13 Soil Salinization in the Mediterranean: Soils, Processes and Implications

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1 INTRODUCTION

In all Mediterranean countries there are areas where the soils have become saline. This can pose a great problem for soil use and conservation, especially as their salinity is continually increasing due to the characteristic climate of dry, hot summers and mild, wetter winters. The excessive presence of salts, especially sodium salts, alters or destroys the soil structure as well as increasing the swelling and dispersion of clay aggregates. These smaller soil particles, which are almost always richer in nutritive elements and in organic matter, become more liable to be transported away by water or wind. The soil thus loses its fertility and the environment can become desertified.

During the summer, high temperatures cause a considerable increase in evaporation and this, together with the lack of summer rainfall, favours salt accumulation. In the autumn–winter period, rain is often of short duration but of considerable volume and intensity, causing clay and organic colloids to swell and deflocculate, altering the soil structure. Intense rainfall events produce torrents that wash the easily eroded soil away, sometimes causing landslides and rockfalls. In soils affected by salinization, cultivation is rendered difficult in the short term. The majority of crop species suffer due to the change in the water/oxygen ratio. Plants are subject to water and salinity stress, and to consequent nutritional deficits, reducing yields considerably. In the medium term many plants cannot survive and the symptoms of land degradation emerge, while in the long term desertification occurs.

2 HISTORICAL PERSPECTIVE

Agriculture has been practised in the Mediterranean since Neolithic times (*c.* 10 000 BC). Continual cultivation, especially as populations have expanded and technology has allowed it, has in many places over-exploited the soil and impoverished it. Intensive cropping and excessive use of mineral fertilizers continue to make the situation worse. In addition, in this arid or semi-arid climate, water for agriculture is an increasingly limited resource as more is needed for urban and industrial use. Therefore economics dictate that water known to be saline and bad for soil fertility is now frequently used for irrigation of crops. Sometimes projects designed to aid crop production fail due to widespread salt accumulation. For example, in Egypt, following the construction of the Aswan Dam on the River Nile, 60% of farmland was affected by salinity. In particular, the highly clayey soils of the Nile Delta are affected by salinity and alkalinity (sodic-saline), due to continuous irrigation with saline groundwater (Chanduvì 1977). It is worth remembering that the decline of ancient civilizations, such as those that flourished in Mesopotamia, was as much due to the salt accumulation in their irrigated soils as to warfare or any other reason.

The problem of salinization in soils is assuming greater prominence today. The greenhouse effect caused by the increasing levels of carbon dioxide and other gases in the atmosphere appears to be leading to a slow but continuous rise in mean annual temperatures in many places. As a result of

Mediterranean Desertification: A Mosaic of Processes and Responses. Edited by N.A. Geeson, C.J. Brandt and J.B. Thornes

this, scientists foresee two possible scenarios for the future (Postiglione 1991). According to the first scenario, sea-water evaporation will increase and consequently cloudiness will increase too, causing more rainfall in dry, pre-desert and desert areas. Both agricultural and forestry production will increase, induced by the effects of a CO_2-rich atmosphere on the photosynthesis and physiology of plant production (Idso 1989). The second scenario is not so optimistic and suggests that there will be a decrease in rainfall during the summer months, an increase in evapotranspiration and a consequent increase in soil salinization. The extent of water courses will be reduced and areas that were formerly temperate will become arid (Adams et al. 1990). Water available for irrigation is likely to have an even higher salt content, due to concentration following evaporation, again promoting soil salinization and desertification (Bultot et al. 1988).

3 DEFINITION

Salinity is a general term including various soluble salts that can affect soil and water in different ways. A preliminary classification distinguishes saline soils, saline–sodic soils and sodic soils (Table 13.1).

Electrical conductivity is used as a measure of saline concentration in water (EC_w) and saturated soil paste (EC_e) and is expressed as dS m^{-1}. Sodium ions are particularly important as they drastically affect soil characteristics and also the absorptive capacity of the plant root system. The ESP (exchangeable sodium percentage) index is the ratio between sodium ions and the total cation exchange capacity.

Saline soils, characterized by the predominance of Ca and Mg ions, are white, with a slightly alkaline reaction and are generally well structured. However, the presence of salts leads to an increase in the osmotic pressure of the circulating solution, making it difficult for the plant roots to absorb water and nutritive elements, which in extreme cases may cause the plasmolysis of the root cells. The overall situation is aggravated by the frequent droughts during the summer in Mediterranean environments. The excessive presence of certain anions or cations may affect the absorption and development of some plant species, while other ions (Cl, B and Na) may even be toxic.

Sodic soils have an acceptable salinity ($EC_e < 4$), but they are found in areas of low rainfall and are characterized by the excessive presence of sodium ions, which causes deflocculation of the clay colloids and hence the loss of structure. This in turn leads to a reduction in permeability, with the ponding of water during the rains or irrigation and a marked lack of soil oxygen and nutritive elements. In times of drought a surface crust or deep cracks are formed. All these circumstances have an adverse effect on the root system, which in some cases suffers irreversible damage, and on the whole underground biomass, exacerbated both by the high pH and by the fact that sodium ions in excess are toxic for many plant and micro-organism species.

Sodic–saline soils occur more frequently in Mediterranean environments, and have the same drawbacks as those found in saline and sodic soils, but to a greater degree of severity, i.e. chiefly the dispersion of colloids and concomitant problems, as well as high osmotic pressure in the circulating solution. Their pH is slightly lower, especially when there are some anions present, although it increases if the anions or some soluble salts are leached.

Soils characterized by high salinity, and especially sodic soils, have different problems according to their location, soil texture and soil profile. If they are situated on a slope, they support few

Table 13.1 Properties of saline, sodic–saline and sodic soils (Riverside US Salinity Laboratory)

Soils	EC_e	ESP	pH
Saline	>4 dS m^{-1}	<15%	<8.5
Sodic–saline	>4 dS m^{-1}	>15%	<8.5
Sodic	<4 dS m^{-1}	>15%	>8.5

Mediterranean *maquis* species and are easily eroded by the impact of rainfall until bare rock is exposed, which is one of the frequent causes of desertification of Mediterranean hill soils. In fact, the situation of the Mediterranean hill soils is itself very fragile, even when salinity problems are not pressing, though it may be possible to help the situation with suitable cultivation techniques and suitable crops or plants (Postiglione 1988; Postiglione et al. 1993). With regard to this issue there was a tragic event in May 1998 in Sarno (near Salerno, southern Italy), when a rainfall event, not even of great intensity, moved all the soil, which was mainly volcanic deposits above calcareous rocks, down the valley. As a consequence of this event, in addition to the destruction of the woodland vegetation and bedrock exposition, the mud flooded an entire village and a large number of deaths were recorded.

On the plains, there are sometimes marshes that permit only sparse vegetation of palustrine plants. In better situations, when abundant rainfall occurs, surface ponding may occur that creates well-known problems concerning soil structure and plant root asphyxia. Subsequently, such surface waters disperse as runoff, taking with them clay which is already suspended due to colloid dispersion. Thus the finer particles are removed, i.e. those that are richer in nutrients, organic matter and micro-organisms, essential for soil fertility. At times, besides the removal of fertile material, there are cases in which the lower soil horizons have highly toxic concentrations, or limestone or large quantities of sand accumulate, and degradation becomes irreversible (Schertz 1983).

4 CAUSES OF SALINITY IN THE MEDITERRANEAN

Soil salinization may be of a primary nature, when salt accumulation arises through pedogenetic processes, or of secondary origin, due either to abiotic factors such as excessive evaporation or sea-water infiltration, or resulting from human intervention, chiefly saline water irrigation.

Primary salinization occurs during the pedogenesis of certain soils. In the weathering of some rock types in extremely dry environments the normal leaching of salts and especially of cations does not take place. A great quantity of salts and cations accumulate over time in the soils.

Excessive evapotranspiration, typical in dry environments (Figure 13.1), causes salinization since only the solvent (water) evaporates. As a result, the surface layers continuously accumulate salts found in the circulating solution, both in the upper and underlying layers, and the circulating solution present in the latter rises by capillarity consequent to the evaporation. This fact is very important in Mediterranean regions in which evaporation reaches even $8-10\,\mathrm{mm\,day^{-1}}$. Naturally, the phenomenon is accentuated if there is saline groundwater close to the soil surface.

Sea-water infiltration frequently occurs along coastal plains, being particularly marked in those areas which in different geological eras, or even in historical times, experienced the phenomenon of bradyseism, which occurs quite commonly in Mediterranean environments. Clearly, in this case the salts in question almost entirely consist of sodium chloride.

Soil salinization from *irrigation* depends on the quality and salt concentration of the water used and the nature of the soils. In fact, the damage caused by using saline water increases in particular in high clay-content soils. By contrast, the rainfall pattern in the rainy season is very important because it may be conducive to the leaching of the salts from irrigation water.

Other *anthropogenic* causes of salinization may include overgrazing and deforestation in semi-arid environments, the excessive use of chemical products, and the contribution (via the air or water) of pollutants emitted by industry. In particular, overgrazing in semi-arid environments leads directly to desertification when even the poor-grade pasture diminishes and no other fodder resources are available (Szabolcs 1994).

In reality, soil salinity almost always stems from the concurrence of two or more of the above factors. However, constant or increasing salinity is chiefly caused by the use of highly saline irrigation water, compounded by excessive evapotranspiration in dry areas. Nevertheless, in the soils of the Mediterranean Basin, given the hot, dry climate in the spring–summer period, only by resorting to irrigation can high crop yields be achieved. As long as there is water with a low salt content available, irrigation is also a means of leaching salts and thus improving the condition of such soils. In reality, water with a salinity of $EC_w < 3\,\mathrm{dS\,m^{-1}}$ (similar to about 2‰ of the total concentration)

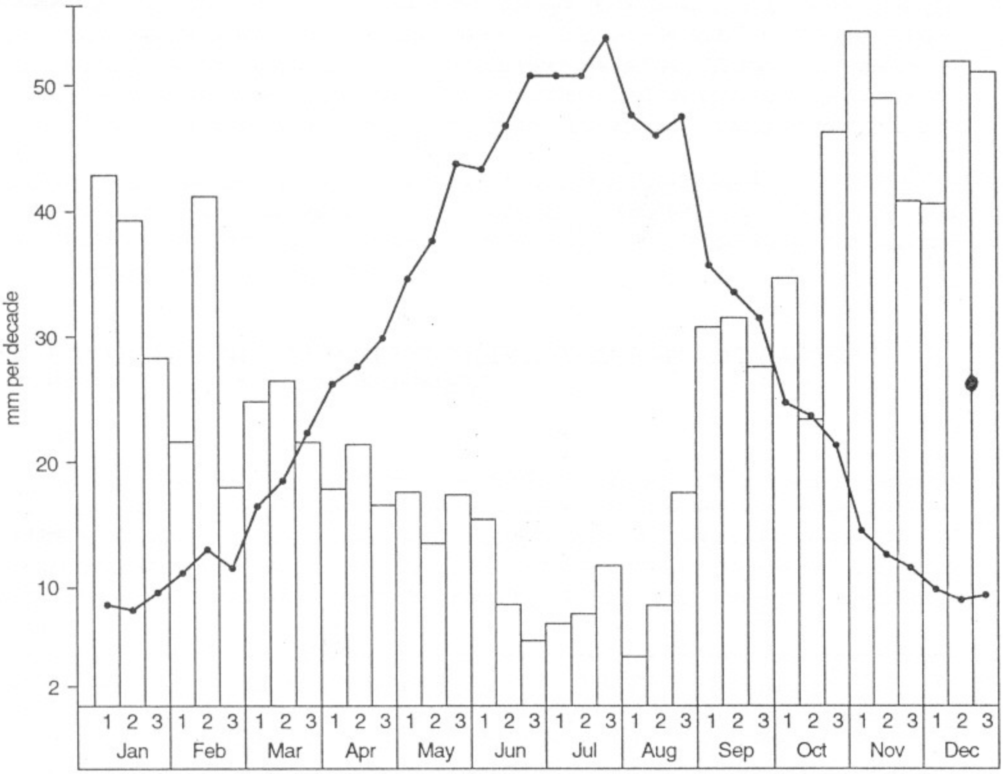

Figure 13.1 Example of potential evapotranspiration trend in relation to rainfall: Scafati, Campania Region, 25 years average (Postiglione 1972)

is considered useful for irrigation. The problem becomes more complicated when the water available for irrigation has a high salt content.

As a vital resource for agriculture in Mediterranean environments, irrigation water may be extracted from surface water (springs, rivers, streams) or groundwater (phreatic boreholes, artesian wells). In the case of surface water resources, in the Mediterranean area springs are sometimes salt-rich since such water passes through rock layers and saline or sodic soils where there is an excess of sodium which has stayed *in situ* during the pedogenetic process, or because there is sea-water infiltration. Such infiltration frequently occurs in some aquifers when well supplies are over-abstracted or when the groundwater fails and is not recharged due to a shortage of rain during the winter. Both types of process may leave a void to be filled by sea-water infiltration. Of course, the situation becomes even more serious when excessive abstraction means that wells have to be sunk deeper, with the consequent risk of reaching saline groundwater.

A case of mixed-origin salinization has occurred in the Sele River Plain (southern Italy), in the area called the Paestum Plain, where there are six springs with a considerable salt content not associated with high temperatures, and a total flow of $3\,m^3\,s^{-1}$. Mean electrical conductivity varies from $11.9\,dS\,m^{-1}$ in the most saline spring with the greatest flow, to $8-9\,dS\,m^{-1}$ for two other springs and 3.9 for the other three. A study was conducted (Celico et al. 1982) on the origin of such salinity. That study examined the following aspects: the geological and chemical nature of the catchment basin; the pattern of the piezometric surfaces in the surrounding mountains; the various cations and anions present in the water and the relationships between them; the effects of using isotope ^{18}O; soil and subsoil properties in the plain; and the circumstances whereby, during eustatic movements in the Quaternary, the current springs were actually below sea level. The study in question showed that the mineralization of such waters is due to various degrees of mixing between low salinity calcium bicarbonate water and sea-water. On the basis of the findings, the following causes were ruled out: derivation from connate water or the circulating solution in evaporitic soils, and the contribution of deep fluids and sea-water infiltration due to groundwater abstraction. "A model is proposed in which the hydrodynamics of the groundwater in the carbonatic massif are such as to remove the sea water *trapped* below the source level during the last eustatic movements in the Quaternary" (Celico et al. 1982).

In a coastal area of Apulia, again in southern Italy, it was observed (Caliandro et al. 1997a) that some wells used for irrigation supplied water with conductivity varying from 1.10 to 4.20 $dS\,m^{-1}$ and that water quality is not affected by the distance of the wells from the sea, but by the heterogeneity of the karst aquifer of the area in question.

5 EXTENT OF THE PROBLEM IN THE MEDITERRANEAN AND IMPACT ON PRODUCTION AND ENVIRONMENT

5.1 Soils

Saline soils are a problem for all the countries in the Mediterranean area, and this problem becomes more and more serious each year because of the climate characteristics and human intervention, which is not always careful to safeguard natural resources. Consequently, in the future, if appropriate measures are not adopted, agricultural yield will decrease consistently, while environmental problems will increase towards desertification, which already affects thousands more hectares each year.

Following trials carried out in different countries, the serious damage to soil structure and reduction of fertility caused by salinity has emerged. So, in the Sele River Plain (southern Italy), on a clayey-silty soil treated for six years with saline water (with 1% NaCl added), the sodium was observed to cause deflocculation of the clay particles, thereby altering soil porosity, i.e. reduced macroporosity and increased microporosity (a typical blockage of the macropores with the formation of microporosity). The increase in microporosity meant that more water was retained, although this was retained with greater force and the plants were not always able to draw such water with their suction capacity (Tedeschi et al. 1996).

In central Sicily, in saline-water irrigation trials conducted for several years on two different soils, salt accumulation was observed, in so far as the winter rainfall was too low to ensure complete leaching. Furthermore, in a vertic soil, an increase in magnesium and sodium soluble ions was observed with the shift from calcic solonchak to magnesium solonchak, and an increase in exchangeable sodium percentage (ESP), with a consequent worsening of the soil structure (Fierotti et al. 1982).

In Greece, saline soils are present and diffused over soils on flat areas due to natural–ecological factors, both abiotic (climate, geomorphology, hydrogeology) and biotic (vegetation, soil fauna). Human activities have been very important, especially with the extension of irrigation and undisciplined use of saline water at the beginning of the 20th century, which has caused over-pumping, and the consequent sea-water infiltration into the groundwater layer. Sustainable management of groundwater resources together with the restoration of drained freshwater wetlands is carried out whenever it is possible (Zalidis 1998).

In Cyprus, sodic and saline soils are present due to irrigation with salt-rich water, which is used because of the scarcity of freshwater. The use of fertilizers and municipal wastewater also contributes to the salinity. In order to limit secondary salinization damage, modern irrigation technologies and cropping systems are now recommended (Papadopoulos 1998).

In Turkey, two groups of saline soils are present: hydromorphic saline alluvial soils and solonchak soils. Both groups may have saline, sodic and saline–sodic classes (Sönmez 1997).

In Israel, there are four major areas that are affected by salinity: Galilee (north), Western and Central Negev (centre) and Arava valley (south). In northern Israel, salinity causes different degrees of damage and it is connected with high evaporation and irrigation water quality, particularly when treated sewage water is used. In coastal areas sea-water infiltration is widespread. In central Israel, soils are damaged mainly by increasing sodicity. For cropping of these soils it is recommended that the optimal land use is chosen according to site characteristic parameters such as water quality, duration of use, soil type, crop type, presence of drainage tiles, etc. In Israel, salinity causes a big decrease in cotton, tomato and corn seedling survival, reduction of citrus tree yield and reduction of the crop development rate in deciduous trees and all perennials, i.e. pears, peaches and plums (Nadler 1998).

In Spain, salt-affected soils are widespread. Saline soils are present in coastal areas, where the main salt affecting the soil is sodium chloride. In the Guadalquivir river valley and the Marismas, located at the estuary of the river, alkalinity is the prevailing factor. Alkalinity is also present in the Ebro river valley (north-east Spain) and also in some southern areas of Spain. Along the Mediterranean coast the problem of soil salinity is increasing due to scarcity of precipitation and irrigation with low quality water (Moreno 1998).

In Mediterranean regions of the African continent, water and soil salinity problems are particularly severe, principally in areas where rainfall is less than 500 mm per year. Such areas are found in Egypt, Libya and Tunisia (Chanduvì 1997).

5.2 Vegetation

Vegetation is affected by salts in the soil to different degrees, with some plants being more susceptible to certain ions than others. Generally salinity causes a decrease in soil hydraulic conductivity and root aeration, and an increase in resistance to root penetration. Moreover, roots meet greater difficulty in suction of water and absorbtion of nutritional elements.

Under these conditions, in natural ecosystems only Mediterranean *maquis* vegetation will grow, especially those plants which have adapted themselves to salinity and drought conditions. In extreme cases excessive salinity can cause the disappearance of some plant species, causing a reduction in biodiversity.

In agro-ecosystems it is worth stressing that when crops are grown on saline land or land irrigated with saline waters, even if salt-resistant crops are used, a large number of alterations occur in plants (e.g. osmotic adjustments and various reactions) which affect the various organs from the roots to the stems and leaves, and which may actually prevent plant growth. These alterations depend on the salt concentration and the species, variety and age of the plants. The most widely studied and evident variations occur in the leaves, and concern both the morphology (leaf surface, surface/weight ratio) and physiology, in particular the gas exchanges and photosynthesis. Such alterations naturally affect yield quantities, which decrease to a different extent according to the circumstances, and product quality, which generally becomes less desirable. In fact, there are some tables, regarding some main crops, in which it has been shown that potential yield reduction is a function of soil EC_e (Ayers and Westcot, 1985). Regarding this issue there is much literature about certain crops. For example, in southern Italy there have been studies on tomatoes (Barbieri et al. 1990; Caruso and Postiglione 1993), eggplant (Ruggiero and Perniola 1992; Barbieri et al. 1994; Ruggiero et al. 1994; Sifola et al. 1995), peas (De Pascale and Barbieri 1996), snap beans (De Pascale et al. 1996), broad beans (De Pascale and Barbieri 1997), watermelons (De Pascale et al. 1998), peppers (De Pascale et al. 2000) and sunflowers (d'Andria et al. 1997; Tedeschi et al. 1997).

6 MANAGEMENT OF SODICITY AND SALINITY

There are several criteria and techniques for conserving soil and limiting salinity damage. Besides irrigation with fresh water, mention should also be made of the benefits of adding organic matter. This, in fact, besides supplying nutritional elements, develops a stabilizing action on pH, and above all it develops a protective action on mineral colloids. In the presence of organic matter, clays can resist the dispersing action of sodic cations, preserving the crumb structure for longer. Unfortunately, in the Mediterranean environment organic matter is in short supply and, where it is available, it is subject to rapid oxidation due to the high temperatures. Hence its effects are not long-lasting.

Of great use, particularly in sodic soils, is the addition of appropriate correctives, such as chalk ($CaSO_4$), which reduces alkalinity but obviously increases salinity. Its application must therefore be combined with rapid salt-leaching conditions (rain or irrigation and, fundamentally, good drainage). With such soils great attention should also be paid to using mineral fertilizers, both in terms of quantity and composition. With regard to fertilizer composition, in sodic soils it is preferable to use "physiologically acid" fertilizers, e.g. fertilizer in which cations are absorbed by plant roots and anions remain in the circulating solution.

In arid and semi-arid climates, freshwater resources are not infinite, and more and more water is needed for civil or industrial purposes, so the use of saline water for agriculture will continue to increase. In these circumstances it is essential to monitor the situation as regards the use of vegetation or crops and land management techniques, to limit soil degradation and stop the advance of the desert.

The situation improves when land improvement schemes are conducted either through appropriate channelling or, better still, through drainage with underground pipes, which allow the leaching of salts into deep layers. Under these conditions in areas with sufficient rainfall during the autumn–winter period, such leaching occurs naturally. In some cases, if low salt-content water is available, leaching may be carried out by irrigation.

As regards irrigation water, attention is nowadays focused on the nature of the salts, in so far as the presence of calcium may mitigate the adverse effects of sodium. Hence if the ratio of sodium to calcium and magnesium, the SAR (sodium absorption ratio), is less than 10, the water can be used without causing damage. When the SAR increases, some limitations occur, and when the SAR exceeds 26, water is generally not utilizable.

In many Mediterranean regions such as Israel, Egypt, Libya and Tunisia and in several areas of Spain, Italy, Albania, Greece and Turkey, where water is chiefly saline, "it nonetheless constitutes a resource" (Chanduvì 1997), and if well-managed, may contribute to limiting damage from soil salinity. Thus in the Nile Delta in Egypt, groundwater is abstracted, while in the same area and in the Nile valley, drainage water from settlements on higher ground is used: in all cases, such waters are saline. In Libya, in the Turga area east of Tripoli, 3000 ha are irrigated with water with a conductivity starting from $2.5\,dS\,m^{-1}$, and in some coastal areas well water is used which, due to continuous pumping, has led to sea-water infiltration. In Fezzan, water is used with an electrical conductivity that ranges from 9.0 to $1.79\,dS\,m^{-1}$ (Chanduvì 1997). In southern Tunisia, in the Tatouine area, the climate is pre-Saharan, with irregular winter precipitation (120 mm annual average) and hot dry summers. The soils have developed over sedimentary materials, are sandy, rich in carbonates and sulphates, are salt-affected, and the natural vegetation is very scarce, dominated by perennial shrubs. This area has been the subject of research, using remote sensing, to study the water infiltration rate for an eventual irrigation scheme (Escadafal et al. 1993).

In the Carpathian Basin, irrigation water as a solvent reactant and transporting agent plays a decisive role in the development of salt-affected soils, but above all it is connected with drainage (Varallyay 1998). In Apulia, southern Italy, a commonly used technique to prevent excessive soil salinization is to irrigate very frequently with amounts of water exceeding crop evapotranspiration so as to keep the soil sufficiently wet throughout the season and, at the same time, ensure a little continuous leaching of salts (Cavazza et al. 1984).

For the above reasons, all the studies and research being conducted on the possibility of using saline water in various countries are of great interest for the future of agriculture and in reducing the risks of desertification. Of particular importance is the relationship between "irrigation = salt in" and "leaching = salt out" (Papadopoulos 1998). In other words, in a dry environment, when saline-water irrigation is carried out to avoid progressive salt accumulation in the soil, a quantity of water must be applied in addition to that normally calculated on the basis of the climate, soil and crops, so as to promote the leaching of the applied salts and their removal, by means of drainage, from the root zone (known as the leaching requirement).

As long ago as 1929, E. de Cillis, a scholar in the field of dry-farming in Mediterranean environments (southern Italy and Libya), wrote: "Saline water will have to be used (in irrigation) in great abundance and on well-drained soils, so that continuous washing takes place and salts do not accumulate." Nowadays the amount of water needed to satisfy the leaching requirement (LR) is calculated according to the electrical conductivity of the irrigation water (EC_w) and the electrical conductivity of the soil saturation extract (EC_e) for a given crop appropriate to the tolerable degree of yield reduction, according to the formula $LR = EC_w/(5EC_e - EC_w)$.

Moreover, there are cases in which the water cannot wet all the soil uniformly (e.g. due to the presence of cracking, or poor irrigation systems for distributing water). Therefore, appropriate consideration must also be given to the leaching efficiency. This is 100% in sandy soils using the sprinkler distribution system, but may fall to 30% in poorly structured or cracked, clayey soils. Thus the percentage obtained with the above formula is divided by the leaching efficiency percentage, and the amount of water required increases further.

In order to be certain of actual salt leaching, the nature of the soil must be duly considered. In loose grounds, leaching usually occurs without great difficulty; in medium soil, two-layer tillage appears useful (ploughing to ~40 cm and ripping to ~60 cm). In compact clayey soils, as are the majority in many Mediterranean areas, a good drainage network first needs to be built, which involves a considerable technical and economic commitment. In Egypt, for example, rudimentary forms of drainage along the course of the Nile date back to ancient times. Drainage programmes have been operating along modern lines since 1909, and by 1997, 1.9 million hectares of farmland had been drained, with much of the drainage water being re-used, as stated above, to irrigate other land (Ramadan 1998).

In pluriennial trials conducted in the Sele River plain, southern Italy, on a clayey-silty soil (fluentic xerochrepts) with three irrigation frequencies (every 2, 5 and 10 days), using freshwater ($EC_w = 0.54\,dS\,m^{-1}$) and four levels of saline water obtained by adding 0.125, 0.25, 0.5 and 1% commercial NaCl ($EC_w = 2.30, 4.43, 8.46, 15.73\,dS\,m^{-1}$), the highest soil salinization values ($EC_e = 20\,dS\,m^{-1}$) were found at the end of each irrigation season in the most saline treatment (Figure 13.2). The latter fell to only $7\,dS\,m^{-1}$ after the rainy season, while in the freshwater treatment the EC_e varied little and returned to normal after the rainy season. After six years, despite seasonal oscillations, the EC_e values showed an increasing trend in the treatments irrigated with various salinity levels, which was more accentuated in the treatments irrigated every two days compared with those irrigated every 10 days. With the latter treatment a larger expansion of the sheet of water occurs in the underlying

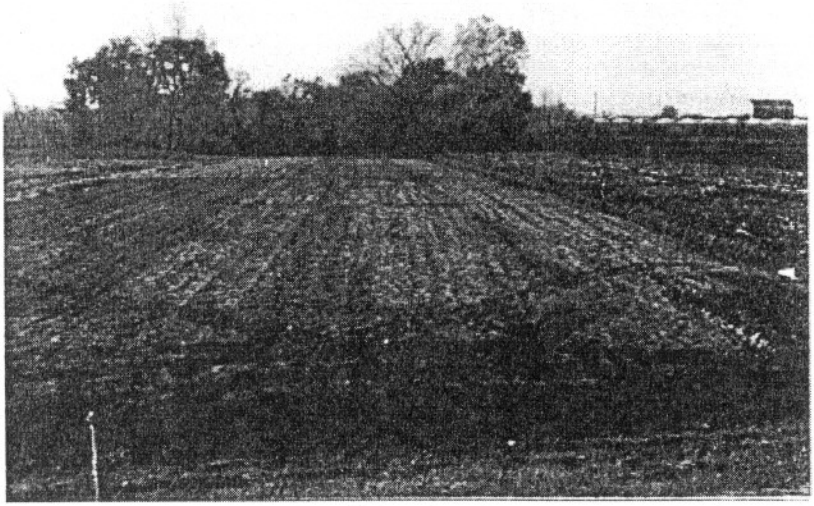

Figure 13.2 Piana del Sele experimental field after six years of irrigation by waters with different salt amounts. From the left are plots watered by fresh water and by water with 0.125, 0.25, 0.5 and 1% NaCl respectively. Beginning with the 0.25 treatment, the presence of saline efflorescence increasing with salt concentration is evident

layers. Moreover, the ESP values also increased considerably, with the pH shifting from 7 to 8. The structure proved degraded due to the deflocculation of the clay caused by the sodium, with very low soil permeability (Postiglione et al. 1995). Hence from these trials it emerges that by spacing out watering events, less salt accumulation occurs in the upper layer.

Nowadays it is recommended that watering events (excluding drip irrigation) are spaced out, in so far as if the surface is kept continuously wet, evaporation causes salt concentration in the surface soil layers. In fact, when the surface is constantly wet, roots absorb water first from the upper layers, unlike when the soil surface is dry due to spaced-out irrigation events when roots absorb water from the lower layers. In other words, evaporation and root absorption processes together cause surface saline concentration when frequent irrigation occurs (Ragab 1996).

It is worth stressing that among irrigation systems, when saline water is used, drip irrigation causes less stress to plants, since it maintains a continuous supply of water in the root zone. There is therefore less probability of a higher salt concentration occurring. In fact, since water is released over small areas, leaching processes prevail on evaporation and root absorption shares.

Finally, when only a small amount of freshwater is available, saline water can be used for salt-resistant crops and freshwater for salt-intolerant crops, or it is possible to alternate saline-water irrigation with freshwater irrigation, so that the latter can accelerate salts leaching to deeper layers. Another strategy, which appears preferable, is to use freshwater for the young stages of the crops, and to use saline water subsequently (Shalhevet 1994).

In Apulia, on the basis of initial results from irrigation trials with saline water on clayey-silty or clayey-sandy soils, it emerged (Caliandro et al. 1997b) that the winter rains are sufficient to leach the salts added by irrigation and that in environments with an autumn rainfall of about 400 mm it does not appear necessary to add the quota of leaching water. However, where irrigation is abundant, the soils appear to be becoming sodic. In other areas, on soils rich in iron and aluminium sesquioxides, which have good structure, permeability and good natural drainage, saline-water irrigation is traditionally applied to vegetable crops in alternate years. The salt is thus leached by the rainfall occurring during two winters.

Finally, it must be recalled that one of the main means of maintaining soil vitality is the presence of vegetation, whether trees, shrubs or crops. When deficient soils are completely abandoned, they undergo further degradation and decline towards desertification. Also harmful for soil conservation is the adoption of unsuitable cultivation systems (i.e. single-crop farming, very intensive cultivation) and unsustainable vegetation exploitation (e.g. excessive cattle densities causing overgrazing, destruction of forests).

In the last few years there has been more research on species and varieties resistant to different levels of salinity and on their tolerance to some ions (Cl, B, etc.). The aim of such studies is to be able to advise on crops, cropping systems and technologies in order to make agriculture possible on saline soils or by using salt-rich water to irrigate. There have also been attempts to grow halophytes (salt-tolerant species) on saline soils in order to produce biomass for conversion into bio-fuels.

All these interventions to restore degraded soils due to excessive salinity and their use according to a modern concept of agriculture ("sustainable agriculture") are undoubtedly fundamental to providing an efficient defence against the slow but progressive advance of the desert.

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