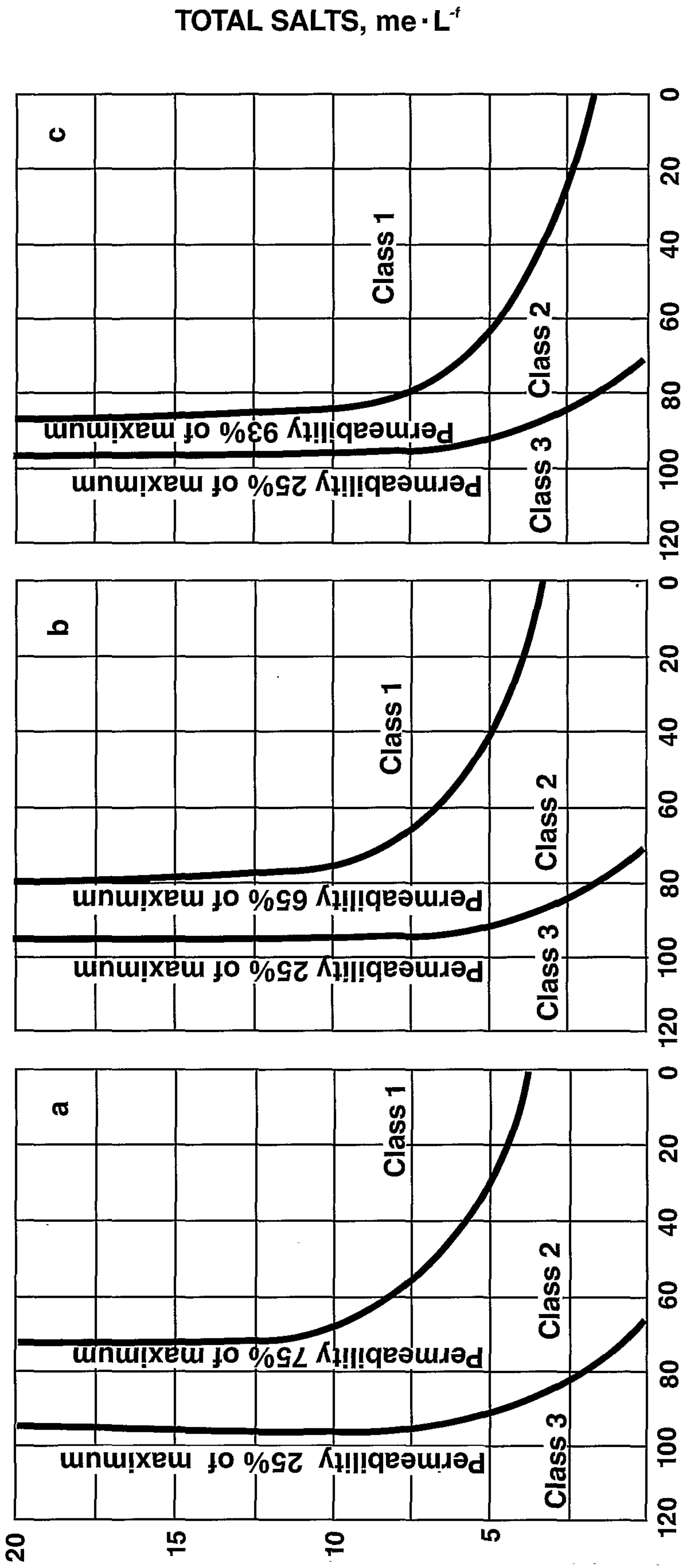

Fig. 1 - *Assessment of irrigation water quality for soils of different initial permeability. a) Soils with initial permeability of less than 2 cm.h^{-1}, b) 2- 12 cm.h^{-1} and c) with permeability of higher than 12 cm.h^{-1}, respectively (Doneen, 1966).*

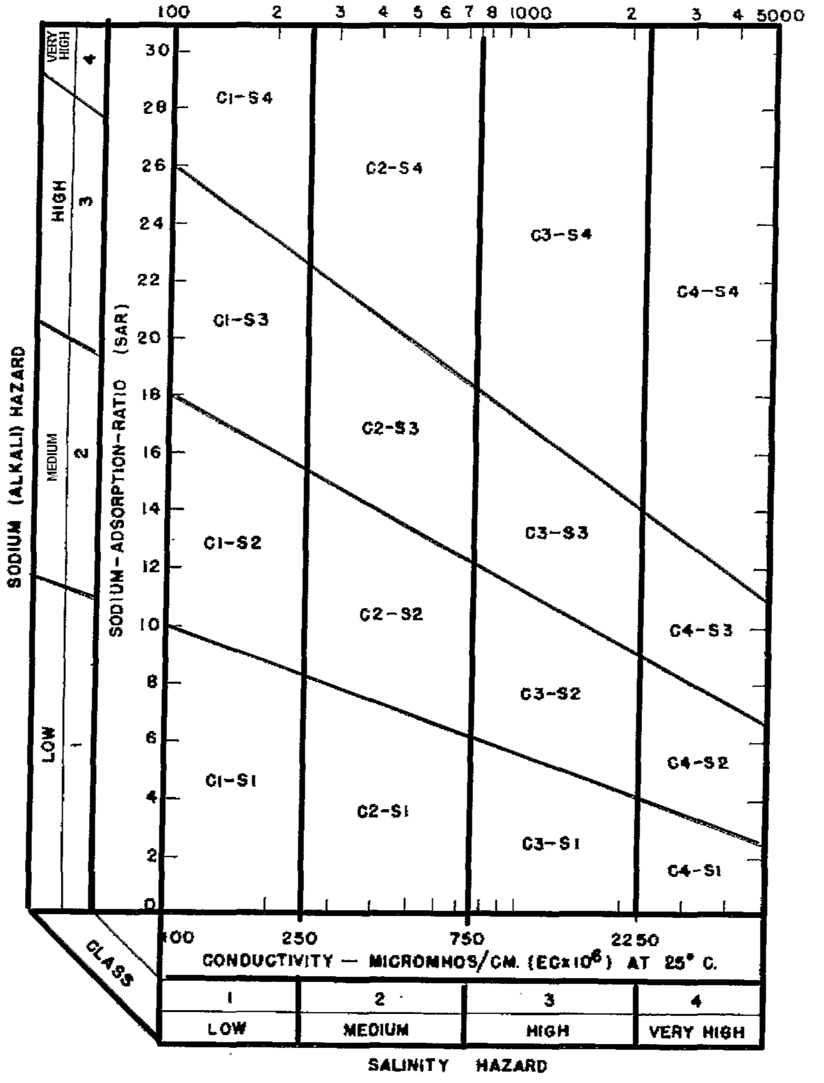

Fig. 2 - Diagram for irrigation water quality classification (USSL, 1954).

Table 6 *- Limit values to assess irrigation water quality*

Quality	ECx10^3 25° C	Na %	SAR	Na_2CO_3 (me/l)	Cl^{-1} (me/l)	ES (me/l)	Boron (ppm)
1	0.5	40	3	0.5	3	4	0.5
2	1.0	60	6	1.0	6	8	1.0
3	2.0	70	9	2.0	10	16	2.0
4	3.0	80	12	3.0	15	24	3.0
5	4.0	90	15	4.0	20	32	4.0
6*							

* Values are higher than those of quality 5.

LIMITATIONS OF IRRIGATION WATER QUALITY CRITERIA

Early irrigation water quality criteria including USSL (1954), have received strong criticism from the users. It was argued that it was not possible, nor was it correct to define clear cut boundaries between different classes of irrigation water. The main emphasis of early criteria was on ionic composition of the water alone, and they did not consider soil properties, salt tolerance of plant species, climatic conditions and existing irrigation and agronomic practices, which are being practised in a given region. A third class of irrigation water in a given region may well be considered second or even first quality in another region. Therefore, a general consensus has been now reached among the users, to use water quality criteria only as a general guideline, and to consider plant, soil and climatic conditions in the final evaluation of the water quality.

Guidelines for irrigation water quality

The University of California Committee of Consultants proposed "guidelines", which evolved from long years of experience and research finding of US Salinity Laboratory (Ayers, 1977). The guidelines (Table 7) tackle mainly four areas: salinity, permeability, toxicity and miscellaneous. The guidelines are flexible and should be modified in accord with local experience, special conditions of crop, soil, climate, method of irrigation and specific agronomic practices used in the area.

***Table 7** - Guidelines for irrigation water quality (Ayers, 1977)*

Problems and related constituent		Water quality guidelines		
		No problem	Increased prob.	Severe prob.
Salinity				
	ECw	<0.75	0.75-3.0	>3.0
Permeability				
	ECw	>0.5	<0.5	<0.2
	adj.SAR	<6.0	6.0-9.0	>9.0
Specific ion toxicity				
1.Root adsorption				
Na(adj.SAR)		<3	3.0-9.0	>9.0
Chloride				
$me.l^{-1}$		<4	4.0-10.0	>10
ppm		<142	142-135	>335
Boron, ppm		<0.5	0.5-2.0	2.0-10.0
2. Foliar application				
Na				
$me.l^{-1}$		<3.0	>3.0	--
ppm		<100	>100	--
3. Micelleneous				
NH_4-N, NO_3-N for sensitive crops				
ppm		<5	5-30	>30
HCO_3 with overhead sprinkler				
$me.l^{-1}$		<1.5	1.5-2.0	>8.5
ppm		<90	90-520	>520
pH			normal range 6.5-8.4	

Soil conditions

Salt accumulation is closely related to soil permeability. Salinization risk of soils with heavy clay texture is far more greater than that of light texture, sandy soils. Use of irrigation waters with high Na concentrations (i.e., SAR > 10) in soil of low permeability may cause further decrease in the permeability. Thus, the salinization risk increases. However, there are examples where irrigation water of high salt concentration are being used for long periods of time with no indication of salinization, in India, Central Asia and in some Middle Eastern countries. The reason for no salinization hazard is possibly due to light soil texture and good natural drainage. Additionally, specific crop varieties used in such areas are highly salt tolerant. In some cases, irrigation water treatment, flowing through gypsum blocks, is also considered among the necessary management practices to use poor quality water for irrigation. In Israel, irrigation waters having salt concentrations as high as 2300 $mg.l^{-1}$ are being regularly used, but only in sandy soils with drip irrigation systems. In some regions of Italy, for example the Bari region, irrigation water used has an unusually high salt concentration, 8000 to 10000 $mg.l^{-1}$. However , specific management conditions are enforced to use such poor quality waters, to maintain existing soil fertility. Irrigation is only allowed once in every two years. Only deep soils (2 - 3m) of light texture, and good drainage can be irrigated. Salts accumulated during the irrigation season can easily be leached with winter precipitation, amounting 400-600 mm annually. Additional limitation is that only certain crops such as maize and tomato can be grown successfully, in these regions.

Crop salt tolerance

Irrigation water quality should be assessed in light of crop salt tolerance. While a given quality of irrigation water may cause significant yield reduction for certain crops, no adverse effect may be observed for other crops. Therefore, irrigation specialists, agronomists and farm advisers should consider crop salt tolerance as the most important factor in evaluation of irrigation water quality (Maas and Hoffman, 1977).

Climate

Annual rainfall in a given region influences significantly salt balance in plant rooting zone. In arid and semiarid regions, crop water requirement is higher than in temperate climates. High crop water requirement calls up high amount of irrigation water application, which in turn, brings more salt in agricultural areas. In the areas where annual rainfall is high, water quality for irrigation may not be of concern if land drainage is adequate. Annual precipitation amounting 400-500 mm may be quite adequate to prevent salt accumulation under irrigated agriculture.

Seasonal changes of water quality

Quality of irrigation water is not constant over the seasons. Salt concentration of rivers, lakes and man made reservoirs may increase toward the end of summer. Relative change of the concentration depends on storage volume of the reservoirs. While the salt concentration change is only 10-20 % in large bodies of water, it may be as high as 100 % in small ponds, lakes and reservoirs. River Nile, for example, has the least salt concentration during floods; whereas, salt concentration is doubled during the dry season. Deep ground water wells show the least fluctuations in salt concentration; whereas, shallow wells may show considerable changes. Therefore, quality of irrigation water must be assessed considering its seasonal fluctuations in salt concentration.

HOW TO PREVENT SOIL SALINITY

Salt balance in plant root zone depends on irrigation water requirement, quality of water, irrigation scheduling and on overall soil and climatic conditions. Guidelines discussed below may help to minimize occurrence of salinity.

Drainage

Drainage is the most important requirement for irrigated agriculture. Drainage systems are complementary to the irrigation systems. If natural land drainage is not adequate. It is essential that either an underground or an open surface drainage system must be implemented in the region. Without adequate drainage, continuity of existing soil productivity will always be endangered.

Land preparation

It is essential that fields under irrigation must be levelled through land grading if traditional surface irrigation methods like furrow, border or basin irrigation methods are being used. Land levelling provides uniform water application which is important for leaching of excess salts brought with irrigation water.

Field preparation must be such that it should increase soil infiltration. Occasional deep ploughing in heavy texture soils may improve infiltration. Mulching, when it is feasible, may prevent surface evaporation and upward transport of salts. Relative placement of seeds along the irrigation furrow may provide a completely different soil environment in relation to salinity (Fig. 3).

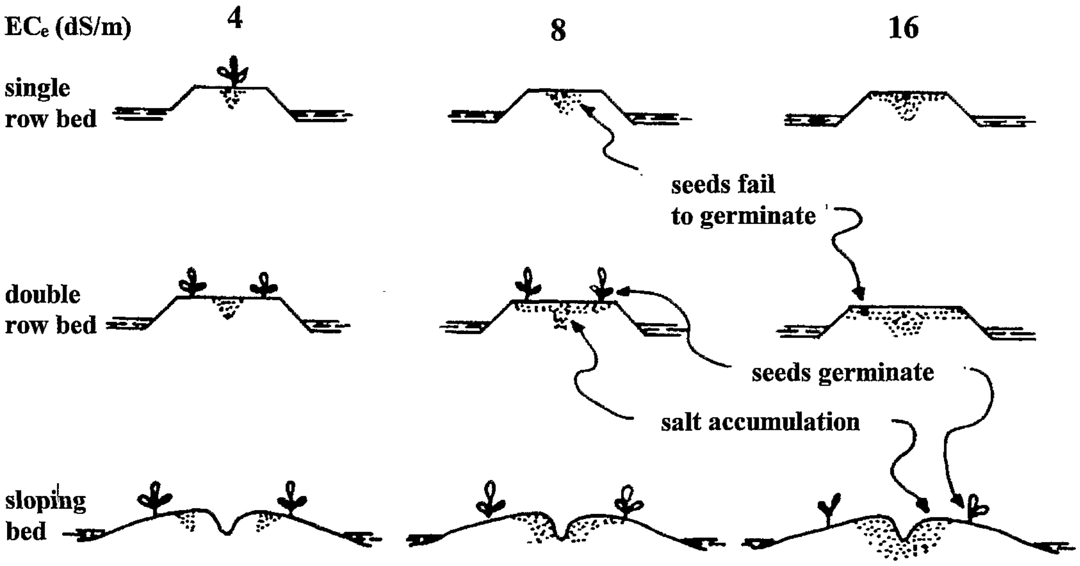

Fig. 3 - Relative placement of seed bed and soil salinity in furrow irrigation (Bernstein et al., 1955).

Crop rotation

When it is possible, crops of high salt tolerance should also be included in the cropping system. Rice cultivation, for example, may improve salt balance in plant rooting zone because it requires continuos water application which leaches excess salts left in previous years. However, a good field drainage under rice cultivation is essential.

Irrigation methods and management

Border and basin irrigation methods should be preferred to furrow irrigation to minimize salinization risk when good quality of irrigation water is not available. Sprinkler irrigation is very effective in leaching of excess soil salts, provided water is not sparingly used.

Irrigation scheduling also influences salinity hazard. Irrigation with small application of water but applied with short intervals between each successive irrigation is better than irrigation made at long intervals. In the former case, soil matrix potential which is allowed to fluctuate within a narrow range of soil water content is closer to field capacity. In such cases, deleterious effect of high osmotic potential of soil water, characteristics of saline soils, decreases and therefore salinity hazard can be overcome.

It has been shown that sprinkler irrigation is more effective in leaching of saline soils (Oster et al., 1972; Kirda et al., 1974) than other irrigation methods. However in general practice, because overall amount of irrigation water applied in sprinkler systems is comparatively lower than traditional gravity systems, some salt accumulation may be evident within the soil profile at the end of each irrigation season. If annual rainfall is not enough to leach accumulated salts, some excess water must be applied to maintain the salt balance. In low pressure irrigation systems, like drip and bubble irrigation methods, water is applied in small quantities, generally on daily basis. Plant-root-zone soil water content is kept relatively high in such systems. Because high soil water content cause low osmotic potential (i.e., low salt concentration), irrigation water having salt contents of 2000 to 3000 mg.l^{-1} can be safely used without any significant crop yield reduction, However, some salt accumulation is unavoidable at the end of the irrigation season. If annual rainfall is not enough to leach the accumulated salts, the leaching must be assured by alternative means.

Leaching requirement

If quality of water is such that it may cause soil salinity, proper irrigation management becomes very important to prevent accumulation of salts in plant rooting zone. Seasonal changes of salt concentration in plant root zone is unavoidable and normally it should not be of much concern. However, if soil salinity starts to show an increasing trend over the years in a given region, the existing management system needs to be examined.

Each water application imports some salts to plant root zone. Although accumulation of salts can be tolerated for short periods during irrigation season, increase of soil salinity must not be allowed on annual basis from year to year. It is important that irrigation water requirement must accommodate leaching water requirement to maintain salt balance within the soil profile. Therefore, salinity balance in irrigation practices is as important as water balance. Water balance within plant rooting zone (i.e., soil profile) can be described as

$$I + P + G = ET + R \qquad [3]$$

where I is irrigation water, P precipitation, G capillary water rise from ground water, ET evapotranspiration and R is recharge/deep percolation water. Similarly one can write salt balance equation as

$$IC_i = RC_r - GC_g \qquad [4]$$

where C is concentration of related water components shown with respective indexes. In the water balance equation, salt removal and salt import with ET and P respectively, are assumed to be zero. Using equations [3] and [4] and further assuming that there is no seepage from high lands one can drive the following equations (Van der Molen, 1973)

$$D = \frac{(ET - P)Ci}{Ctk - Ci} \qquad [5]$$

$$I = \frac{(ET - P)}{Ctk - Ci} \qquad [6]$$

where D is drainage water percolating through soil profile defined as D=R-G, Ctk is soil salt concentration at field water capacity with additional equalities of Ctk=Cr=Cg. The equations [5] and [6] can also be written in electrical conductivity units:

$$D = \frac{(ET - P)ECi}{2ECe - ECi} \qquad [7]$$

$$I = \frac{(ET - P) \cdot 2ECe}{2ECe - ECi} \qquad [8]$$

where ECe and ECi are salt concentrations in electrical conductivity units (dS.m^{-1}) of soil saturation extract and of irrigation water, respectively. EC of soil solution at field water content is related to EC of saturation extract with the equation $ECtk \approx 2ECe$. If both drainage coefficient (i.e., daily drainage water out flow) and irrigation water requirement are estimated using the equations [7] and [8], salt accumulation risk under irrigated agriculture is essentially nil. Irrigation methods where water is applied sparingly, may cause salt accumulation during the growing season. If annual precipitation is not sufficient to leach out the accumulated salts under such systems, then extra salt leaching is essential during off-season periods. It should further be commented that relatively less amount of salts is imported under new methods of irrigation such as trickle, mini-sprays and the like, as compared to traditional surface irrigation methods (furrow, border etc.) and therefore leaching of annually accumulated salts should not necessarily be of a problem and generally, annual precipitation may be sufficient for the leaching. In the areas where precipitation is very low, occasional light leaching may prevent salinization and sustain soil fertility.

CONCLUSIONS

Irrigation water quality alone is not enough to evaluate potential salinity hazard which may be confronted under irrigated agriculture. It is not possible to classify different qualities of irrigation water with clear-cut boundaries, and therefore one must consider plant, soil, climatic conditions as well as existing agronomic and irrigation practices in a given region in the final evaluation of water quality. Agronomists and irrigation specialists should advice farmers for appropriate management practices to overcome potential salinity hazard if the quality of available water would pose any problem. Water quality criteria should be used as a guideline to define appropriate management practices in irrigated agriculture to maintain existing soil productivity with the benefits of high crop yields under irrigation.

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