The use of saline water for irrigation

Introduction

The availability of an adequate quantity of decent quality water is an indispensable renewable natural resource for plant growth. In some parts of the world the problems of water quality are more severe than the problems of water availability (BATISSE 1974). Arid and semi-arid countries, in particular, are facing the exhaustion of their natural water resources and are being forced to use poor quality water for their irrigated agriculture. The result is often disastrous as extensive productive regions become salinized and go out of production.

Water quality problems are mainly created by dissolved salts and by plant nutrients. Of the numerous examples, the following are just a few:

- In the Rajasthan region in India about 56 per cent of the total irrigated area is salt-affected through the continuous use of poor quality irrigation water (PALIWAL 1972)
- In Israel no additional water resources remain to be developed and the use of poor quality water is gradually increasing
- In the U.S.A. a 20-year study of the Rio Grande River showed a tenfold increase in the mean annual salt concentration, attributed almost entirely to irrigation return flow (WILCOX 1962)
- On the Caribbean island of Curaçao heavy overpumping of groundwater has caused a degradation of the groundwater quality and an in-

trusion of seawater at sites along the coast

 In various countries the increased use of fertilizers has led to harmful concentrations of nitrogen and phosphorus in irrigation return flow and has caused water quality problems in both surface and groundwaters

In fact, the improper use of water by man has contributed more to the salinization of land than has the inherited salinity by natural causes. HART (1974) states that 'environmental degradation' has generally occurred because of a lack of concern for the mechanisms by which man's actions interact with his environment'. Against this background it is understandable that in circumstances where saline water has to be used for irrigation, great care is nowadays being taken to prevent the accumulation of harmful amounts of salt in the soil.

The use of saline water for irrigation is not a new development. Farmers in parts of North Africa and the Middle East have been using it for centuries. They learned from experience how to use this water without the risk of salinizing the soil and without jeopardizing their crop yields. Those farmers did not have modern methods of measuring the salt content of water and soil. At best they tasted the water to determine how salty it was, and learned by trial and error whether they could use it successfully.

In the future, as water of good quality becomes scarcer and will probably have to be reserved for

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International Agricultural Centre, Wageningen (guest worker International Institute for Land Reclamation and Improvement). man and industry, it can be expected that saline water, or at least water of poor quality, will be increasingly used for irrigation.

The definition of saline water is, in a sense, rather arbitrary because irrigation water always contains some salts. Saline water is generally defined as water containing more than 1 to 1.5 g salts per litre, which corresponds with an electrical conductivity (EC) of 1.5 to 2.3 mmhos/cm. The total salt content, however, is not the only criterion for determining the suitability of the water for irrigation. All following factors should be considered: - the quality of the water

- the soil
- the climate
- the crops
- the irrigation and drainage conditions
- the management practices of the farmer

No absolute criteria exist for these factors, in the sense that a given quality water, soil, or crop is never suitable for irrigation. The various factors interact, as will be discussed below.

Water quality

Total salt content

The total salt content of irrigation water indicates the total of dissolved salts whereby Ca, Mg, K, Na, Cl, SO₄, HCO₃, and occasionally NO₃ account for 99 per cent of the salt content of most

Figure 1. Development of EC_e per layer. Water quality test in Tunisia (based on data from UNESCO 1970).

waters. The total salt content of irrigation water strongly influences the salinity of the soil. In a long-term experiment on a silty clay loam in northern Tunisia (UNESCO 1970) four different qualities of water were used, their total salt contents being 0.2, 1.3, 2.3, and 3.5 g/l (Figure 1). The soil in the upper 40 cm has clearly different salt contents for the four different qualities of water, although in the deeper horizons the differences are less. Obvious seasonal fluctuations in salt content occur in the upper layer due to a more intensive leaching in the winter. The different salt contents in consecutive years are due to changes in leaching which, in their turn, are the result of











Date palm oasis in southern Tunisia, irrigated with water containing 2 g/l salts. The palms suffer from excess salts due to irrigation with saline water, insufficient water availability, and lack of drainage

the irrigation method used and the quantity of water applied – factors related to the crops that are grown.

Another example is an experiment in the Punjab (Pakistan) which also used four water qualities with total salt contents: 0.175, 1.0, 2.0, and 2.7 g/l. Figure 2 shows the average salt content of the layers 0–30, 30–90, and 90–150 cm during the first three years of the experiment (de MOOY et al. 1975).

These examples show that the salt content of the soil increases as the salt content of the irrigation water increases. However, the salt content of the soil also depends on the leaching fraction. If, therefore, the leaching fraction varies strongly, the relation between the salt content of the irrigation water and that of the soil cannot be used for precise predictions of soil salinity (PALIWAL and GANDHI 1973).

Chemical composition

In considering the chemical composition of irrigation water, one must consider both the total quantity of the various ions and the mutual proportion in which they occur. If ions like sodium, chloride, and boron occur in large quantities, they may have direct toxic effects on the crops. Most sensitive in this respect are fruit trees and other woody perennial crops, in the leaves of which these toxic ions concentrate, causing the leaves to dessicate and die. Apart from the direct toxic effect that sodium may exert on the crop, it also influences the soil structure and thus indirectly affects the crop. In this respect the mutual ion proportion of sodium to calcium and magnesium must be considered. This ratio can be expressed by the 'Sodium Adsorption Ratio' SAR, i.e. the ratio of the sodium concentration in milli-equivalent per litre (meq/l) and the square root of the half concentration of calcium and magnesium (RICHARDS 1954). If the SAR of the soil moisture increases, more sodium will be adsorbed by the soil complex, thereby negatively affecting the soil structure. A relation exists between the SAR of the soil moisture and the 'Exchangeable Sodium Percentage' (ESP) of the soil. The ESP, which is used as a criterion of sodicity in the soil, is defined as the amount of exchangeable sodium in the soil expressed as a percentage of the cation exchange capacity. The SAR of the soil moisture depends, in its turn, on the SAR of the irrigation water and is greater because the soil moisture has a higher salt concentration. Provided that the proportions of the ions remain constant, the SAR increases with the square root of the total salt concentration. The relation between the SAR of the irrigation water and the ESP of the soil varies with the nature of the adsorption complex of the soil and with the irrigation and drainage conditions, which together determine the concentration factor of the soil moisture. As well, rainfall and capillary rise from the

The same after the irrigation water supply is improved and a drainage system is installed.

ECe mmhos/cm



Figure 2.

Relation between soil salinity, expressed as EC_e in mmhos/cm, and salt content of irrigation water (based on data from de MOOY et al. 1975).

ions with respect to calcium and magnesium ions

subsoil may play a role.

Figure 3 A illustrates the influence that the SAR of the irrigation water has on the ESP of the soil. This example is taken from the earlier mentioned experiment with four water gualities in Tunisia (UNESCO 1970). At the end of the first summer season, the ESP had already reached a rather constant level, the minor seasonal fluctuations being due to differences in leaching fraction. More leaching took place in winter, resulting in a lower concentration factor of salt in the soil moisture: rainfall also contributed to the water movement. Figure 3 B shows that the ESP increases with depth and that the differences between the ESP values become smaller owing to an increase in the concentration of the soil moisture and to the initial salt content of the soil. The SAR of the soil moisture may differ considerably from the SAR of the irrigation water. If the irrigation water has a high concentration of carbonate and bicarbonate ions and if this water becomes concentrated as soil moisture, calcium and magnesium precipitate as carbonates when the solubility product is exceeded. Calcium and magnesium are thus withdrawn from the soil solution and the SAR value increases much more than in case of concentration without precipitation. The excess of carbonate and bicarbonate

was originally characterized by EATON (1950) with the term 'Residual Sodium Carbonate' (RSC), which is the sum of carbonates and bicarbonates minus the sum of calcium and magnesium in meq/I. As the RSC increases the SAR of the soil moisture increases and makes the water less suitable for irrigation. A shortcoming of the SAR concept is that the SAR values are supposed to indicate the sodium hazard of the water, but in fact they do not reveal whether residual sodium carbonate is present. The SAR concept was therefore modified and a new term 'the adjusted SAR' introduced, incorporating the effect of carbonate and bicarbonate in the SAR equation (BOWER et al. 1965; AYERS and WESTCOT 1976). The introduction of the SAR_{adi} concept means an improvement on the old concept, although recent research has shown that it leads to a somewhat overestimated sodicity hazard (OSTER and RHOADES 1977). Irrigation water in which the concentration of carbonate and bicarbonate ions exceeds that of calcium and magnesium ions, as in Venezuela (PLA 1968), often shows a low total salt content and a low SAR value. Using the total salt content as a criterion for suitability, we would classify this water as non-saline and therefore suitable for irrigation. But this would be wrong because the composition of the salt is unfavourable as indicated by the RSC and SAR_{adi}, which is higher

than the SAR.

This type of water is, in fact, much more dangerous than water with a higher salt content but with a favourable chemical composition. If the chemical composition of the water is unfavourable, problems of soil structure may arise and the permeability of the soil may decrease. This reduces the possibility of leaching the soil, which, if neglected in the irrigation process, will soon cause the salt content of the soil to rise to unacceptable levels. In some regions of India and Pakistan, the water has both a high total salt content and an unfavourable chemical composition because of a high content of carbonate and bicar-



Figure 3. Water quality test in Tunisia (UNESCO 1970).

bonate ions, or, as in Tunisia and Libya, it has a. high sodium content. Such waters can only be used successfully if salt-tolerant crops are grown on light-textured soils with a good permeability. There, because the adsorption complex is almost lacking, the soil's structure and permeability are hardly affected by the excess of sodium in the soil moisture.

An unfavourable chemical composition of the water can be remedied by applying gypsum, either in the irrigation water or on the soil. But gypsum is not always available or may be too expensive for the farmer.

The above discussion illustrates that the interaction between the chemical composition of the water, crops, soil, and means of the farmer all play a role in determining the suitability of water for irrigation.

Soils

As mentioned earlier, poor quality water can only be used on permeable soils. The key point of the percolation process is that the permeability of the soil must make it possible to wash the soil and leach the salts from the rootzone. The extra quantities of water needed for leaching can be calculated, but if the permeability of the soil is low, this extra water may stagnate on the surface, causing the crops to suffer from waterlogging without any leaching taking place. The structure and permeability of the soil must be good and remain good under long periods of irrigation. If the SAR of the soil moisture increases through an unfavourable chemical composition of the irrigation water, it may be necessary to restrict the use of such water to soils with a low clay content. Such soils will have a small adsorption complex and their structure will therefore hardly be affected by the composition of the soil moisture. Owing to their structure, heavy and medium-heavy clay soils may originally have a fair permeability, but if their structure deteriorates, it will strongly affect their permeability. As the total salt content of the irrigation water increases, so too does the leaching requirement. and with that the permeability requirement of the soil. The poorer the quality of the water, the higher the requirements of the soil structure to maintain a fair to good permeability. These requirements explain why the use of saline water or water of poor chemical composition is generally restricted to light soils with a good permeability. Calcium in some form is often used to reclaim sodic soils, the most common form being avpsum. Lime, owing to its low solubility, is less often used, although by applying organic matter (manure or green manure), which increases the CO₂ content of the soil air, the solubility of the lime can be improved. On lime-bearing soils sulphur compounds can also be applied, which, after oxidation to sulphuric acid, form gypsum with

the available lime.

Experiments in India have shown that soils with very high ESP values can be gradually reclaimed by applying gypsum or pyrite. Initially these soils, at least in their upper 0.50 m, belong to the saline sodic soils. After leaching, a sodic soil is left whose ESP may vary between 50 and 100. Amendments of gypsum or pyrite can gradually reduce these high values. Careful irrigation with small amounts of water (because of the low infiltration rates) have proved to give good yields of crops tolerant to a high ESP, for example rice (CSSRI 1977).

Climate

Evaporation, rainfall, and temperature are the most important climatological components to be considered in determining the suitability of water for irrigation. A high evaporation rate means that more water and thus more salt will be applied than when evaporation is low. In general, this will cause a higher salt content in the soil, notwithstanding leaching.

If water with a high salt content is used, it may be wise to grow winter crops or crops that do not need irrigation during periods of maximum evaporation. For instance, in Tunisia it was possible to cease irrigation of alfalfa from early July to the end of August and to harvest seed instead of hay in that period.



Rain may contribute substantially to the leaching process, provided it falls during periods of low evaporation as happens in regions around the Mediterranean Sea and in the Middle East. If the soil is irrigated at the beginning of the rainy season, the soil moisture content will then be approximately at field capacity and most of the rainwater will contribute to the leaching instead of being needed to make up the soil moisture deficit. This is illustrated by Figure 4 which shows the decrease of soil salinity under the influence of winter rainfall (347 mm) in southern Iran (van AART and OOSTERKAMP 1968).

Crops grown during relatively cool periods of the year show, in general, a greater salt tolerance than when grown in warm periods. Summer tomatoes have proved to be more sensitive to blossom-end-rot than spring or fall tomatoes (UNESCO 1970). This disease is caused by a lack of calcium, which occurs when saline water is used at high temperatures (BERNSTEIN 1964).

Crops

The osmotic potential of the soil moisture increases as the salt content of the soil moisture increases. If this happens, less water will be available to the plant, thus reducing its growth and causing a yield depression. Usually the vegetative growth is more seriously hampered than the formation of seed. Apart from the osmotic effect, the

Figure 4.

Fluctuation of soil salinity (EC_e : 0–25 cm layer) under influence of rainfall and irrigation on land cultivated with wheat in southern Iran (van AART and OOSTERKAMP 1968).

salt can exert a toxic effect on crop growth. In principle, the relation between yield depression and salt content is an S-shaped curve. In the yield depression range of 5 to 75 per cent, this relation is approximately linear, as is shown in Figure 5 (MAAS and HOFFMAN 1977). At yield depressions as high as 50 per cent, the crops may still develop regularly and homogeneously without visible salt damage. Consequently, one is apt to underestimate the damage caused by the salt, which appears only at harvest and after the yield is compared with that obtained under non-saline conditions. The reduced crop growth may thus be erroneously ascribed to other factors. The experiment with four different water gualities in Tunisia showed that the maize irrigated with the 3.5 g/l water was less developed and ripened earlier than the maize irrigated with the 0.3 g/l water. The yield depression was about 50 per cent. Similar results were obtained with wheat in experiments in southern Iran, where water with salt contents of 0.6 and 4.2 g/I was used (FAO 1972). Notwithstanding the yield depressions the crops in the above examples were regularly developed and did not show the stunted growth or discoloration usually observed on saline soils. If growth is stunted,





Figure 5. Relation between yield and salinity (adapted from MAAS and HOFFMAN 1977). the yield depression is much greater than 50 per cent.

From research conducted in different countries under different soil and climatic conditions, it has been found that the classification of crops into low, medium, and high salt-tolerance classes agrees well. Differences in the various classifications can often be ascribed to differences in variety. For instance, alfalfa in the U.S.A. is classified as medium salt-tolerant, whereas in North

, African and Middle Eastern countries it is reckoned among the highly salt-tolerant crops. Local varieties of wheat and barley in those countries usually also have a high salt tolerance. Most vegetable crops have a low salt tolerance, which can be explained by the osmotic effect. Vegetable yields are usually highest at relatively low moisture potentials. With an increasing salt content of the soil solution, the osmotic effect causes a rapid rise in moisture potential. In the last decades little research has been done on the development of salt-resistant crop varieties, the main research efforts being devoted toward making the environment fit for the growth of conventional salt-sensitive crops. Only in very recent years has a new approach been made to modify the crops genetically to make them fit for saline environments (EPSTEIN 1978).

Irrigation and drainage conditions

Leaching

As already mentioned, the salt content of the soil depends not only on the salt content of the irrigation water but also on the leaching fraction. Figure 6 shows the results of an irrigation experiment with four different quantities of water corresponding with a daily water application of 4, 6, 8, and 10 mm, all with a salt content of 2.3 g/l (UNESCO 1970).

The evaporation was approximately 7 mm/day. Clear differences were observed in the salt content of the soil, and also clear increases of the salt content with depth.

The increase in salt content with depth, which can be expected under long-term irrigation, occurs because the uptake of moisture by the plants decreases with depth. Hence the quantity of water percolating through the rootzone decreases with depth. If we assume that 100 per cent of the irrigation water infiltrates into the top layer, only about 25 per cent may percolate through the bottom of the rootzone to the subsoil.

To calculate the required quantity of leaching water, the simplest method is to regard the rootzone as a single layer in which one wants to maintain a salt concentration that is acceptable to the plants. This leads to the well-known salt balance equation (RICHARDS 1954) in which the quantity of salt supplied by the irrigation water is

considered equal to the quantity of salt discharged by the percolation water. In reality, the salt content of the upper soil layers, which take up most of the water, is lower than the average salt content while that of the deeper layers is higher. The onelaver concept of the rootzone thus leads to an overestimate of the required quantity of leaching water.

Part of the leaching water, however, quickly percolates through the cracks and rootholes, hardly removing any salt. As this part of the leaching water is not effective in the leaching process (BOUMANS 1963; UNESCO 1970) it therefore compensates for the overestimate of the quantity of leaching water made by regarding the rootzone as a single layer. Only if nearly all the water contributed to the leaching process - and this would depend on the soil structure and the irrigation method applied - would it be justified to reduce the quantity of leaching water. Theoretically, so much leaching water could be applied and the salt content of the soil so reduced that the soil moisture finally attains the same concentration as the irrigation water. In practice, however, this is impossible because it would cause waterlogging on most soils. One should therefore accept the salt content of the soil that corresponds with that of the irrigation water and with the quantity of leaching water that the crop can tolerate, adapting the choice of crops accordingly.



Figure 6. ECe mmhos/cm Irrigation test in Tunisia (UNESCO 1970).

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If the rootzone is regarded not as one layer but as several layers, it can be calculated that, under good irrigation and drainage management, the effective leaching water should be about 15 per cent of the irrigation water. Taking into account that only part of the leaching water is effective, the total quantity of leaching water should be about 25 per cent of the irrigation water. It is then possible to maintain the soil solution at three to four times that of the irrigation water, which will suffice provided there is good irrigation and drainage management.

Leaching can be done in one of two ways: by applying extra water either frequently, (e.g. at each irrigation) or seasonally. With frequent leaching, more water must be applied than the plant needs for evapotranspiration. This raises the peak use of water during summer when water is usually scanty, and also increases the salt supply. With seasonal leaching, the operation can be conducted in periods of low evaporation when water may be more plentiful and when rain may contribute to the leaching process.

Experiments conducted in Tunisia under different soil and climatic conditions showed that seasonal leaching gave excellent results (UNESCO 1970). The salt content of the soil was only slightly higher and the crop yield was not, or only slightly, lower than with frequent leaching. These findings agreed with local practice, which uses salt water economically in summer and makes use

Maize experiment in northern Tunisia (Cherfech); qualities of irrigation water: 0.2 and 3.5 g/l salt.

of the winter rains.

Irrigation methods

With frequent irrigations the soil moisture content will be higher and the salt concentration of the soil solution lower than with less frequent irrigations. The osmotic potential will thus remain lower, thereby favouring crop growth. This procedure produces a more marked effect on light textured soils than on medium and heavy textured soils, where smaller fluctuations in moisture content occur.

Surface irrigation is the oldest and most widespread irrigation method and can also be used for saline water. Its disadvantage is that because the soil surface serves as a transport medium, water quantities cannot be precisely controlled because of differences in the soil's infiltration rate. The quantity of water applied must be large enough to cover the whole field, but if applied frequently, the crops may suffer from excess water, especially on medium and heavy textured soils, while particularly on light textured soils the water use will be excessive.

Sprinkling offers better possibilities for frequent irrigation because it is easier to control the water quantities, thus preventing too much water from being applied. At high temperatures, however, sprinkling with saline water may cause the leaves of the crops to burn. Experiments in Tunisia showed that no leaf burning occurred when water of 4 g/l was sprinkled at temperatures less than 20 to 22 °C. This means that sprinkling with saline water can be applied on winter crops, and on summer crops in their first growth stage. Another advantage of sprinkling is that, owing to the small quantities of water applied, the struc-



Damage to coconut plantation due to the high salinity of irrigation water along the coast of Saurashtra, State of Gujarat, India.

ture of poor or sensitive soils deteriorates less than with surface irrigation, and that the germination and emergence of crops are usually better. Once a good crop stand has been reached, surface irrigation can again be applied, thus making it unnecessary to install a permanent sprinkling system, instead of which mobile units can be used, as is done in the Imperial Valley of California (MARSH et al. 1975) and in Tunisia (UNESCO 1970).

Drip irrigation makes possible a regular and very frequent water supply, which can lead to a nearly stable salt content of the soil solution at the lowest possible level because the moisture content of the soil approximately corresponds with field capacity. Since the wetted soil volume is leached continuously, the salts move and accumulate at the rim of the wetted soil body. Drip irrigation is particularly advantageous on light-textured soils with a low water-holding capacity. Even better than with sprinkling, drip irrigation can provide a regular moisture supply, without causing leaf burning. This has been confirmed by several reports (BERNSTEIN and FRANCOIS 1973; 1975; GOLDBERG and SHMUELI 1970). As drip irrigation supplies water to the site of the plant and not over the whole field, weed growth is restricted. If rainfall is insufficient to leach the salt from the rim of the wetted soil body, other ways of leaching must be found, with due consideration given to their feasibility, costs, and effectiveness



(FAO 1973).

Drainage

Drainage serves to dispose of the leaching water that percolates through the root zone. Drainage can be either natural, as when river levees are drained by the adjacent river, or artificial, either through canals, ditches, and pipes (horizontal drainage) or through a system of tubewells fitted with pumps (vertical drainage). Drainage is the necessary complement to irrigation. This is true for all types of irrigation, not only for irrigation with saline water. But, if drainage is poor and the irrigation water saline, soil salinity problems will be sooner created than when the irrigation water is fresh. If saline water is to be used in a new irrigation project, the installation of a drainage system is even more urgent than otherwise. Postponing drainage in such a project can lead to disaster.

Management practices

Good management practices aim at obtaining a good stand of the crop by a rapid and homogeneous germination of the seed and emergence of the seedlings. A failure at this stage generally leads to a poor stand and a considerable yield decrease. This applies to all crops - non-irrigated as well as irrigated - but especially to crops irrigated with saline water. Mistakes made when irrigating with saline water have a far more harmful effect than those made with fresh water. Salinity, although it will usually delay germination, does not prevent it. The emergence of the seedlings, however, can suffer far more severely from unfavourable soil and weather conditions than from salinity; such conditions can even prevent emergence. In spring, for example, a relatively low temperature may occur in combination with a strong drying wind which forms a crust at the soil surface. The young seedlings, whose germination was delayed by the salinity and the low temperature, may be caught in the crust that has formed in the meantime. The non-uniformity of the plant emergence then makes it necessary to irrigate more frequently and this increases the hazard of the plants suffocating.

A good emergence of the seedlings with the shortest delay is of primary importance for the development of the crop. Measures that can help to achieve it are the following:

- Improving the soil structure through good cultural practices; crust formation caused by applying large quantities of water during the first irrigation after sowing can be prevented by sprinkling with small amounts at a low rate
- Good land grading, which allows a homogeneous moisture distribution to be obtained and prevents water from stagnating at the surface
- Sowing at favourable temperatures so as to shorten the time between sowing and seedling emergence

If the irrigation water has a composition that negatively affects the soil structure, the application of gypsum or organic manure may improve matters.

Since the infiltration rate strongly depends on the structure of the top layer, tillage should aim at keeping this layer open. To prevent its structure from deteriorating, irrigation methods that allow small quantities of water to be applied should be chosen.

It is obvious that management practices depend on the skills of the farmers and on the implements they have at their disposal. When deciding whether saline water can be used under local conditions, these two factors must also be considered.

Epilogue

In the last decades a better insight has been gained into the factors that affect the use of saline water for irrigation. This is clear when one compares the well-known classification of irrigation water by RICHARDS (1954) with the classification standards given by AYERS and WESTCOT (1976). In Richards's handbook one can find almost all the factors that play a role in determining the suitability of water for irrigation, but one gets the impression that the users of this handbook only take the salt and sodium content of the water into account. Since the use of saline water causes problems, they classify this water as unsuitable, and judge the possibility of using it on the basis of a laboratory analysis, without taking into consideration other local factors like the soil. the adaptation of the cropping pattern, etc. AYERS and WESTCOT emphasize the problems one faces when using saline water, indicating that they become more severe as the salt content of the water increases or its composition becomes less favourable, but they also discuss the

possibilities of solving these problems. This new approach provides guidelines that consider each problem and its solution separately. The guidelines are a tool developed to help the trained field man and scientist to better understand. characterize, interpret, and improve soil and plant response under a given set of conditions. They stress that the decision whether to use saline water depends on the conditions at farm level, i.e. the decision must be made in terms of the specific use and the potential hazard to crop production under local conditions. The use of saline water may constitute a considerable restraint, but the increase in soil salinity and in the exchangeable sodium at the adsorption complex are not irreversible processes.

Summarizing, the main conditions for the successful use of saline water are:

- soils of sufficient permeability
- crops chosen for their salt-tolerance
- good irrigation management to ensure sufficient and properly distributed water
- good drainage, either natural or artificial
- skilled and well-equipped farmers

When fresh water is used, frequently occurring defects like inadequate drainage, imperfect land levelling, and poor tillage will be disclosed only very gradually. When saline water is used, those defects will show up very rapidly as the margin of safety is much smaller.

Of course, the problems of using saline water for

irrigation could be overcome by desalinizing the water. Various technical processes are nowadays available to do so. But the costs are prohibitive and are likely to remain so for some time to come. Desalinization of water for irrigation will therefore be applicable only under special circumstances and for special cash crops like vegetables. It is unlikely that desalinization will cause a breakthrough for the large-scale application of saline water.

Progress can perhaps be expected from the technology of breeding for salt tolerance. The development of crop varieties that are better adapted to the saline environment could cause a break-through in crop production. This new approach is at present receiving attention. Great research efforts, comparable with those for the breeding of new grain, rice, and maize varieties during the sixties, may well be justified.

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