Prospects of Soil Salinity for the 21st Century

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Introduction

It was the second half of the 20th century when mankind awoke to the importance of major environmental problems, including the hazards resulting mainly from the growth of world population, finite natural resources and, last but not least, from the ever increasing detrimental effects of the improper technologies of production and the current patterns of civilization.

Following this recognition extensive political and scientific activities began in order to characterize the hazards, outline the limits for growth in population and production, and to elaborate new technologies and new life styles which can make possible to sustain the conditions for the survival and even development of the biosphere and society.

There has been an immense number of national and international projects, studies, scientific and political undertakings during the last decades, dealing with environmental problems. It is enough to refer to the activities of the Club of Rome, the UN Conference in Stockholm during 1972 or the UN World Conference in Rio in 1992 to see the world-wide importance of these issues. It can be stated without exaggeration that no other problem exists, except the threat of nuclear war, which is so crucial for the future of mankind as the deterioration of global environment (World Commission on Environment and Development, 1987).

In spite of the abundance of projects, books, publications, events, societies, etc. dealing with this subject, we are short of reliable technical studies which not only describe one or other of the part processes which contribute to the present dangers to the environment but also offer methods of prediction and prevention.

It would be useless to try and list the major processes causing harm to the environment and it would be an even more futile attempt to establish which of them should have priority for our attention over the rest because in this respect a great many branches of science, decision-making, politics, education, etc. are also concerned.

One of the major components of the environment is the soil. So it is evident that soil forming processes, soil properties and the productivity of soils are often decisive factors in environmental issues. A broad range of technical literature is available, discussing soil forming processes and soil as an important entity among the natural resources regulating mass and energy flows within the ecosystem, on the one hand, and serving as a larder for living organisms, on the other hand (ARNOLD et al., 1990).

Among the numerous processes related to the soil as well as to environmental risks one of the well perceivable and well defined in relation to changing production systems and changing environment is the process of soil salinization which poses a serious hazard at present and threatens with even more dangers in the foreseeable future.

Salinity as an Environmental and Economic Hazard

It is already textbook material that salt-affected soils which are extended on all the continents are a burden to the productivity of agri-, sylvi-, and horticulture. But, more than that, salinity poses a threat not only to agriculture, but may also have detrimental effects on the whole biosphere. In an ecosystem affected by salinity or alkalinity not only plants suffer from the unfavourable effects of harmful substances but also microorganisms, invertebrates, vertebrates and even human beings.

Salinity affects the biosphere indirectly through the soil but also directly by accumulating in waters, plant tissues, etc. and changing the equilibrium of substances in the entire food chain.

With the development of up-to-date environmental studies it became more and more evident that soil salinization is a hazard not only for agriculture but also for the whole environment.

The few inorganic salts, mainly sodium salts, that cause soil salinity, are highly mobile. In the course of their geochemical migration processes they act not only on the spot of their accumulation but also penetrate into surrounding territories, rapidly expanding and affecting larger and larger areas. The appearance of new sources of salts influences extended territories.

The salts (mainly sodium chloride, sodium sulphate, sodium bicarbonate and carbonate, rarely sodium silicate, as well as calcium sulphate, magnesium sulphate, magnesium chloride,. iron and aluminium sulphates), which are responsible for salinization, decisively influence soil forming processes, and if their electrolyte content surpasses a certain threshold value the soil will become salt-affected. This in turn will dominate soil forming entirely as well as the physical, chemical, and biological properties of the soil. As a rule, this phenomenon is associated with lowering soil productivity and sometimes leads to total soil degradation, to the deterioration or desertification of the land. The high electrolyte contents of the solid and liquid phases of the soil determine soil forming processes. Their effect is so strong that it overshadows all other factors or the previous patterns of soil dynamics, and inevitably brings on the formation of salt-affected soils with all their adverse properties. High electrolyte concentration is the only common feature of all salt-affected soils. Their chemistry, morphology, pH, and many other properties may be different depending on the character of salinization and/or alkalization.

Soil salinization is not only an environmental disaster but is also associated with very serious economic and sometimes even political problems, as the decay of land productivity often results in shortage of food, fodder, and shelter. Not only agricultural production diminishes or is reduced to nothing, but pastures, bushes, and forests also disappear due to the adverse effect of salts. There are cases when a national economy, a region, or even a country collapses. The sad experiences of Mesopotamia, South-East Asia, or Pre-Columbian America are well known from history. In all these places once fertile river valleys and lowlands became deserts due to salinization and a great number of living beings, including humans, disappeared.

In spite of promising developments in science and technology salinization is an increasing tendency, as it will be discussed in the forthcoming chapters. What is disquieting is that neither science, nor society has fully recognized the gravity of the increasing hazards which they must face right now, or in the near future.

The Present Status of Soil Salinity and Alkalinity on the Continents

Technical literature is abundant on the properties, genetics, morphology, classification, etc. of salt-affected soils (RICHARDS, 1954; KOVDA, 1937, 1947; SZABOLCS, 1974, 1989) so these problems will not be discussed in this paper. It should be mentioned however that different types of salt-affected soils cover about 10% of the surface of the continents. They occur on every continent, evidently not evenly distributed as they are more frequent in desert and semi-desert regions and less frequent in humid and semi-humid areas. Table 1 shows the extension of salt-affected soils on the continents.

More than a hundred countries have salt-affected soils, occupying different proportions of their territories. In many of them a great part of utilizable land is covered by such soils causing great problems, often principal problems, for the national production and economy. Salt-affected soils are particularly extended in dry areas, in many developing countries of Asia, Africa, and Latin America, hindering agri-, sylvi-, and horticulture and reducing the potential of food production. Salt-affected soils may be found not only in the vast territories of deserts and semi-deserts but also occur frequently in fertile river val-

Table 1
Salt-affected soils on the continents and subcontinents

Continent	Area (million hectares)
North America	15.7
Mexico and Central America	2.0
South America	129.2
Africa	80.5
South Asia	87.6
North and Central Asia	211.7
South-East Asia	20.0
Australasia	357.3
Europe	50.8
Total	*954.8*

leys, lowlands, foothills, sea shores and other areas where all natural conditions, apart from salinity, would be favourable for production.

In Figure 1 the global distribution of salt-affected soils is demonstrated.

As it is shown in the map, salt-affected soils occur practically in all climatic belts, from humid tropics to beyond the polar circle. They can be found in different altitudes, from territories below sea level, e.g. the district of the Dead Sea, to mountains rising over 5,000 metres, as the Tibetan Plateau or the Rocky Mountains. The rather widespread opinion, sometimes voiced not only in the mass media but even in scientific circles, which limits the occurrence of salt-affected soils to desert conditions, is simply not right. On the contrary, more and more salt-affected soils are being discovered e.g. in the tropical belt of Africa, Latin America and even in Arctic regions, particularly in the territory of the Antarctic. Accordingly it is necessary to broaden our sight whenever and wherever salt-affected soils are concerned in association with environment and production.

In spite of the great number of literary sources more advanced studies and classification systems of salt-affected soils are necessary, adapted not only to local circumstances but also to rapidly developing scientific and social demand. We cannot be satisfied with recent data on the extension of salt-affected soils in different regions, or with the rather orthodox classification systems which do not always meet the requirements of modern technology and give little consideration to environmental aspects.

At the same time it must be admitted that a tremendous amount of valuable information is recorded and available on soil salinity and alkalinity problems which, if properly processed and applied, would better contribute to estimating the present situation on soil salinity and elaborating up-to-date methods to combat these adverse processes.

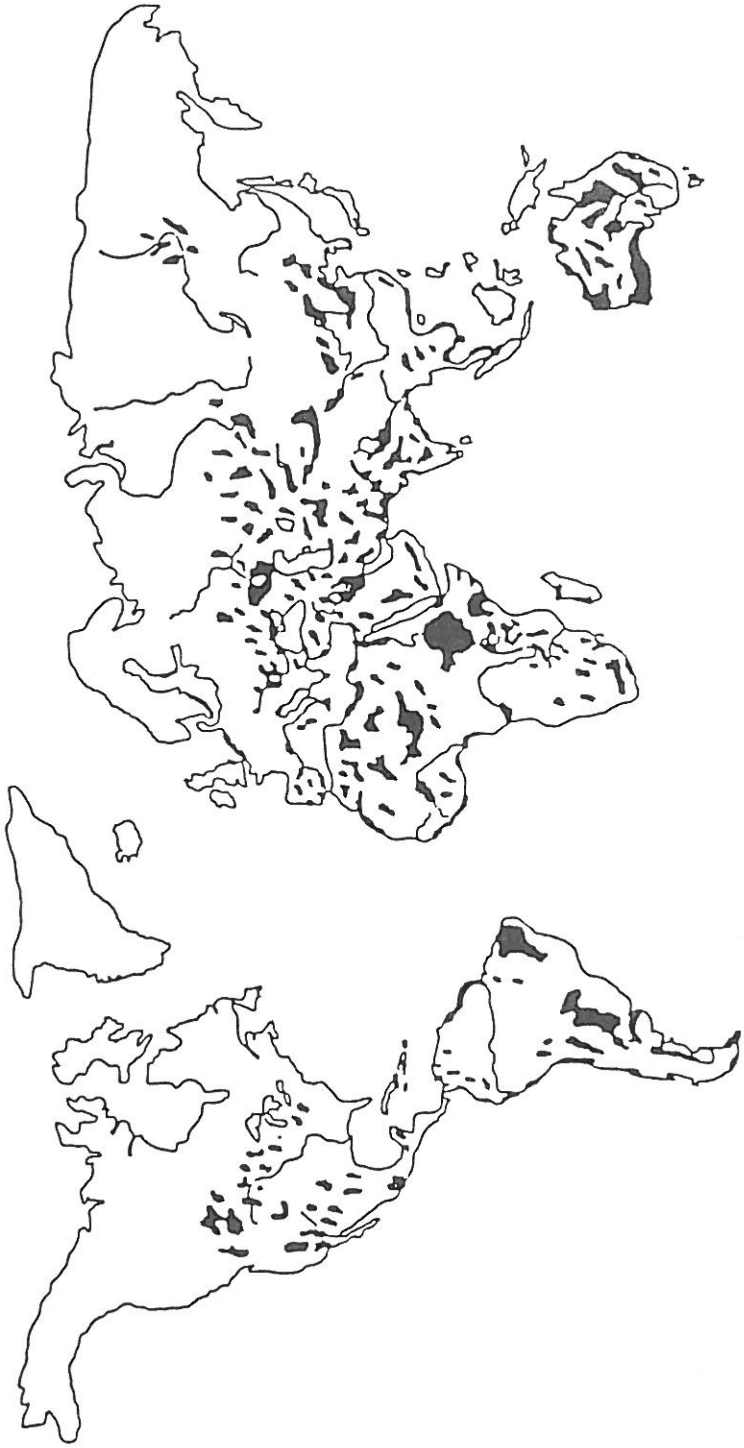

Figure 1
The global distribution of salt-affected soils

Whenever and wherever salt-affected soils are studied, and methods are elaborated for their reclamation and utilization, first of all the amelioration of such soils and their environment should be taken into consideration. The properties of salt-affected soils are, as a rule, in close correlation with the geochemical and geomorphological conditions of their environment, as it is shown in Table 2.

In Table 2 a simple grouping of salt-affected soils is presented in close correlation with their basic properties, environmental conditions, and the possibilities of their utilization and reclamation.

The grouping system demonstrated in Table 2 can be utilized for general interpretation of the different groups of salt-affected soils without going into the particular problems of their classification.

Secondary Salt-affected Soils Resulting from Irrigation

Apart from those salt-affected soils which developed due to natural salt accumulation processes and a great part of which developed in prehistoric times even before the appearance of the human race on earth, Man also created vast territories affected by so-called secondary salinization which means that this phenomenon was not brought into existence by primary natural soil forming processes but appeared as a consequence of human activities, mainly irrigation.

The history of irrigation and its role in the salinization of dry countries, has never been fully covered in a comprehensive volume, although many books and papers have been published over the years, describing this adverse phenomenon and its consequences. While we have more or less precise data and records on the total territory of salt-affected soils on the different continents (Table 1), we do not have such figures on soils influenced by secondary salinization. However it is well-known that, in the valleys of the rivers Tigris and Euphrates in old Mesopotamia fertile soils yielded abundant quantities of grain and other produce for a long time, feeding large populations in places now covered by barren deserts. It is also well-known that in ancient China, the Indus Valley, and South America, there are vast territories which became affected by salinity during irrigation by ancient societies and turned into deserts.

The problem of secondary salinization runs through the whole history of mankind. Evidently there was neither sufficient knowledge nor technical means to predict, explain and combat salinization for many thousands of years. In consequence, the degradation of soils and other adverse effects were recognized too late to do anything against their development.

Many people were compelled to leave the land that had become saline. Others decided to cease production or to shift irrigation to another place which, in many cases, also became salinized. As long as new territories were available, the shifting of irrigated agriculture temporarily solved the problem;

Table 2

Grouping of salt affected soils and their environmental relations

Type of salt-affected soils	Electrolyte(s) causing salinity and/or alkalinity	Environment	Properties adversely affecting the biota	Methods for reclamation
Saline	Sodium chloride and sulphate (in extreme cases nitrate)	Arid and semi-arid	High osmotic pressure of soil solution, toxic effect of chlorides	Removal of excess salts
Alkali	Sodium ions capable of alkaline hydrolysis	Semi-arid, Semi-humid, and humid	High (alkali) pH, poor water physical conditions, Ca deficiency	Lowering or neutralizing the high pH by chemical amendments
Magnesium	Magnesium ions	Semi-arid and semi-humid	Toxic effect, high osmotic presure, Ca deficiency	Chemical amendments, Leaching
Gypsiferous	Calcium ions (mainly $CaSO_4$)	Semi-arid and arid	Low (acidic) pH Nutrient deficiency	Alkaline amendments
Acid sulphate	Ferric and aluminium ions (mainly sulphates)	Seashores and lagoons with heavy, sulphate containing sediments, diluvial inland slopes and depressions	High acidity and the toxic effect of aluminium Nutrient deficiency	Liming

but either the growing density of population or the exhaustion of new land eventually led to tragic consequences. More than one such example is known from history.

Although irrigation dates back to prehistoric times, its rapid development only began about 200 years ago. Table 3 represents this development.

Table 3

World development of irrigation

Year	Irrigated land (million ha)
1800	8
1900	48
1949	92
1959	149
1980	230
1990	265

There were not more than ten countries which accounted for two thirds of all the irrigated soils of the world at the beginning of the 20th century, mainly in those dry territories, where irrigated agriculture had long traditions.

From Table 3 it can clearly be seen that the acreage of irrigated land grew from 8 million ha in 1800 to 48 million in 1900, and trebled in the last 50 years. This trend is very remarkable and has resulted not only in increased world production in agriculture but also in a number of technical and environmental problems. In the following, I can only refer to some of them.

1. At the turn of the century, when less than 50 million hectares were irrigated all over the world, the majority of these lands could be found in a few dry countries. However the recent extension of irrigation has involved not only arid and semi-arid but also many semi-humid and humid regions. The regularities of salt accumulation and secondary salinization differ in arid and humid countries in respect of the chemistry of salt accumulation, as well as of their relation to production and environmental consequences.

2. In many countries irrigation has been introduced as a new method in recent decades. The experiences of countries with a long history of irrigation were not always known and/or applied to prevent secondary salinization in the new irrigation systems. Sometimes it happened the other way round: the experiences of dry countries were applied mechanically to the conditions of non-arid countries where they were not applicable.

3. The extension of irrigation has affected, beside the irrigated land itself, neighbouring non-irrigated territories. Occasional irrigation of small areas has,

of course, much less environmental effect than the big irrigation systems affecting large territories around them.

4. The tremendous increase of irrigation has had many effects on the biosphere (besides the irrigated crop), some of them adverse, such as:
- salinization and contamination of drinking water,
- waterlogging and salinity as a breeding ground of parasites and diseases,
- toxic effects on microorganisms, invertebrates, etc.,
- salinization and contamination of drinking water for animals and human beings causing different diseases and metabolic abnormalities.

The listed phenomena, and others, constitute in many places a barrier not only to the development of agriculture and human civilization but also to maintaining the present level of production.

Where irrigation was introduced under non-arid conditions, mainly in densely populated areas, its side effects were different from those appearing in most of the arid countries. In dry regions the vast deserts which surround irrigation systems makes possible the disposal of drainage and brackish water and so the consequences of irrigation, like secondary salinization in the adjoining areas, can be tolerated. In other countries with dense population, lacking non-productive wastelands, e.g. Hungary where the utilization of land is over 70%, the above mentioned and similar side effects would be catastrophic.

It is a tremendous waste that neglected or abandoned irrigation systems are rather frequent and account for a very high percentage of all those existing. According to the estimates of FAO (Food and Agricultural Organization of the UN) and UNESCO (United Nations Educational, Scientific and Cultural Organization), as much as half of all the current irrigation systems of the world are more or less under the influence of secondary salinization, alkalization and waterlogging. This phenomenon is very common not only in the old irrigation systems but also in areas where irrigation has been but recently introduced.

According to the estimates of all the above mentioned agencies, as well as of the Subcommission on Salt-Affected Soils of the International Society of Soil Science, 10 million hectares of irrigated land are abandoned yearly in consequence of the adverse effects of irrigation, mainly secondary salinization and alkalization (SZABOLCS, 1989).

The harms and losses mentioned are not evenly distributed among the irrigating countries. In some of them the damage is comparatively low, in others it can be high enough to constitute a major problem in agriculture or even in the national economy. Unfortunately we are rich in sad examples. In Pakistan NAZIR AHMAD (1965) carried out statistical analyses of secondary salinized land. His data show that out of 35 million acres of irrigated territory salinized areas account for 5.3 million acres after a few years of irrigation. He mentions among the causes of secondary salinization in Pakistan the combined effect of irrigation and groundwater. According to ZAVALETA (1965), practically all irrigated alluvial soils in Peru show the symptoms of salinity and alkalinity. It is known from a FAO report (1981) and the papers of KOVDA (1980) that more than 40% of irrigated soils in Iraq are affected by secondary salinization. In Syria and in many other developing countries with a dry climate the adverse effect of this process is also serious.

At present no continent is free from the very serious occurrences of this phenomenon. In Argentina 50% of the 40,000 ha of land irrigated in the 19th century are now salinized. In Australia, secondary salinization and alkalization take place in the valley of the River Murray, and in Northern Victoria 80,000 ha have been affected. The same phenomena can be observed in Alberta, Canada. Similar processes have been recorded in the northern states of the USA, where irrigation was introduced much later than in the dry West. It should be noted that the above mentioned, and many other irrigated regions are far from being arid and the majority of salts accumulating are associated with the sodium salts capable of alkaline hydrolysis, not with the neutral sodium salts that are familiar to desert and semi-desert areas.

As a rule, secondary saline and/or alkali soils were abandoned, remained salt-affected, and so it went on for many thousands of years. Secondary salt-affected soils have accumulated and with fair estimation now account for a great part of existing salt-affected soils on all the continents.

Such soils are seldom ameliorated and where they are, the pace of amelioration cannot keep up with accelerating secondary salinization. In fact the ratio of the former to the latter is negligible.

In spite of the fact that large-scale soil reclamation has been carried out on salt-affected soils in many countries no data are available on their impact which suggests that it is hardly remarkable. We cannot expect change in this situation in the foreseeable future.

Anthropogenic Processes, Other than Irrigation, Causing Secondary Salinization

Improper irrigation and drainage are presumed to be responsible for the major part of secondary salinized and alkalized soils. However there are other anthropogenic effects which also lead to the intensification or initiation of secondary salinization and/or alkalization.

The most important are as follows:

1. *Deforestation* - In arid and semi-arid conditions, but even sometimes in non-arid conditions, intensive deforestation often results in changes in the water economy of the landscape and consequently in the place of forests bare land appears, sometimes even in such cases when the target has been to establish plantations. It results in changes in the mass and energy flow of the soil forming processes. This is significant for the migration of soluble salts in soils and water, which often lead to considerable salt accumulation by the elevation of the groundwater table or, to alterations in the biological processes in plants

and soil microorganisms, progressive salinization and/or alkalization. E.g in the 1970s and 80s in north-east Thailand, and in many other places, large territories have been salinized even without irrigation following deforestation.

2. *Overgrazing* - The overgrazing of pastures is another factor which often leads to the intensification of salinization. In consequence of overgrazing the original balance and metabolism of compounds between the natural plant cover and the soil will alter. Concurrently, salinization often develops due to the decomposition of organo-mineral compounds and is followed by the accumulation of water soluble salts in the upper layers of the soil. As yet another consequence of overgrazing the groundwater table often rises, elevating great amounts of salt into the soil profile.

3. *Changes in cultivation pattern* - Similar problems may arise in the wake of changing the type of cultivation e.g. by turning natural meadows into arable land or utilizing them for plantation. The latter methods of cultivation often drastically change the water and nutrient balance in the soils, depleting them and initiating salinization.

In several cases the annihilation of the natural plant cover of pastures and meadows contributes to the decomposition of organic matters in the soil. Parallel with such processes the elevation of the table of mineralized groundwater may be another cause of salt accumulation.

4. *Depletion of fresh water layers near the surface of the soil and their replacement with saline groundwater from deeper layers.* - This may happen due to irrigation (tube wells), or by the over-utilization of fresh water reserves for drinking by people and animals, for household purposes, etc. All of these courses of action further the salinization of both soil and water.

5. *Utilization of wood and shrub reserves in arid areas for fuel* . - It is well-known how widespread this practice is in many dry countries of Africa, Asia and Latin America. Due to the mineralization of organic matter considerable amounts of water-soluble salts accumulate in the soil layers and cause salinization in many places. The extensive practice of utilizing manure for fuel in many arid and semi-arid countries has the same consequences because the burning of manure also adversely changes the balance of organic compounds in the given territory and leads to the accumulation of water-soluble salts.

6. *Chemical contamination* . - In intensive farming and particularly in greenhouses large amounts of mineral fertilizers have been applied, particularly in the last decades. Part of the fertilizer residues accumulates in the soil and causes salinization which has been observed e.g. in Japan, The Netherlands, and other countries in connection for instance with the production of vegetables which are particularly sensitive to salts.

Due to the emission of industrial plants in the vicinity of big chemical factories and mines soil salinity also appears as a result of air-borne chemicals, including mainly sulphates, chlorides, nitrates and other inorganic compounds.

Potential Salinity and the Outlooks of Soil Salinization

Apart from primary and secondary salinization we also have to reckon with the potential salinization of soils.

Potential salt-affected soils, which are not saline or alkaline at present, can turn salt-affected in the shorter or longer term as a result of predicted or predictable natural or anthropogenic processes. Evidently ad absurdum all soils can be salinized or alkalized, still when discussing potential salinity we have to consider only the agents and changes of reasonable possibility. For instance, the introduction of irrigation in dry conditions in most cases carries a high risk of secondary salinization while the same action in humid and well-drained soils has practically no hazard of this adverse process. Consequently, when speaking of potential salinization and/or alkalization this always should be associated with a given place and with a given pattern of environmental and technological conditions.

It is evident that soil salinity has become a global problem not only in respect of agricultural production but also as a major environmental issue. In consequence of the extension of irrigation and other methods causing salinity larger and larger territories are becoming affected by this process overpassing the traditional administrative and geographical borders. Due to the multiplication of cultivated and irrigated territories not only the pedosphere but also the whole environment suffered significant changes including surface and groundwaters, plant cover, and even the whole biosphere. The desiccation or waterlogging of great areas became very frequent. Surface and subsurface water resources, carrying tremendous amounts of water soluble salts, have changed and shifted to a great extent which represent a potential hazard of salinization.

Based on the above described processes and possibilities, we have to study the prospects of soil salinization, mainly its global aspect not limiting the outlook and predicting to local situations. It does not mean that surveys on the spot are not important. On the contrary, they are always necessary when planning, designing, constructing and exploiting agricultural and irrigation systems, but as they are in most cases under the decisive influence of major regional or global processes, the latter should always be taken into consideration as a dominant factor.

Parallel with the development of production and environmental changes the global processes of salt accumulation have become more and more important even in the study of particular or local issues related to soil properties and soil utilization.

It is evident that a further extension of irrigated areas should be expected for the 21st century. Partly the demand for food and fodder in dry areas, mainly in developing countries, partly the development of technology in agriculture and civil engineering will certainly result in the construction of new irrigation systems which will probably not always be associated with proper environmental considerations, particularly with perfect drainage and irrigation technology.

In Figure 2 the global development of irrigation and secondary salinization of soils is demonstrated with indication of the envisaged increase of irrigated territories and the estimated increase of secondary soil salinization for the beginning of the 21st century.

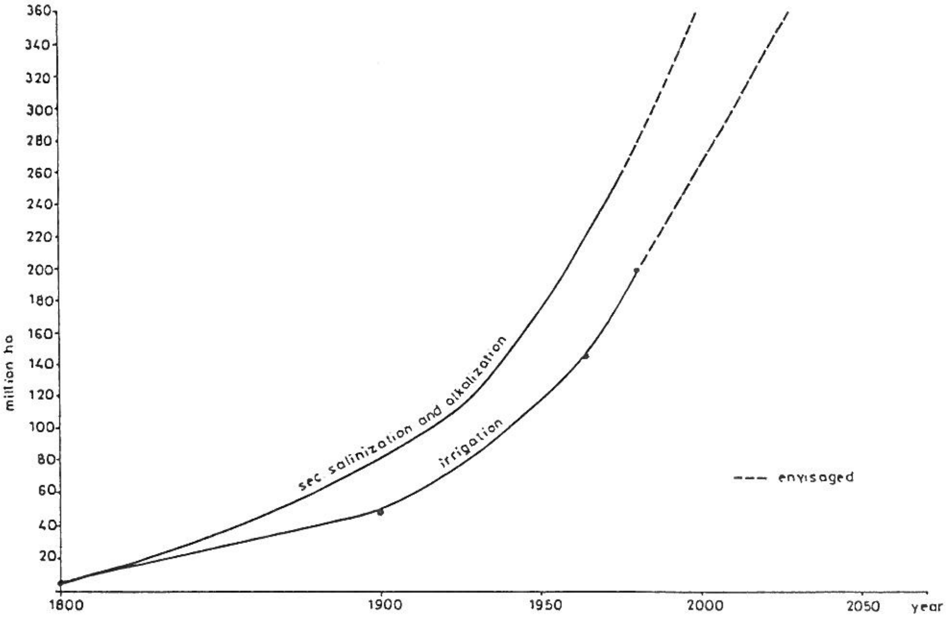

Figure 2
Global development of irrigation and secondary salinization of soils

Figure 2 clearly shows that the trends of increased irrigation and progressive salinization are nearly parallel, the increase of secondary salinization and alkalization even surpassing that of irrigation. It should be noted that the territory of secondary salinized soils is larger than the territory of irrigated land because the former includes all those which were affected by irrigation for a long time in the past, even if they have not been irrigated any more for centuries. This fact and that secondary salinization induced by irrigation influences to an ever growing extent the larger and larger areas surrounding the irrigation systems results in a sharp increase of the secondary salinization of soils which accelerates with the further extension of irrigated agriculture.

Apart from the hazard of salinization caused by increased irrigation, in the following some of the major environmental issues of foreseeable processes threatening with the salinization of soils will be discussed briefly.

Predicted Climate Change as a Factor of Salinization

Abundant technical literature is available predicting change in the climate due to the so-called greenhouse effect. Caused mainly by the emission of industrial plants the accumulation of CO_2 and other gases in the atmosphere threatens with certain climatic changes which in particular regions may result in the increase of aridity. This will directly or indirectly lead to increased salt accumulation in, and diminished leaching from soil layers and consequently to progressive salinization (SZABOLCS, 1990).

Apart from this effect, increasing aridity will certainly call for further extension of irrigation in several regions entailing the hazard of further secondary salinization. Besides, the expected elevation of sea level caused by climatic changes may also result in the salinization of littoral areas.

There are rather few predictions in this respect. One of them was prepared by SZABOLCS and RÉDLY (1989) for Europe. It shows that even on this continent, which is not the most threatened by this process, territories larger than the present extension of salt-affected soils, may be salinized during the next 50 years as a result of soil forming processes caused by predicted climatic changes.

In the paper referred to above, different scenarios have been elaborated predicting the extension of salinization caused by increasing irrigation, rising sea level, etc. From the available scenarios in Figure 3 the west Mediterranean region of Europe is shown where at present salt-affected soils are extended mainly in the Iberian Peninsula and only to a smaller extent in Southern France, Italy, Sicily, Sardinia and Corsica, as well as the Dalmatian coast of the Balkan Peninsula. According to meteorological predictions the average annual temperature of the territory will go up by about 1°C in the next 50-70 years. Consequently, the aridity index will also increase, creating progressive salinity in those marginal territories where at the time being salinity does not exist or can only be found in latent form in grounds or in waters.

In Figure 3 the territory of salt-affected soils and potential salinity as a consequence of climatic changes are demonstrated in the west Mediterranean region of Europe. The map clearly shows that the territory of potential salinity is more than twice as large as the present area of saline and alkali soils which cover 6.34% of the total land surface.

On the drier continents the hazard of salinization resulting from climatic changes is often very expressed in correlation with progressive desertification in most cases (SZABOLCS, 1991).

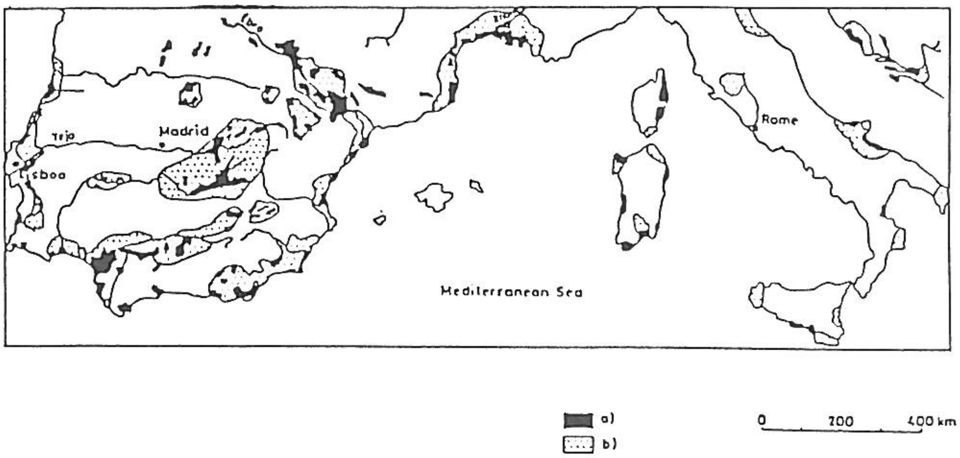

Figure 3
Salt-affected soils and potential salinity as a consequence of climatic changes in the west Mediterranean region of Europe. a) Existing; b) potential salinity

Salinization and Desertification

Salinization is closely associated with several adverse environmental processes, one of the most significant and acute of which is the process of desertification. Desertification and salinization are, as a whole, different albeit closely interrelated, which means that progressive salinization induces the development of desertification and vice versa, desertification is commonly associated with increasing salinity. Consequently, when studying or combating either salinization or desertification the other process, too, should be taken into account.

There are certain differences between the territorial occurrence of desertification and salinization, mainly because salt-affected soils are widely distributed not only in arid and semi-arid regions but also in moderate, subhumid, or even humid climatic belts. Nevertheless, desertification can mostly be observed in the regions where salt-affected soils also occur. One can say that not all salt-affected soils occur in arid regions but the occurrence of salt-affected soils is frequent or even dominant in all arid areas (KOVDA, 1937; SZABOLCS, 1989).

Desertification and salinization are associated not only with non-cultivated areas but are also related to human factors as a consequence of improper policy and land use, overloading the environment and neglecting its conservation.

It means that besides natural factors socio-economic causes also contribute to the extension of both processes.

All the above factors and considerations lead to the conclusion that the study of, as well as the actions against, either desertification or salinization should be conducted jointly and reciprocally because salinization has at least the following correlations with desertification:

1. salinization promoting desertification;
2. salinization developing concurrently with desertification;
3. salinization induced by desertification;
4. salinization strengthened by desertification.

Table 4

Interrelations between the attributes and consequences of desertification and salinization

Desertification		Salinization
Increase of salt accumulation Decrease of leaching Increase of salt concentration in ground and surface waters as well as in soil layers Secondary increase of water soluble compounds	← →	Reduction of water availability Hindering of nutrient uptake Reduction of biota diversity Limitation of plant cover on the soil surface Diminishing of humus content Worsening of thermal and water physical soil properties Adverse consequences of irrigation, overgrazing and deforestation

In Table 4 some of the interrelations between desertification and salinization are presented. As it can be seen from Table 4, during salinization and desertification some attributes of the other process appear. E.g. desertification, as a rule, provokes salt accumulation, which is one of the attributes of saline soils. On the other side e.g. salinization causes a thinning of plant cover on the soil surface which is, in this case, one of the attributes of desertification. Such correlations clearly demonstrate the interrelations between the two processes. During desertification, partly as a result of introducing irrigation, and partly as a result of the degradation of biota, secondary salt accumulation also often occurs (SZABOLCS, 1992).

A good example demonstrating the close interrelation between salinization and desertification is the sad story of the Aral Sea where desertification in close correlation with salinization resulted in the deterioration not only of the fertile soil cover but also the entire natural environment.

As a result of improper planning and methods of irrigation, drainage, water regulation, and land use in the Pre-Aral region, mainly in the deltas of Syr-Darya and Amu-Darya rivers as well as in the dry river bed and delta of the Jana-Darya river a cycle of desertification has begun. The formerly "living" deltas of Amu-Darya and Syr-Darya desiccated. The consequent progress of salinization, loss of soil structure and soil dehumification bring the risk of desertification to the irrigated delta lands. It leads to an intensive development of desertified areas where irrigation is stopped or watering rates are decreased.

Recent desertification in the region is caused by different factors. The most important are:

a) salinization of river waters, which lead to an increase in the soluble salt contents of soils and groundwaters of the delta;

b) the regulation of river flow resulting in lowering the level of the Aral Sea and drying the delta lakes, as well as in a shortage of productive water resources in the delta.

It is characteristic of the recent desertification in "living" deltas that the main causes of desertification are at considerable distances from the desertifying areas proper.

The present desertification in the deltas has been caused by the domino effect; i.e. the changes in the water balance of deltaic ecosystems initiate a new chain of desertification factors for the territory (KUST, 1992).

The "Aral story" is also a good example for illustrating how local processes develop into regional ones, which finally result in the global problem of salinization associated with global environmental issues.

What Should and What Could be Done in the Combat Against Salinization

It is evident that a very serious environmental hazard of salinization can be forecast for the 21st century with grave, even drastic consequences not only for agriculture but also for the quality of surface and groundwaters, flora and fauna, and finally for the well-being of the human sphere. Salinization will affect more and more extended areas posing a real global problem.

In spite of the fact that the threat of salinization was recognized a long time ago and different means and measures have been used in an attempt to check it for epochs, all these have proven far from being sufficient to offset the expansion of salinization and even less to counterbalance the increase in salinization predictable for the forthcoming decades.

It is highly necessary to pay more attention to the process of soil salinization and to intensify the combat against it in many areas of science, education, technology, and policy.

In the following several aspects will be listed of what should be and could be done to meet the increasing demand of the combat against soil salinization.

1. *Research*

Although abundant material is available on soil salinity and alkalinity we still lack a systematic approach to the dynamics of salinization in the most threatened areas of the world in relation to natural and anthropogenic processes.

A great number of scholars and institutions have carried out research into soil salinity. Here the activities and achievements of the Subcommission on Salt-Affected Soils of the International Society of Soil Science should be mentioned which initiated the preparation of a world map of existing and potential salinization nearly 30 years ago. The maps of Europe and Australia have been completed and published (NORTHCOTE & SKENE, 1972; SZABOLCS, 1974). Unfortunately the maps for the other continents have not been finished. It is highly desirable to complete the world map of salt-affected soils which will enable us to size up the present situation and the predictable processes.

The action described above as well as other scientific projects related to soil salinity require coordinated international cooperation with the participation of governmental and non-governmental as well as UN organizations.

Besides the existing fairly numerous physical, chemical, and biological studies dealing with the important basic part processes of soil salinization, integrated studies by teams including not only soil scientists but also representatives of other sciences, even economists, decision-makers, etc. are more and more necessary.

Apart from global approaches, regional and local integrated investigations and feasibility studies, with particular regard to environmental conditions, also should be extended and intensified.

The prediction of processes triggered by increasing production, their monitoring as well as the prevention of those which are harmful are of particular importance. Parallel with the elaboration of monitoring and early-warning systems their principles and the methods of their local application should also be elaborated in the threatened areas.

2. *Education and training*

At present education for and public awareness of soil salinity are far from being sufficient. In many cases even very vulgar and primitive definitions and interpretations of soil salinity are offered.

It is highly desirable to improve education not only on the subjects of agronomy and irrigation but also on environmental aspects, as well as on the nature and hazards of soil salinization in the global, regional and local ranges.

Particular importance is assigned to special projects and courses dealing with the description, prediction, and prevention of soil salinization.

3. *Decision-making, policy, and international collaboration*

Soil salinity and its predictable hazards have not been given sufficient consideration in general planning, particularly in connection with the construction of irrigation systems, land consolidation, deforestation and reforestation, the amelioration of waterlogged territories and river basins. Pedological aspects are often neglected in the designing, construction and exploitation of such projects.

Not only the decision-makers are insufficiently trained in and informed of such subjects but also public awareness is less than satisfactory.

National and international organizations seldom deal with the problem of salinization holistically, and unilateral approaches often lead to dire consequences. For instance, the desiccation of waterlogged territories and swamps, which is principally justifiable, often leads to the salinization of soils which could be avoided if the planning and execution had been accompanied with proper measures of prediction and prevention.

The prospects of soil salinization for the 21st century give no reason for satisfaction. They present a real global hazard of disaster which however can still be aborted or mitigated in case of a proper recognition of the problem and by taking the necessary steps on local, national, and international levels, which is much more than has been done so far.

The world's scientific community, the collaboration of experts from different branches of science and policy and, last but not least, the International Society of Soil Science have the task of honour to meet these requirements.

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