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Role of Salinity and Alkalinity in the Pollution of Developed and Developing Countries *)

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ABSTRACT

In arid regions potential evaporation is higher than precipitation on the long turn. Rain water contains ions and run-off water is leaching soils and rocks. This leads inevitably to an accumulation of solutes in soils (especially in lower areas) even under natural conditions. Erosionbasins in arid areas are more or less saline and often surrounded by halophytic vegetation. Soils of irrigated agricultural areas of those regions exhibit a rather fast accumulation of salts - this is clearly a type of pollution. In humid regions the natural leaching process helps to avoid an increase in salinity. Nevertheless the use of de-icing salts on roads or the inproper use of fertilizers also causes salinity problems there. The factors enhancing salinity and the scale the salinity problem has reached are different in developing and in developed countries but mainly according to the prevailing climatic regime.

Various types of salinity (chloride-, sulphate-, carbonate-, Magnesium-, Boron-) are known and are dependant on soil properties, ecosystem-processes and environment. Effects of salinity on flora and vegetation as well as the ecological role of excessive ions in ecosystems in arid and humid regions are on various levels. The detrimental decrease with respect to productivity and other problems in agriculture derived from salinity mainly caused by man needs great effort and a variety of means to solve or at least to minimize the salinity problem.

INTRODUCTION

Plants are subject to a variety of ecological factors, varying with space and time, daily or annually or in longer trends. Ecological factors which are dependant on human activities and have negative effects on plant growth and development are sometimes regarded in general as pollutants. Definitions on what is to be called a pollutant are not clear. If we take the definition, coined by ZIEGLER (in this Symposium), then salinity is to be a pollutant, if caused by human activities, by irrigation or whatever. But just the example "salinity" shows that the line between a pollutant and a natural ecological factor cannot be drawn precisely in some cases.

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*) dedicated to Professor Dr. Dr. h.c. HEINRICH WALTER on the occasion of his 90th birthday.

In this review salinity in particular and alkalinity to a minor extent will be regarded with respect to their effects on plants or vegetation units, on agro-ecosystems as well as on natural ecosystems.

A few examples will be taken to show specific items. Some basic principles are so fundamental and yet well known, but have to be stressed again because of their overall importance.

GEOCHEMICAL CYCLES AND ARIDITY AS BASIC PRINCIPLE FOR SALINITY

When looking on a global scale where to find arid areas, we have to distinguish between coastal and inland areas. In coastal areas in the tropics (without winter frost), we find mangroves, in higher latitudes we find only salt marshes along the coast-lines. Much larger areas, however, covered with a variety of saline biomes are to be found in the deserts and semideserts, in arid areas in general (CHAPMAN, 1974).

Arid areas may be here defined as areas where the water budget is negative, this means: precipitation is lower than potential evapotranspiration. The hydrological balance on the long run defines an area as arid or humid (Fig. 1).

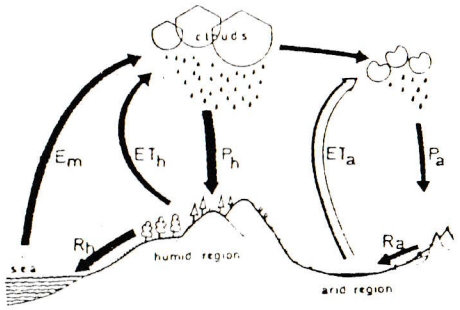

Fig. 1 : Hydrological Cycle. On left half in humid regions, on right side in arid regions with short-cut water-cycle. E_m : Marine evaporation; ET_a : Evapotranspiration in arid regions; ET_h : Evapotranspiration in humid regions; P_a : Precipitation in humid regions; R_a : Run-off (above and below ground) in arid regions; R_h : Run-off (above and below ground) in humid regions (from BRECKLE 1982).

In semiarid areas, as e.g. in monsoon regions, it is sometimes difficult to draw a clearcut line between arid and humid, especially when the contrast between the rainy season and the dry season is great, and furthermore, if the consecutive years differ very much in their climate. The water budget of an area is determining many other things, in our respect mainly the budget of soluble ions. By geochemical reasons the Na^+- and the Cl^--ion are especially abundant soluble ions. Salinity is mainly a problem of NaCl. Other salts and ions may play specific roles, this will be mentioned briefly lateron.

The water cycle of an area is closely related to the salt-cycle. Not only is the NaCl transported by rain-water, but also the leaching of minerals from bedrocks leads to an ever increasing concentration of Na and Cl in run-off-water. NaCl is transported by rain-water to a rather large extent. On the whole on the globe about 40.000 km^3 rainwater are transported from the oceans to the continents per year, 70.000 km^3 of water evaporate from terrestrial areas and feeding clouds (BAUMGARTNER & REICHEL 1970, LARCHER 1984). These 110.000 km^3 of water per year contain about 5 - 20 ppm NaCl. This means, on the average about 10 km^3 NaCl are transported by rain water (cyclic salt, TEAKLE 1937, BRECKLE 1976) and are falling down on the continents, this amounts to about 10 billions of tons of NaCl.

Aridity of an area is furthermore determining the fate of the cyclic salts and of the leached salts. In humid areas this salt is leached out from soil and transported to the erosion basin which is generally the ocean. In arid areas, however, eventually also some leaching occurs and transportation of salts e.g. by torrents after thunderstorms. This transport normally ends in an erosion basin, which is in this case often an independant basin, a salt lake. These geomorphological features a commonly used to characterize endorheic areas.

This shows clearly that the water balance of a distinct region is structured by climatic parameters. It has been shown, that the major areas of the continents are arid (HENNING & HENNING 1976), about 2/3 of the globe (see Table 1). This has also been calculated for smaller distinct areas and the climatic maps and the available climatic diagramms give enough precise information on that matter.

Table 1 : Arid and humid areas of the continents (10^6 km^2), (calculated according to HENNING & HENNING 1976)

continent	area, total	area, arid	% arid
Asia	44.2	31	70
Africa	29.8	25	85
N-America	24.2	14	58
S-America	17.8	7.8	43
Europe	10.0	4.2	42
Australia	8.9	7.4	84
total	134.9	90	66
Antarctica	14.0	?	?
total	148.9		

As is well-known, agricultural areas on the globe have to be increased on a large scale, if there will be any chance to feed all people in the near future. Of course, this is not indefinitely possible, as everyone knows. In the very near future the problem of the exponential population growth of mankind has to be solved, then all other problems will slow down automatically. But this problem is beyond our scope of this symposium.

Salinity is a worldwide problem. Soils with excessive amounts of salts are occuring naturally as well as enhanced by man in agro-ecosystems worldwide. The salinity problem is the more severe the more arid the region is. In humid regions it is almost incomprehensible to have a salinity problem in agro-ecosystems. There, it is in reality only a problem of short term periods. Table 2 shows some examples of salinity hazards and percentages of salinity influenced areas in various countries.

Table 2 : Agricultural Areas, influenced or damaged by salinity (areas in 10^6 ha) rounded data, in most areas increasing tendency. (various sources)

USSR	salt-influenced	75	
	solonez-soils	60	
	saline/sodic	(89% of irrigated land)	
China	salt-influenced	20	
Iraq	salt-influenced, damaged	4	(ca.80% of irrig.land)
India	salt-influenced	10	
W-Pakistan	salt-influenced	5	(25% of irrig.land)
	saline	0.55	(no more arable)
Spain	saline/sodic	0.1	(Guadalquivir)
Hungary	salt influenced	0.5	sodic soils
Egypt	saline	0.2	
Canada	alkali	0.36	(Saskatchewan)
	solonez	2.85	(Edmonton)
USA	saline	0.15	(SW)
	salt influenced	about 25% of irrig. land	
N-Dakota	saline	0.17	
Puerto Rico	salt influenced	(36% of arable land)	
NE-Brazil	saline/sodic	0.05	
Australia	saline	(20% of arable land)	
	salt influenced	0.41	(W-Australia)
	solonez	5	(W-Australia)
	solonized brown soils	42.5	(SW-,S-W-Austr., mallee)
Turkey		?	

There is a large concordance of humid areas with developed countries, except the humid tropics and equatorial zonobiomes. We can exclude the humid tropics from our survey. There Na is a very rare, but very desirable element for organisms. In arid and semiarid regions, we find predominantly underdeveloped or developing countries. The ecological base and the resources dependant on climate dominate to a wide extent the potential of economic development of a country. Highly industrialized countries, not always highly civilized, too, are predominantly to be found in temperate, humid areas (W-Europe, Japan, USA). But also in the USA there are areas where salinity is a pollution problem in agriculture, as e.g. in semiarid California or in Arizona, caused by intensive but not adequate irrigation practices.

Natural Saline Areas

As already mentioned in arid areas in a hydrotope the corresponding own erosion basin develops with geological times. Inland salines are very variable in ion accumulation. This is because the ion pattern is dependant on the geological structure of the area and the climatic character of the region. Inland salines thus are always also rich in NaCl, but the proportions of SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, HCO_3^-, boric acid, phosphate etc. may vary on a large scale and may be the source for mining activities (Dead Sea Region, Great Salt Lake etc.).

The solubility of salts is one of the facts governing the accumulation in inland saline lakes to form deposits in distinct layers in geological times. Gypsum ist normally precipited after Calciumcarbonate, then NaCl layers start to be deposited and finally there may come potassium-salts, with a solubility in the range of $CaCl_2$ or $MgCl_2$, see Table 3 .

Other salts are more rare to be found. However, local people distinguish normally between salinity types. In Afghanistan sodic soils are called "zamin-e-shoree", saline soils "zamin-e-namakee" and soils with Mg-salts "zamin-e-talchee"; acc. to KREEB (1964) in Iraq the fellahs call the "sabach" a soil type characterized by hygroscopic salts (NaCl with $CaCl_2$, $MgCl_2$, and nitrates of Ca and Mg); the "shara" is a soil with no hygroscopic salts, main types are with NaCl and some Na_2SO_4, $MgSO_4$.

Table 3 : Solubility of salts at 25°C (meq.l^{-1} H_2O) (from MARSCHNER 1986)

$CaCl_2 \cdot 6\ H_2O$	25,470
$MgCl_2 \cdot 6\ H_2O$	14,955
NaCl	6,108
$MgSO_4 \cdot 7\ H_2O$	5,760
$NaHCO_3$	1,642
$Na_2SO_4 \cdot 10\ H_2O$	0,683
$CaSO_4 \cdot 2\ H_2O$	0.030

In inland basins the salinity is normally restricted to the lowest parts around the erosion basin. Physical and chemical weathering leads to the typical catena corresponding with the particle sequence from rocks - blocs - scree - sand - silt - clay to soluble salts. This is sharp contrast to man-made saline lands, where by mainly irrigation salinity is enhanced and thus artificially the agro-areas are functioning as erosion-basins.

Salinity by chloride may be added to by sulphate. In continental areas with frost often bicarbonate is accumulating. There is no overall terminology on the soil types according to salinity type, and various systems are used (cf. RICHARDS 1954, STROGONOV 1962). A schematic classification of saline soils according to degree and type of salinity, which is applicable also for field crops, is given by IVANOVA & ROZANOV (1939), see also Table 4

Table 4 : Classification of saline soils according to degree and type of salinity and effects on growth conditions of agricultural crops (derived from data from STROGONOV 1962, IVANOVA & ROZANOV 1939)

soil type		I	II	III	IV	V
soil salinity	ratio Cl/SO_4	non-saline	slightly saline	medium saline	strongly saline	solonchak
% water soluble salts (total solids) in horizon of maximal salt accumulation from 0-60 cm soil depth						
bicarbonate		0-0.1	0.1-0.2	0.2-0.3	0.3-0.5	>0.5
chloride-bicarbonate/ bicarbonate-chloride	1 1	0-0.15	0.15-0.25	0.25-0.4	0.4-0.6	>0.6
sulphate-bicarbonate/ bicarbonate-sulphate	1 1	0-0.15	0.15-0.3	0.3-0.5	0.5-0.7	>0.7
mean % of salt content (total solids) in soil layer 0-100cm						
chloride	2	0-0.15	0.15-0.3	0.3-0.5	0.5-0.8	>0.8
sulphate-chloride	1-2	0-0.2	0.2-0.3	0.3-0.6	0.6-1.0	>1.0
chloride-sulphate	0.2-1	0-0.25	0.25-0.4	0.4-0.7	0.7-1.2	>1.2
sulphate	0.2	0-0.3	0.3-0.6	0.6-1.0	1.0-2.0	>2.0

Conditions of field crops of moderate salt tolerance:

soil type I : field crops show good growth and development (no dead plants in stand, normal yield)

soil type II : slightly stundting growth of crop plants (some plants die, decrease of yield 10-20%)

soil type III : moderate stunting (some plants die, decrease in yield 20-50%)

soil type IV : marked stunting and discolouring of crop plants (most plants die, decrease in yield 50-80%)

soil type V : only few plants survive, few halophytes (practically no yield from crops)

The alkaline soils with varying amounts of salts exhibit pH-values of 9 or even 10, very unfavourable for plant growth. In USSR huge areas are saline or alkaline, and have only a very limited potential to be used for intensive agriculture. The higher the salinity the more decrease in yield is to be expected. Always the crucial point is the quality (and quantity) of irrigation water.

In natural saline areas by selection a number of species have evolved, mainly in the families of the Chenopodiaceae, Aizoaceae, Plumbaginaceae, Polygonaceae and a few others, which are more or less adapted to saline stands. The Chenopodiaceae, the overall halophyte plant family, have one of their evolutionary centers in Central Asia. In the Flora of Kasakhstan (PAVLOV 1960) about 236 species in 47 genera are mentioned; in VVEDENSKY (1972) for Middle Asia 281 species in 51 genera and in Flora of the USSR 347 species in 50 genera are listed. BRECKLE (1986) has listed the number of plant families, genera and species in the Flora Europaea region in comparison to that of Flora Iranica.

Few of the halophytic taxa have at present real economic importance, but will have it in future to an increasing scale.

HUMAN INTERFERENCE IN ARID REGIONS

The few dozens of crop-species used by mankind are rather salt-sensitive. Only few crops (*Beta, Spinacia, Cocos*) may be used in saline fields. If people start with agriculture in arid areas, they use nonsaline plots at first and there must be enough irrigation water available, if agriculture will not be restricted to extensive, low yield plots ("lalmi"-farming).

The quality and quantity of irrigation water becomes again the crucial point, unless a good technology in irrigating and draining the agricultural plots is used.

Modern agricultural techniques apply methods to look for important soil parameters concurrently, as e.g. pH, soil conductivity, status of available main nutrients etc. and to be equipped with procedures to maintain soil fertility.

Increasing salinity in agricultural regions is an old problem. In medieval times often civilizations and highly developed cultures were destroyed by damaging the irrigation systems, the base for the whole economy.

Thousands of years ago in Mesopotamia an old highly developed culture existed, for apparently a rather long time, based on a good functioning agriculture by irrigation with Euphrat and Tigris water. However, the accumulation of salts, during a steady irrigation procedure kept in the subsoil for decades or centuries or partly drained with groundwater streams, was steadily increasing. By any disturbance in the irrigation systems or by interruption by war, the salts are rising to the upper soil horizons and make agriculture furthermore impossible.

In the river systems of Mesopotamia about 1.7 billions of NaCl are accumulated. This is a train filled with salt, going 3 times round the globe, as KREEB (1964) had calculated.

In many other arid areas with irrigation dependant agriculture the same problems arise. Mostly the technique of a good drainage system in addition to the irrigation channel system was not installed because of additional high expenses. Thus the enrichment process with salts in the soil is inevitable. A small model calculation may demonstrate this very clearly (derived from data by KREEB 1964):

Salinity of Tigris River water	:	300 $mg.l^{-1}$
Irrigation per year (equiv. 1000 mm rain)	:	1000 $l.m^{-2}$
Salinity Input by Irrigation Water per year	:	300 g NaCl
Weight of 1 m^3 soil	:	1500 kg
Salt-input after 50 years of irrigation	:	15 kg
Salinity	:	1 % !

RESULT : Agriculture impossible! (cf. Table 3).

The same processes are going on at the moment in a variety of large development projects, the problems with Nile-water and the Assuan-dam are on the same scale. The annual flood before the times of the Assuan-dam which brought mud and nutrients, also leached out accumulated salts.

Of course the individual situation is different in each region, the severeness of salinity problems differ from area to area, aridity of the climate and availability of good water being the main factors, but also soil and subsoil characteristics, nutrient status etc. play a role.

In humid regions agriculture has a big advantage insofar as the leaching of salts is steadily going on and the drainage is here a natural process by the complete river systems continously or discontinuously by monsoon rains in the semiarid/semihumid regions. Salinization on a large scale is thus not a problem in humid or semiarid regions.

Other sources of salt may be prevailing. The use of large amounts of fertilizer, as it is common in industrialized countries nowadays, may often lead to damages in the soil structure, especially when Na^+ to some extent is brought in with the fertilizer. Na^+ replaces K^+ and Ca^{2+} and other essential cations by ion exchange processes from soil particles (clay or humus) und thus may cause mud or sludge structure of soil and increasing anaerobic conditions with an increased waterlogging. This is, however, a small scale problem only, when regarding salinity on a worldwide scale.

Another more severe problem, especially in winter-cold areas, is the use of de-icing agents in winter time. In the FRG alone more than 1.10^6 t of NaCl per winter is brought on the various roads of the traffic network. Depending on the severeness of the winter, as can be seen from the Table 5 , the network of roads all along Germany is rather salty in spring time.

Table 5 A : Average amount of deicing salts used in winter on German Autobahnsystem (acc. to DIMITRI & BROD 1982, BROD pers. comm.) (data in t . km^{-1} of roadside).

winter	t/km	winter	t/km	winter	t/km
1959/60	3.72				
1960	4.46	1970/71	25.60	1980/81	40.24
1961	7.87	1971	16.90	1981	28.95
1962	18.26	1972	17.90	1982	13.70
1963	11.90	1973	21.60	1983	19.80
1964	17.84	1974	10.98	1984	26.0
1965	20.62	1975	14.96	1985	ca 28.00
1966	16.98	1976	20.98	1986	?
1967	33.10	1977	23.66	1987	?
1968	36.90	1978	42.95	1988	?
1969	50.20	1979	17.60		

Table 5 B : Total amount of deicing salts in t used in winter on German roads (BAB Autobahn network; BS : other roads and streets) and E : estimates used by private people, urban municipalities and industry (acc. to DIMITRI & BROD 1982, BROD pers. commun.)

	BAB	BS	E	total
winter 1969/70				ca. 3.000.000
winter 1981/82	305.638	269.274	ca.500.000	ca. 1.100.000
winter 1982/83	146.548	145.256	ca.300.000	ca. 600.000
winter 1983/84	219.816	222.127	ca.350.000	ca. 800.000
winter 1984/85	217.000	300.000	ca.400.000	ca. 900.000
winter 1985/86	578.000		ca.350.000	ca. 1.000.000
winter 1986/87				ca. 500.000

The input of salts along roads has caused and is still causing the suffering and fast death of hundreds of thousands of trees dying by salt damages along road sides and in cities. The trees exhibit first K-deficiency symptoms, a shortened vegetation period and occasionally a second flowering in fall and then after another year often die. On the other side some halophytic plants, originally only found in salt marshes e.g. along the North Sea Coast, are now to be found all along the road sides as the marsh gras *Puccinellia distans*. A recent distribution map looks like a road map of Germany. This kind of pollution is also affecting cars, bridges, others technical equipment, enhancing rust und thus causing much more damage than the aim of deicing roads intended to prevent.

Salinity in soils, plants, in wood along roadside (SCHÜRE & BRECKLE 1985) has increased the last 20 years to a large extent. In Fig. 2 and 3 the sodium and chloride content of leaves respectively is shown for *Achillea millefolium* in march, may and june in individuals from stands with increasing distance from roadside (HOFMANN & BRECKLE 1985).

Salinity along roadside is, however, only an impact on a linear structure in biomes, and thus not affecting a very large area, though the groundwater may be affected, too.

In humid areas parts of the salts are washed down into deeper soil layers in the next rainy season, especially the Cl^-, with Na^+ it takes a longer time. In any way it takes more than one year to leach out the salts from the soil, the recovering of trees need even longer times, because some of the ions are bound and are circling in the ecosystem or are bound in the wood (see Fig. 4) and may be set free only very slowly. In arid areas, however, again most of the salts are kept for years in the upper soil horizons.

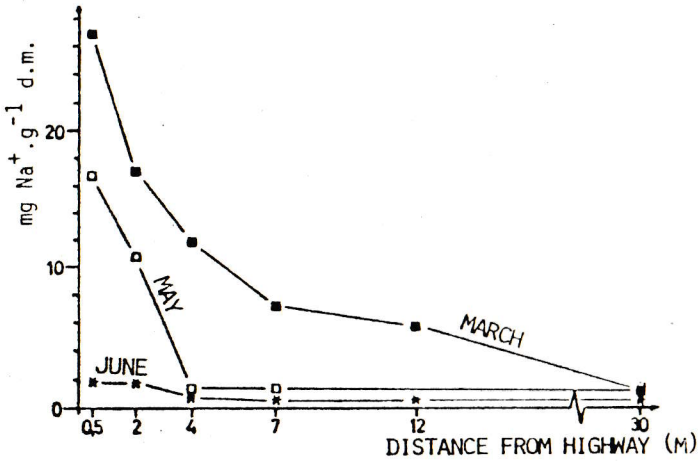

Fig. 2 **Sodium content in washes leaves from *Achillea millefolium* (in mg Na^+. g^{-1} dry matter) of plants with increasing distance from roadside (from HOFMANN & BRECKLE 1985)**

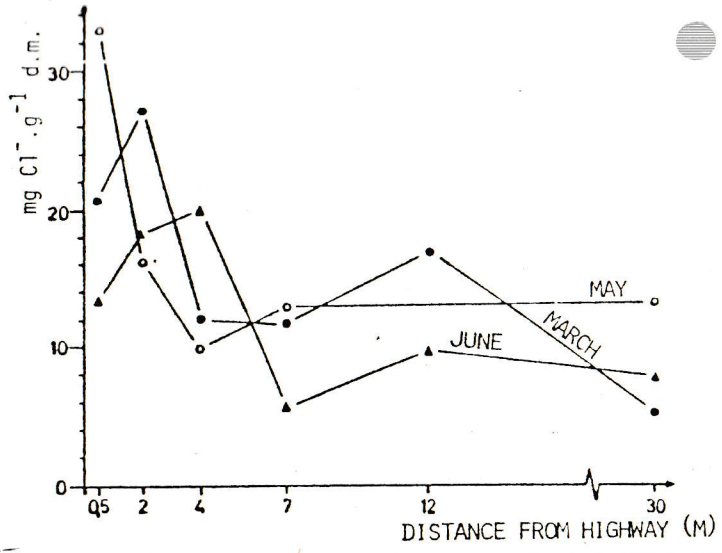

Fig. 3 Chloride content in washes leaves from *Achillea millefolium* (mg Cl^- . g^{-1} dry matter of plants with increasing distance from road-side (from HOFMANN & BRECKLE 1985)

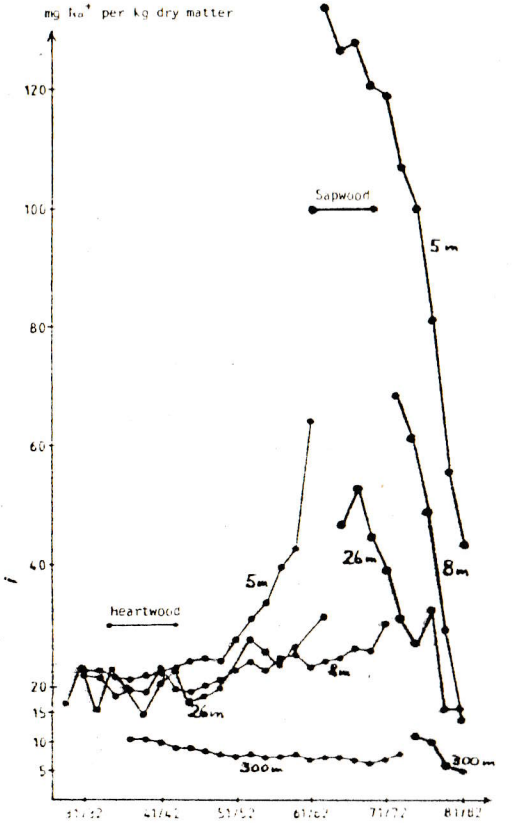

Fig. 4
Sodium content in annual rings in stem wood from *Quercus robur* with increasing distance from roadside. Sapwood is indicated by thicker lines, heartwood by thinner ones; (redrawn from SCHÖRE 1984, see also SCHÖRE & BRECKLE 1985)

A further problem in industrialized regions is the emission of a variety of compounds, aerosols and also more particulate substances and the transmission through the atmosphere. Immission of pollutants is a major problem allover, as most of the relevant articles in this symposium demonstrate. Additionally, however, it should be pointed on the fact, that also dust particles, containing acids with HCl or salts with chloride salts as aerosols are transported and play their role in the increasing salt balance of rain water, as part of the wet deposition, but also as an impact by dry deposition. However, all this pollution pathways are not a main problem in the salinity or alkalinity context, which is as a large scale problem restricted to arid regions.

SALINITY EFFECTS ON PLANTS

In natural vegetation cover some distinct plant families have evolved halophytic species to alarge proportion, as was mentioned earlier. Response of plant individuals to salinity stress is of great importance for survival of a plant species under saline conditions. Under interspecific competition, in natural ecosystems, growth and productivity, as well as development are the main parameters used for ecological success. There are glykophytes (or Non-halophytes) on one side and halophytes on the other, but there is a gradual scale.

Understanding the survival of halophytes on saline stands promotes knowledge on the possibilities for using new crops for agricultural purposes and improvement of cultivation techniques. But the problem is much more complex. There are e.g. many classification systems of halophytes, according to the parameters used. The response and the adverse effects of salinity as well as the possible mechanisms of adaptation were given by WAISEL 1972, and recently by GREENWAY & MUNNS 1980, but many other papers can be cited (see espec. ALBERT 1982, BRECKLE 1982, WALTER & BRECKLE 1983, 1985).

Taking the liveform as an adaptive means into consideration the various control mechanisms for maintaining a constant level of sodium concentration in the chlorenchyma tissues of a plant, it is possible to define five main types, here used with acronyms S-L-X-P-N (see Table 6 B, lower part). The various control mechanisms are often used in combination, thus sharp limits between types cannot be drawn. Table 6 shows examples of mechanisms and additionally some genera exhibiting mainly the mentioned adaptations.

Salinity control mechanisms always stand in close relation to water balance of a plant, because of osmotic reasons. The phloem- and especially the xylem-transport of ions as well as ion exchange processes with adjacent parenchyma tissues play an important role in determining compartmentation of salts within the plant body.

Table 6 : Control mechanisms in plants for maintaining a constant level of sodium ion concentration in cell-sap of plant-tissues (particularly in chlorenchyma cells) and main type of halophytes (from BRECKLE 1986).

A). Mechanisms

1 AVOIDANCE
- a Growth only during favourable seasons
- b Growth only on favourable sites
- c Limitation of root growth and root absorption activity to distinct, more favourable soil horizons

2 EVASION
- a Selectivity against Na^+ and Cl^-
- b Leaching of salt out of the shoots
- c Diversion of salt out of the assimilating tissues
- d Compartmentation of salt within plant, tissues, cells
- e Retranslocation of salt to root and recretion by roots
- f Disposal of older plant parts ("salt-filled organs")
- g Recretion of salt by gland-like structures on shoots
  - I salt-glands
  - II bladders

3 TOLERANCE
- a Increasing of salt-resistance of tissues, cells, organelles
- b Increase in halo-succulence
  - I increase in leaf-succulence
  - II increase in stem-succulence, reduction of leaves

B). Types of Halophytes

and examples of genera exhibiting one of the mechanisms predominantly

Mechanisms common more or less in all plants : especially important in Non-Halophytes (N)	1, 2a-d
Mechanisms most characteristic in Pseudo-Halophytes (P) (*Juncus*, rosette-plants etc.	2d-f; partly 3a
Mechanisms most characteristic in Recreto-Halophytes (X)	2g
in Exo-Recreto-Halophytes: (*Cressa, Frankenia, Limonium, Tamarix*)	2gI
in Endo-Recreto-Halophytes: (*Atriplex, Halimione, Mesembryanthemum p.p.*)	2gII
Mechanisms most characteristic in Eu-Halophytes:	2d-f, 3a,3b
in Leaf succulent Eu-Halophytes (L) (*Salsola, Suaeda etc.*)	3bI
in Stem succulent Eu-Halophytes (S) (*Salicornia, Halocnemum, Halostachys etc.*)	3bII

In natural halophytic biogeozenoses, around salt-lakes or at the sea-shore it is obvious that at least in a floral region rich in halophytic plant genera and species there is a distinct sequence of halophyte types along the salt-gradient (BRECKLE 1986). This indicates that some of the lifeforms are better adapted to high salinities than others. Thus it seems clear that e.g. recreto-halophytes are less competitive under ecological conditions than succulent halophytes when under high saltstress, under natural conditions with fully effectice competition between species. Under moderate salinities recreto-halophytes become dominant, however, mainly because most of them are C4-plants, and are thus more drought-resistant.

Moderate saline stands within a haloseries are often characterized by seasonally changing salinities and water-regime. Examples of such halo-catenas from Iran and Afghanistan with a rich halophytic flora are given by BRECKLE (1986), they indicate the typical S-L-X-P-N-sequence, as demonstrated in Table 7 .

Table 7 : Abundancy of halophyte types (% of total species) in halocatenas in Iran along the salinity-gradient (steps of soil salinity in log-scale, % NaCl of soil dry matter) (from BRECKLE 1986)

S =Stem-succulent, L = Leaf-succulent Euhalophytes, X = Recreto-Halophytes, P = Pseudo-Halophytes, N = Non-Halophytes

soil salinity	S	L	X	P	N
>15	71	29	0	0	0
10	63	32	5	0	0
5	51	30	19	0	0
3	18	72	0	5	0
2	3	30	60	7	0
1	12	56	27	5	0
0.5	7	51	28	15	0
0.2	4	18	41	23	14
0.1	11	35	4	24	26
0.05	10	18	9	45	24
0.02	0	10	0	68	22
0.01	0	0	2	10	88

Most crop species are rather salt-sensitive. Even low salinity levels in crops affect yield to a large extent or are deleterious. In Table 8 the strong effect of salinity on maize, on beans and on sugar-beet is shown as an example. It reveals that the Chenopodiacean *Beta* has some halophytic abilities, the other two crops give high yields only on nonsalty soils.

Table 8 : Effect of increasing NaCl concentration in substrate on three crop species (data from LESSANI & MARSCHNER 1978 and MARSCHNER 1986)

crop	NaCl (mM)	relative dry weight	content ($meq.g^{-1}$ dry weight) Na^+	Cl^-	K^+	Ca^{2+}
sugar beet	0	100	0.1	0.05	3.3	1.6
(cv.Monohill)	25	108	1.7	1.0	2.2	0.5
	50	115	2.1	1.2	2.0	0.4
	100	101	2.6	1.5	1.9	0.3
maize	0	100	0.02	0.01	1.6	0.5
(cv.DC 790)	25	90	0.2	0.5	1.8	0.3
	50	70	0.2	0.6	2.0	0.3
	100	62	0.3	0.8	2.0	0.3
bean	0	100	0.02	0.01	1.7	2.9
(cv.Contender)	25	64	0.04	1.0	2.2	3.7
	50	47	0.2	1.4	1.9	3.4
	100	37	0.4	1.5	2.2	3.6

Another factor in saline regions is waterlogging, often combined with salinity. Other factors, e.g. temperature influence the whole response pattern of a plant. In natural salty swamps, but also in irrigation plots sometimes plants are under these conditions and are affected by a decreased selectivity of the roots against ions.

A bundle of various constraints has to be mentioned under such adverse conditions. Depending on bicarbonate accumulation these saline soils sometimes tend to become also more and more alkaline. Both properties cause major constraints on plant growth as was shown by MARSCHNER (1986), see Table 9. Nutritional deficiencies and toxicity of some ions by very imbalanced ion pattern in soil is thus often to be observed in those agro-ecosystems.

Table 9 : Relative Abundance of alkaline soils and major constraints on plant growth in these soils (from MARSCHNER 1986). (parentheses indicate less frequently important, or only in certain situations)

	soil pH 7	8	9
dominant soil associations	rendzinas (chernozems, xerosols)	solonez (sodic soils) (solonchaks, saline soils)	
relative abundance	5 6 7 8 8 9 9 9 8 8 6 5 4 3 2 2 1 1 1 1 1 0 0 1 2 3 4 5 6 7 7 8 8 9 9 9 9 8 8 8		
major nutritional constraints	deficiency: Fe, Zn, P, (Mn)	Zn, Fe, P, (Ca, K, Mg) toxicity: Na, B	
other constraints	excess of HCO_3^- water deficit mechanical impedance	poor aeration excess of HCO_3^- water deficit mechanical impedance	

Effects of salinity on plants is a broad scope. As a last example salt resistance should be mentioned. This is an important phenomenon. It is already touched by mentioning above the various strategies of halophyte plant types, but some more details have to be mentioned. Salt resistance can be regarded under various aspects. One should realize that salt resistance is not just a single figure, a definite value of salinity, a threshold beyond that a plant is dead. In Table 10 and Table 11 the cardinal points on one side and the variability on the other side is demonstrated.

Table 10 : Aspects and definitions of salt resistance (acc. to HAYWARD & WADLEY (1949), RICHARDS (1954), WAISEL (1972), BRECKLE (1976), ALBERT (1982))

1. **Ecological Aspect**
   the ability of plants to survive and to complete their life-cycle under saline conditions
   (survival ability, endurance, criterion for wild species - growth, yield is neglected)
2. **Physiological / Ecophysiological Aspect**
   the relative ability of a species to grow on saline soils in comparison to its growth on non-saline, optimal conditions
   (determines adaptability of species more than their ultimate resistance)
3. **Agricultural Aspect**
   the relative ability to grow and yield on saline soils in comparison to other species
   (determines yield e.g. 20 or 50% reduction, but not competitive abilities e.g. under ecological conditions

Table 11 : Factors affecting salt resistance of plants

Two cardinal points: upper limit of either growth or existance of a plant species - both is used in literature and thus causing confusion!

--- varies during different growth or development phases of a plant
--- varies with ionic pattern in soil
--- varies with life form and halophyte type
--- varies with the plant organ affected by salt
--- varies within one species forming ecotypic varieties

Effects of salinity and especially of NaCl are on all levels, as is shown by Table 12 and needs research and investigations by many interdisciplinary scientists. The levels 1 and 2 are mainly the subject of biochemistry, 2 and 3 of physiology, 4 and 5 of ecophysiology, 5 to 7 of ecology and 6 and 7 of ecosystems research as well as of geologists, climatologists, geomorphology and geography.

Table 12 : Effects of NaCl on various levels

1--- Biochemical Effects
(enzyme activities, halo-enzymes etc.)
2--- Effects on Membranes
(membrane-bound enzymes, electric potentials, active transport etc.)
3--- Effects on Cell Organelles
(respiration, photosynthesis, salt-resistance, secondary compounds)
4--- Interactions with Cells and Tissues
(formative effects, succulence, compartmentation, salt-resistance)
5--- Interactions with individual plants
(ecological adaptations, salt-tolerance, salt-resistance)
6--- Interactions in and with ecosystems
(cycling of salts, zonations, halo-catenas, competition, budget etc.)
7--- Interactions in biomes, in the biosphere
(transmission, cycling, budget, leaching and accumulation etc.)

Plants during long times of evolution had a chance to evolve special adapted forms. Not only the longterm evolved halophytes in distinct plant families, but also the more short-term evolving ecotypes form variable populations which may be a chance in breeding future crop plants more resistant to salinity, though the relative yield of such halophytic crops always will be lower than by crops on nonsaline soils, because parts of the energy from assimilates has to be used for compartmentation processes etc. to withstand salinity.

By accumulation of other ions or toxic compounds the salinity effects might be enhanced, as e.g. by alkalinity as already mentioned, or by accumulation of Mg (bittersalt-lakes).

In other regions a slightly increased boric acid input shows the similar geochemical accumulation processes as NaCl and the effects can be detrimental to plants. Boron is an essential element for plants, but there is no other element, where the limit between deficiency and toxicity effects is very narrow. Thus the boron-sensitive lemon-tree *Citrus limon* may show already toxicity symptoms, whereas the alfalfa, exhibiting a high demand for boron, may exhibit deficiency symptoms below these Citrus-trees.

In halophytes very often the boron-tolerance is enhanced (BRECKLE 1976, LETSCHERT 1986), because of a distinct antagonism with chloride-uptake. Boric acid or Sodiumtetraborate may be a natural easily water soluble compound, but more often it is brought in by irrigation water (e.g. in California) and mining activities (e.g. Balikeshir, see this symposium). The permissible limits of boron for irrigation waters are rather low. In Table 13 a survey is given.

Table 13 : Permissible limits of boron for 5 classes of irrigation water, in ppm (partly acc. to RICHARDS 1954).

Boron class	sensitive e.g.Tamarix, Phoenix, Beta, Alfalfa	semitolerant tomato, cotton, olive, wheat, barley	tolerant crops apple, Citrus, grapes, beans
1	<0.3	<0.7	<1.0
2	0.3 - 0.7	0.7 - 1.3	1.0 - 2.0
3	0.7 - 1.0	1.3 - 2.0	2.0 - 3.0
4	1.0 - 1.3	2.0 - 2.5	3.0 - 4.0
5	>1.3	>2.5	>4.0

The occurrence of boron compounds in toxic concentrations makes it necessary to consider this element in assessing the water quality. The boron classes of irrigation water are given in Table 13 (RICHARDS 1954). In soil the boron content should remain below 0.7 ppm in the saturation extract, which is a rather low limit, but necessary for sensitive crops. In most saline soils, even after leaching techniques the boron content remains relatively high and appears thus a hazard.

SALINE ECOSYSTEMS

Saline ecosystems have no distinct structures differing from non-saline, however, they are often poor in species. The canopy-structure is rarely with

tall shrubs or trees (except mangals). In general the productivity is lower. The cycling of sodium in these ecosystems is a typical parameter, and is dependant on proportions and activity of the dominant halophyte types. An example is given from the moderately saline *Atriplex confertifolia* semidesert in Utah in the Great Salt Lake Area in Fig. 5. It can be shown, that about 50 t of NaCl in the soil (down to 1 m depth in an area of 1 ha) are present. Only about 0.3% of this mass of salt is circling annually, despite the fact that *Atriplex confertifolia* with the typical bladder structure on the leaves is a recreto-halophyte. Recretion to bladders is only one process, also foliar leaching and litter fall play an important role.

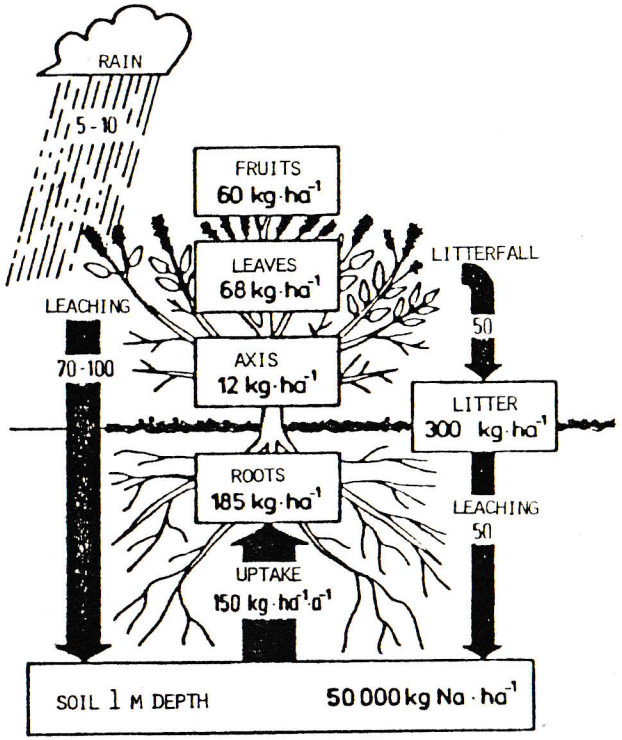

Fig. 5 Standing phytomass and cycling of sodium from an arid saline location in Northern Utah, cold shrubby semidesert with *Atriplex confertifolia* (BRECKLE 1976, LARCHER 1984)

Mechanisms and processes of salt-circling may play also a role in agro-ecosystems for desalinization and in special crops in the future.

Very important is in this respect to have an idea of the quantities of the input and output of salt. For calculations the salt balance formula can be used, despite the fact that some of the used figures only may be estimates.

This is applicable also for agro-ecosystems.

SALT BALANCE FORMULA :

$$\text{input} = \text{output}$$

$$S_P+S_F+S_L+S_I = S_A+S_G+S_D$$

A = Absorption by ion-exchange by substrate
D = drainage-water and loss by run-off
F = Fossil salt leached from parent rocks
G = loss to groundwater
I = Irrigation-water or run-off input, by catched water
L = Leached from substrate (soil) and ion-exchange desorption
P = Precipitation
S = amount of salt (e.g. in $kg.ha^{-1}$)

ALKALINE ECOSYSTEMS

Salinity is in many areas more or less responsible for a sharp decrease in productivity, but often this is even more pronounced, if soils are additionally alkaline, because of bicarbonate accumulation. Alkaline ecosystems in nature develop mainly in rather continental climates with a distinct winter-cold season. Sodium is retained by organic matter in the litter, the litter is only incompletely mineralized and partly decomposed to bicarbonate. pH becomes more and more basic. Only few plants really can be called alkaliphytes and can withstand pH-values more alkaline than 9.5, this is the case probably with a few *Plantago*- and *Camphorosma*-species. Crop plants striving under such conditions are not known.

DISCUSSION, FUTURE PROSPECTS AND CONCLUSIONS

The large areas affected by salinity and/or alkalinity in many countries are a problem, which is not easy to solve. The question arises how to regenerate those large unproductive areas.

Since about 3 or 4 decades it is cannot easily be solved. The nosis of soil composition and structure may help and is even necessary to start with improvement measures. In the last years analytical procedures could made much faster and more reliable than before. Nevertheless the great variability of soils needs always a thorough investigation, and it is sometimes in this respect much better to have many but not so detailed and precise results, than a few, very accurate measurements. Already in 1954 the US Dept of Agriculture gave a sequence of determinations and means for the diagnosis and treatment of saline and sodic soils, which is still applicable (RICHARDS 1954).

Technology of irrigation culture in developing countries (but also in developed, highly specialized industry-like agriculture in developed countries with semi-arid climates) needs improvement. The sprinkler, furrow- or flooding irrigation should only be applied, where there is enough good water available and the geomorphological situation suitable. To minimize evaporation

losses and to give more precisely the exact amount of water needed by a distinct crop trickling irrigation and covering soil surface should be introduced everywhere, where applicable. But always, depending on landscape structure and climatic conditions, it should be kept in mind, that on the long run, irrigation depends on the quality of the water and almost always needs the equivalent drainage system.

Control of nutrient supply and pH, etc. by automatic computer systems may be already applicable and could or will be introduced in highly specialized crops, but it is normally a financial problem and not applicable on huge agro-plains.

Breeding and large-scale introduction of new more salt resistant crops and timber is a need.

Pollution by salinity is only one severe constraint among other environmental problems. But because it is affecting huge areas and directly decreasing crop yields it is a major problem of mankind, especially in developing countries with arid climate and low financial and thus technological abilities.

Pollution by salinity is affecting the natural resources of mankind on various levels. It is not direct a deadly threat as some toxic pollutants might be, but it is a constraint reducing the resources and areas where to live and thus restricting the potentials of a region and is thus an increasing and almost global impact for the basic need of mankind, the agriculture.

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