in: Int. Soil Sci., 1998, 436-444
Proc. of Sustainable Management of Salt affected Soils
in the arid Ecosystem. Cairo/Egypt. Sept. 22-28,1997

445

Plant Response Under Saline Conditions

A., Amberger

Institute of Plant Nutrition, Technical University Munich

1. Saline soils

Salinity is abundant in semiarid and arid regions as a result of high evaporation of saline underground water or poor irrigation water quality and bad irrigation techniques depending on soil properties. Salinization is a soil degradative process defined as accumulation of excess salts in the root zone resulting in partial or complete loss of soil productivity finally leading to desertification. In irrigated areas, it is mainly caused by an excess of water through overflooding or furrow irrigation, the old traditional methods where no functioning drainage system exists which could flush out the salt accumulated on the soil surface to a drainage system. A saline soil is characterized by an electrical conductivity (Ec) of more than 4 mmhos/cm which is equivalent to about 40 mM NaCl in the water saturated soil extract, considering that NaCl is the dominant salt. Irrigation water has been classified by Thorne and Peterson (US Sa. Lab., 1954) upon its electrical conductivity (table 1).

Table 1. Salinity and electrical conductivity of irrigation water.
(Thorne and Peterson, 1954).

Salinity rating	Conductivity (EC mmhos/cm)
Low	< 0.25
Moderate	0.25-0.75
Medium	0.75-2.25
High	2.25-4.0
Very high	> 4.0

However, other compounds such as Mg, Ca, bicarbonate and boron can become critical for plant growth. In this respect the sodium adsorption ratio (SAR) in the water saturated soil extract is an important parameter (Wilcox, 1955) which represents the relationship between Na and other cations (in milli equivalents per L):

$$SAR = [Na^{+}/0.5(Ca^{2+}+Mg^{2+})]^{0.5}$$

Irrigation projects can politically easily "sold" because of obvious yield improvement, however it is much more difficult to get a common consent for drainage. As long as traditional irrigation methods consuming excess water cannot be changed for any reason, a good drainage system is a strict demand to avoid salinity.

2. Salinity and plant growth

A part from soil impairment, growth can be affected by high salt concentration in which creates a high osmotic potential of soil solution and correspondingly a low water potential for crops (= water deficit).

Fig.(1) demonstrates the increasing conductivity (ECe) and osmotic potential (MPa) depending upon the salt content in the soil with curves of different water saturation in the paste (where 50% corresponds with the field capacity of soils). A low water potential for crops [illegible] and Mg [illegible], while the transport of Na, Ca^{2+}, NO_3^- and Cl^- is a matter of mass flow in soil solution. High concentrations of specific ions such as Cl^-, Na^+ and Mg^{2+} can lead to nutrient imbalance, micronutrient deficiency and finally toxicity. Plants suffering from salt stress show a stunted root system and bluish-green leaves with higher turgor. Marginal chlorosis, scorch symptoms and necrosis of leaves are typical for NaCl salinity and Cl^- toxicity when Cl content in leaves exceeds 1% of dry matter. Germination of seeds and rooting is a very sensitive stage of development.

3. Physiological and biochemical effects of salinity and strategies to adapt to saline substrate and avoid salt injuries.

Under salinity net CO_2 assimilation is reduced and respiration is increased, both probably due to Cl^- toxicity of sensitive crops (fruit trees, grapevine).

Imbalance of Na^+/K^+ or Na^+/Ca^{2+} can result in physiological disorders affecting membrane integrity and displacement of Ca^{2+} from plasma membranes by Na^+ or blossom end rot of tomatoes and pepper through Ca deficit. Membrane bound ATPases in roots can either be activated or inhibited by specific ions. Synthesis of abcissic acid (ABA), amino acids and protein is generally promoted by salinity, whereas sucrose and starch content are lowered. PEP Caboxylase and RuBP-Carboxylase are decreased (Joshi and Naik, 1980). A limited osmotic adjustment of plant cells to a saline medium has been observed with tomatoes a moderately tolerant crop, along with improved quality (sweeter, more flavor). Also for many other corps the increasing osmotic pressure of salts in the root environment is of second order, if the supply with essential elements in optimal (Sonneveld 1988, Sonneveld and Van der Burg, 1991).

There are **two strategies** to avoid toxicity: some plants restrict salt uptake (excluders) through root impermeability to Cl^- based upon specific lipid components or free sterols on they exclude them by Na^+ and Cl^- efflux pumps (halophytes). Others take up ions in higher rates, transport them to the shoots (includes) and sequester Na^+ into vacuoles or secrete them through specific salt glands, from which they can be washed out by rain or irrigation (halophytic grasses) or depose them in leaf hairs (tomatoes). The salt tolerant chenopodiaceae (e.g. spinach) can utilize salt ions for turgor maintenance (osmotic adjustment) Succulence are typical for morphological adaptation to high substrate salinity by transporting Na^+ to the vacuole with increasing their volume. Some plants accumulate compatible organic solutes to lower the osmotic potential of cytoplasm very effectively without interfering with cellular metabolism (Greenway and Munns, 1980). Such as betaine (chenopodiaceae), sorbitol (plantaginaceae), proline (gramineae) or other cytosolutes like sugars, sugar alcohols, organic acids etc. even the exact mechanism is not yet clear.

4. Salt tolerance of crops

References in literature are sometimes contradictory with respect to soil types (sand, clay etc.) and they show a great variability among crops and cultivars (Fig. 2).

In case of Suaeda maritima, a typica halophyte, growth even increased up to a concentration of 250 mM Cl^- in the external medium through secreting Na^+ and Cl^- into the vacuoles (with increasing osmotic pressure), whereas halophytic crops (e.g. sugar beets and to a lesser extent also tomatoes and date palms) show a greater salt tolerance compared to barley or cotton or the most sensitive crop beans. To the later category belong also sugar cane which is more sensitive to sulfate than chloride toxicity (Joshi and Naik, 1980), onions, citrus and avocado, the later ones show characteristic leaf tip burn symptoms. However also among these

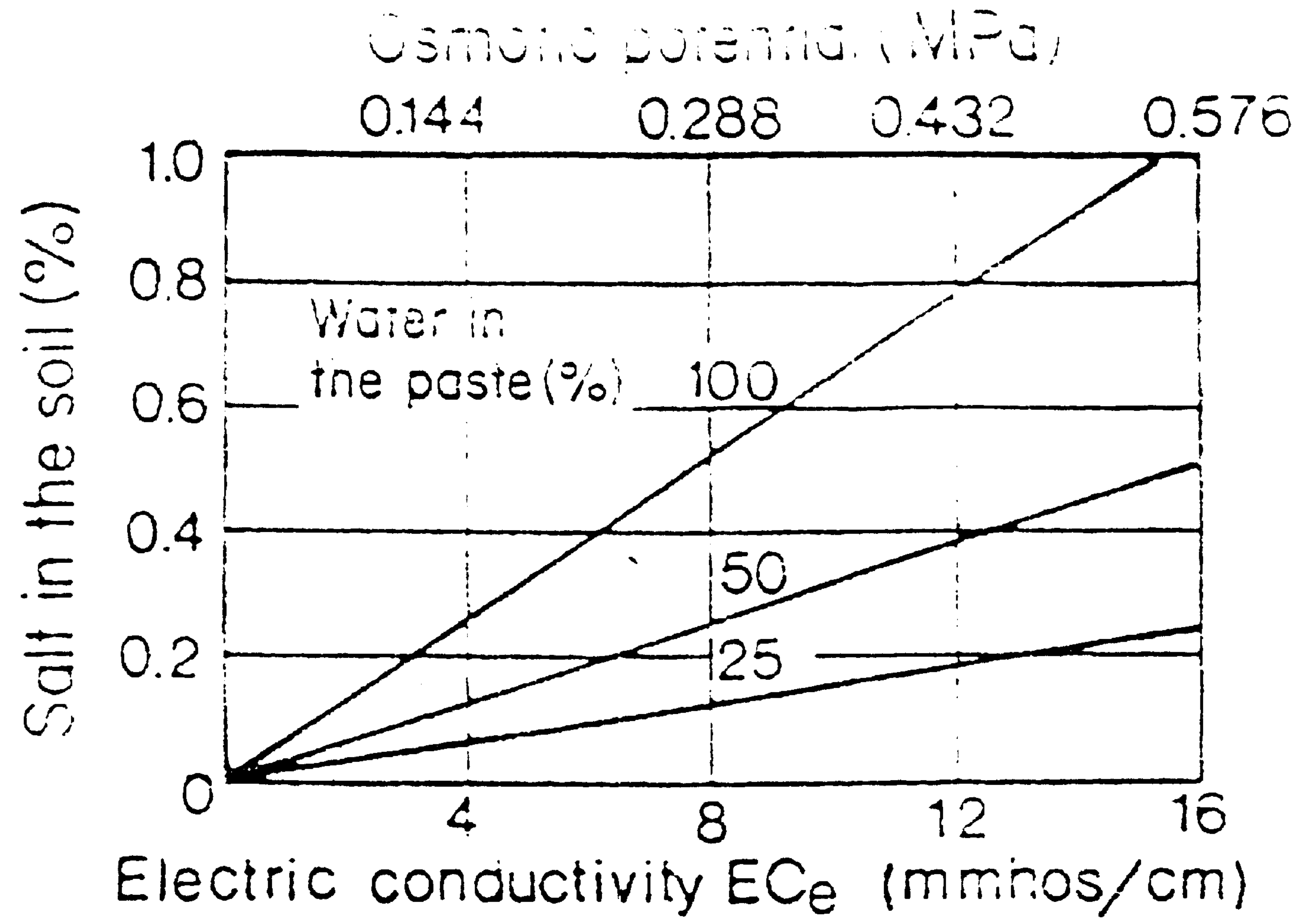

Fig. 1: Electrical conductivity, osmotic potential and salt content of soil (US Salinity Lab 1954)

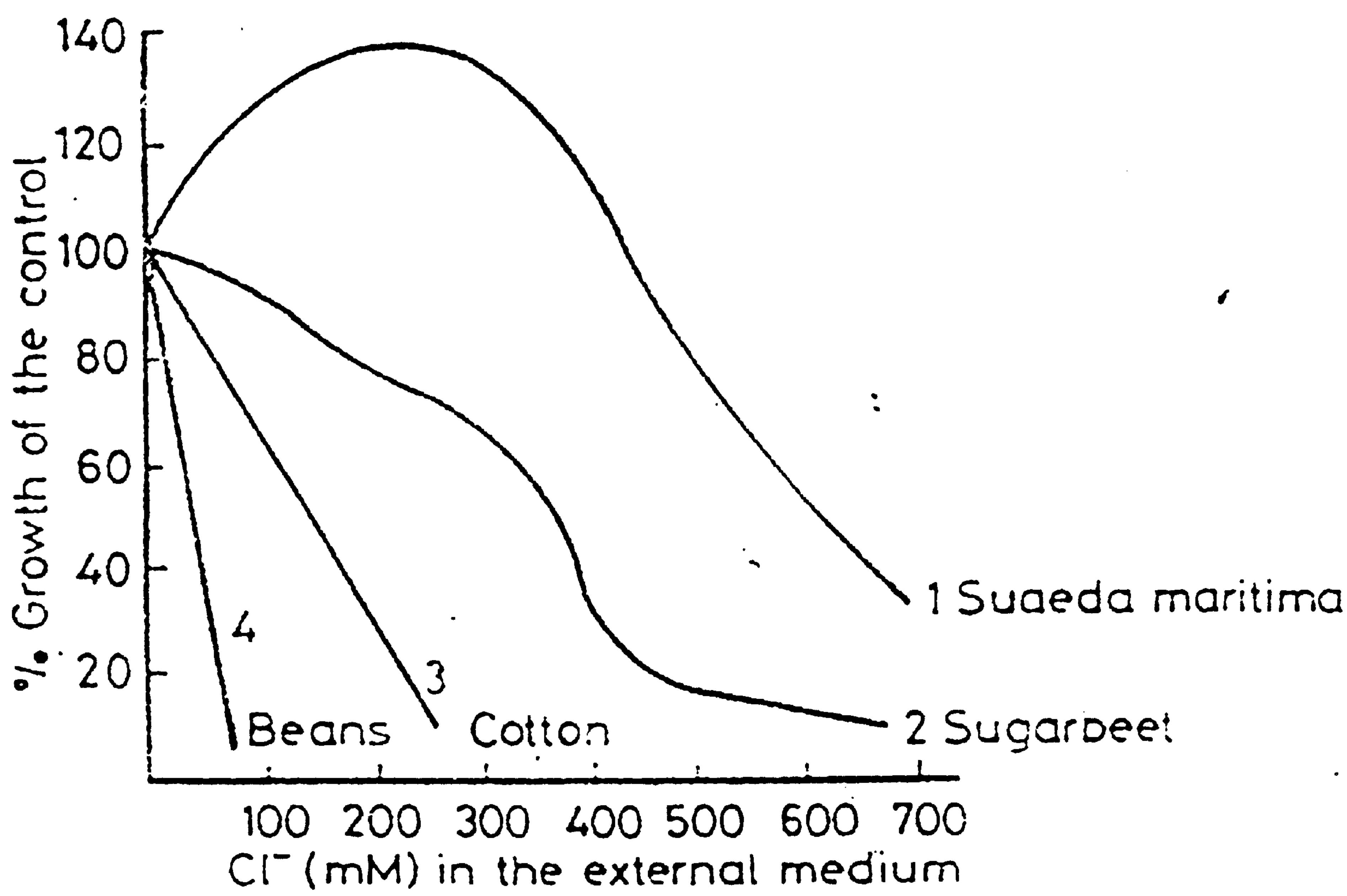

Fig. 2: Growth response of species with different salt tolerance to increasing Cl^- concentrations in the external medium (modified after Greenway and Munns. 1980)

crops there is a great difference of sensitivity. Bernstein (1970) has given a rough survey of crops differing in their response of yields to salinity (tables 2 and 3).

Table 2. Crop response to salinity (Bernstein, 1970).

Salinity (EC mmhos/cm at 25°C)	Crop responses
0 to 2	Salinity effects mostly negligible
2 to 4	Yields of very sensitive crops may be restricted
4 to 8	Yields of many crops restricted
8 to 16	Only tolerant crops yield satisfactorily
Above 16	Only a few tolerant crops yield satisfactorily

Table 3. Salt tolerance of various field crops as conductivity (mmhos/cm at 25°C) at which the yield is reduced by 25%. (Bernstein, 1970).

Crop	EC	Crop	EC
Barley	15.8	Rice (paddy)	6.2
Sugar beet	13.0	Maize	6.2
Cotton	12.0	Sesbania	5.8
Safflower	11.3	Broadbean (*Vicia)*	5.0
Wheat	10.0	Flax	4.8
Sorghum	9.0	Beans (*Phaseolus*)	2.5
Soybean	7.2		

5. How can salinity problems tackled in practice:

1) Salinity is caused by high evaporation and the followed accumulation of salts on the surface, thus the most strict demand is to **minimize evaporation and optimize water and fertilizer management** according to the real requirements of the crops. That means to give up the old traditional irrigations overflooding and furrow irrigation which is connected with an excess of water. Also changing over to water saving commodities can be a method to reduce water use. In case this change cannot be performed and/or a more or less saline water is used for irrigation (Bernstein and Francois, 1975) a functioning drainage system is necessary and a regular extraflooding without cropping must be set into the program to flush out the accumulated salts from the root zone. Modern irrigation techniques such as drip or microirrigation have many benefits, among them it can save water up to 50-80% compared to sprinkler or surface irrigation (Hochmuth, 1995, Locascio et al., 1981) together with a lower chloride and sodium content in Chili leaves (table 4).

Table (4) Effects of sprinkler and drip irrigation with saline water on the mineral element content of leaves of Chili (*Capsicum frutescens* L.). (Bernstein and Francois, 1975)

Salt content of the water	Mineral content of leaves (meq/100 g dry wt).					
	Choride		Sodium		Potassium	
	Sprinkler	Drip	Sprinkler	Drip	Sprinkler	Drip
Low	110	20	20	1	101	118
Medium	121	51	26	1	97	121
High	165	76	48	1	86	113

Under drip irrigation the wetted (evaporating) zone is very restricted and the roots of orange trees expand to moisture zones (El Fouly et al., 1995), that is about 80 cm from the trunk and up to 40 cm deep increasing with years (Fig. 3).

2) Optimization of fertilization means the application of nutrients in quantities judicious to the real requirement calculated on an input - output basis. In this context it is worthwhile to mention, that the real output of nitrogen and P (= export from the orchard) by apples or bananas is very low (table 5).

Table 5. Nutrient uptake of apples (kg/ha).

	N	P	K	Ca	Mg
Fruit-yield (kg/ha) 20 000 export	12	3	30	1	1
remaining in trees (branches, leaves)	15	3	11	23	3
Total uptake	27	6	41	24	4
Fruit-yield (kg/ha) 40 000 export	24	6	60	2	2
remaining in trees (branches, leaves)	15	3	11	23	3
Total uptake	39	9	71	25	5

Table 5a. Nutrient uptake of bananas (kg/ha)

Whole bunches	N	P	K	Ca	Mg	S
20 000 kg/ha	34	4	100	4	5	4
40 000 kg/ha	68	8	200	8	10	8

The same holds true for grapes (30-40 kg N/ha). Addition of K and Cl ions shows a beneficial effect (table 6) counteracting the competitive Na^+ and Cl^- ions (Lagerwerff and Eagle, 1961, Schleiff and Fink, 1976). Potassium seems to be functioning as a specific physiological barrier in citrus cell (Ben-Hayyim, 1987).

Table 6. Effect on an increasing supply of KCl on the yield, K and Cl content in the leaves, and the osmotic potential of the leaf sap of Phaseolus vulgaris grown in a saline medium. (Lagerwerff and Eagle, 1961)

KCl concentration (me/l)	FW g	K content me/g DM	Cl content me/g DM	Osmotic potential (Ψ_S)bars
3.5	534	1.45	1.91	-11.7
8.8	544	1.66	2.06	-12.9
14.1	562	1.92	2.27	-15.3

The application of NH_4^+ (amended with a nitrification inhibitor) showed an antagonistic effect to Na^+ in wheat (Shaviv and Hagin, 1993). Also urea as the non ionic form of nitrogen proved to be advantageous (El-Leboudi et al., 1973) realizing that even under inhibited hydrolysis with salinity, urea can also be taken up as a molecule by roots. Phosphorus fertilization compensates the inhibited P uptake under saline conditions (Patel and Wallace, 1970).

Application of gypsum can considerably decrease salinity mainly in Na^+ affected soils by improving soil structure and Ca^{2+}/Na^+ ratio (Carter et al., 1977) and also by a sodium excluding mechanism of Ca^{2+} in beans, maize and citrus (Benuls, Legaz and Primo Millio, 1991).

3) Drip and microirrigation fertigation includes a synchronization and precise timing of both economic water and nutrient supply directly to the rhizosphere following the crop nutrient demand during the season, provided that totally soluble salts are used to avoid clogging of the nossels.

4) Also in greenhouse, salinity is a serious problem. For the benefit of full control of osmotic pressure and equilibrium of nutrients in the substrate, salinity builds up during cultivation has to be leached out with extrawater.

5) Based on this knowledge that there is a great variability among species and cultivars. Lahav et al. (1993) could demonstrate that avocado trees grafted on resistant West Indian rootstocks showed a much less chloride accumulation than the salt sensitive Mexican hybrids (Fig. 4).

Selection and screening in breeding programs (including tissue cultures) show a great potential for better adaptation through strict compartimentation of Na^+ and Cl^- within individual cells or in nonphotosynthetic tissues. Introduction of components for salt tolerance from wild relatives had been convincingly demonstrated with tomatoes. Furtheron, Cl^- exclusion in soybeans is controlled by a single gene pair (Abel, 1969). Modern gene techniques may also be a great help to solve salinity problems in future.

CONCLUSIONS

1. Salinization is a very serious soil degradative and growth inhibiting process, caused by high evaporation of saline underground or irrigation water, bad irrigation techniques and inefficient drainage systems.
2. Salinity can be avoided or controlled by minimizing evaporation (modern irrigation commodities) and optimizing water and fertilizer management according to the real requirement of crops.

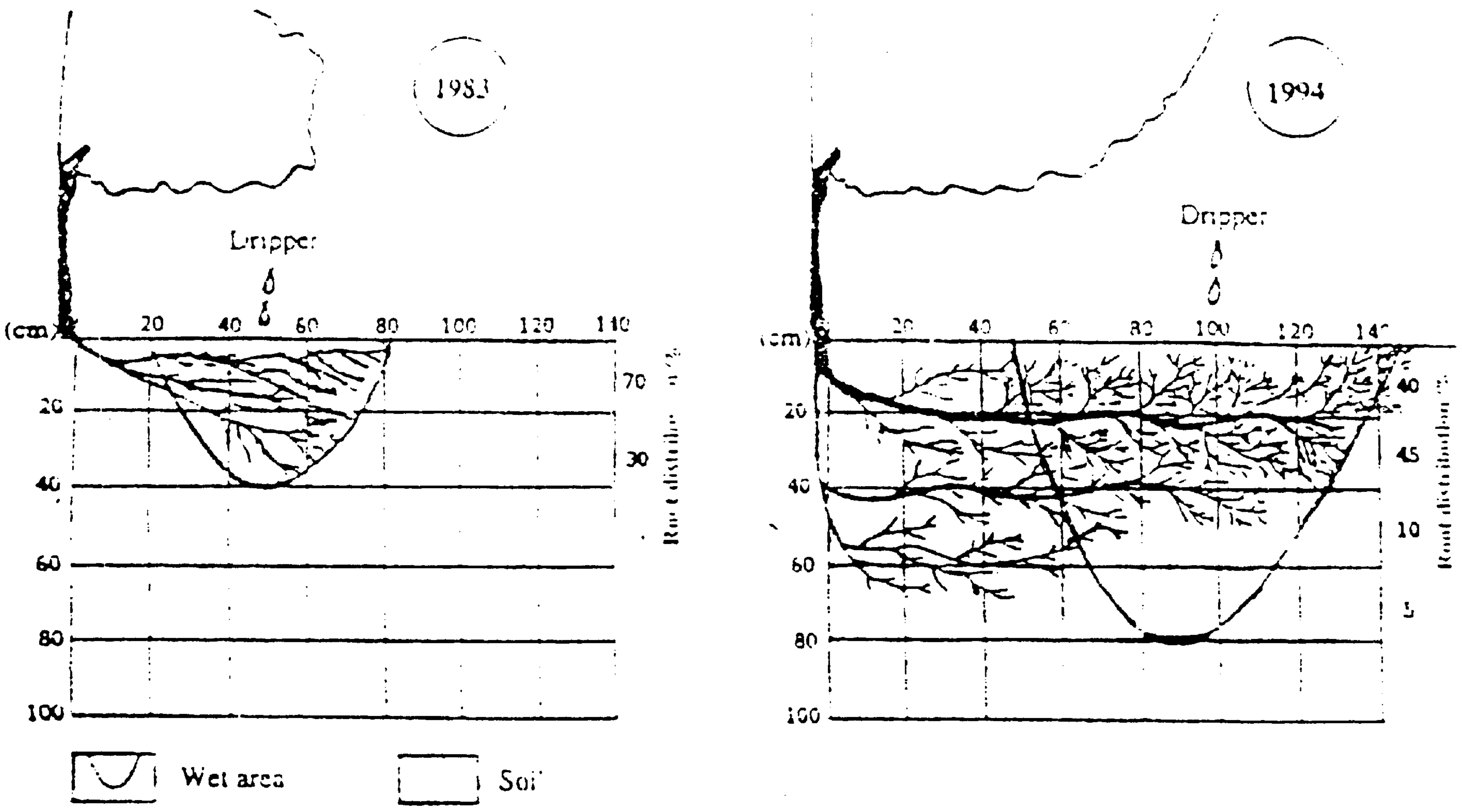

Fig. 3: Root distribution of Valencia Orange tree (1983 and 1994)

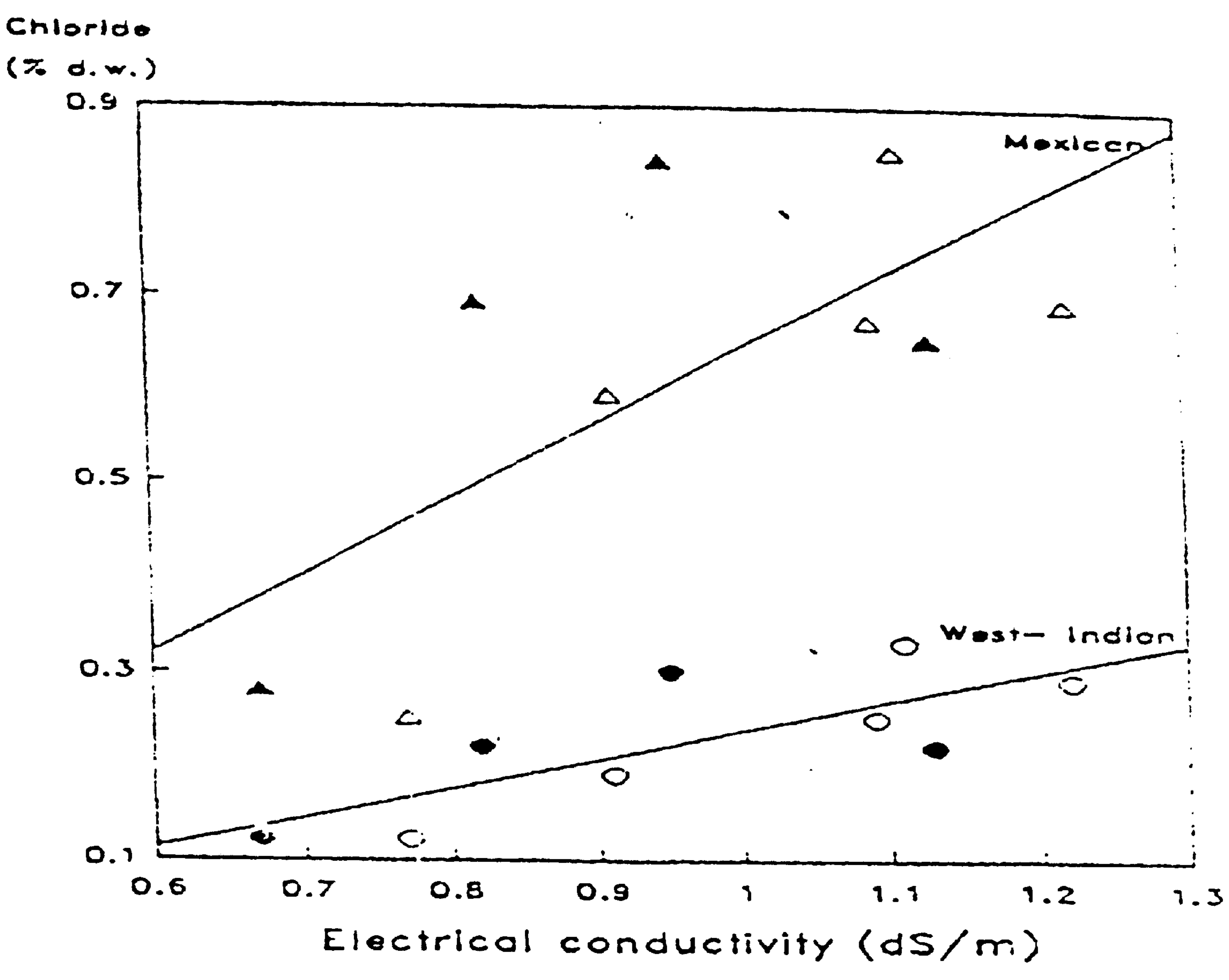

Fig. 4: Effects of salinity, rootstock and water amount (full symbols = surplus supply) on chloride concentration in the leaves (Lahav et al. 1993)

3. [illegible] differences among crops, different strategies (salt excluders and includers) and physiological mechanisms of plants to adapt to higher osmotic pressure of soil solution.
4. Screening in breeding programs show a great potential for better adaptation to saline conditions.

REFERENCES

Abel, G.H. 1969. Inheritance of the capacity for chloride inclusion and chloride exclusion by soy beans. crop Sci., 9, 697-698.

Banuls, J., F. Legaz, and E. Primo-Millio, 1991. Salinity-calcium interactions on growth and ionic concentration of Citrus plants. Plant Soil, 133, 39-46.

Ben-Hayyim, G. 1987. Relationship between salt tolerance and resistance of polyethylene glycol-induced water stress in cultured citrus cells. Plant Physiol. 84, 430-433.

Bernstein, L. 1970. Salt tolerance of plants. Agric.Inf. Bull. (USA), 283.

Bernstein,L. and L.E. Francois, 1975. Effects of frequency of sprinkling with saline waters compared with daily drip irrigation. Agron. J. 67, 185-190.

Carter, M.R., R.R. Cairn, and G.R. Webster, 1977. Amelioration of a brown solodized Solonetz soil by surface application of gypsum plus ammonium nitrate. Can. J. Soil. Sci. 57, 139-145.

El-Fouly, M..M., A.F.A. Fawzi, and A.A. El-Sayed, 1995. Optimizing fertilizer use in oranges through fertigation. Proc Int. Symp. on Fertigation, Technion Haifa.

El-Leboudi, A., T. El-Kobbia, and S. El-Hamaharis, 1973. Investigation on the behaviour of nitrogen fertilizers in some typical alkali soils of Arab. Rep. Egypt. Agrokem. Talajtan, 22, 265-274.

Greenway, H. and R. Munns, 1980. Mechanisms of salt tolerance in non-halophyte. Ann. Rev. Plant Physiol. 31, 149-190.

Hagin, J. and B. Tucker, 1982. Fertilization of dryland and irrigated soils. Springer 1982.

Hochmuth, G.J. 1995. Fertigation of vegetable crops in Florida USA. Int. Symp. on Fertigation, Technion Haifa, 199-214.

Joshi, G.V. and G.R. Naik, 1980. Responses of sugarcane to different types of salt stress. Plant Soil 56, 255-263.

Lagerwerff, J.V. and H.E. Eagle 1961. Osmotic and specific effects of excess salts on beans. Plant Physiol. 36, 472-477.

Lahav, L., R. Steinhardt, and D. Kalmar, 1993. Effect of salinity on the nutritional level of the avocado. In: Optimization of Plant Nutrition. Kluwer Academic Press. 593-596.

Locascio, S.J.J., M. Myers, and S.R. Kostericz, 1981. Quantity and rate of water application for drip irrigated tomatoes. Proc. Flo. Stat. Hort. Sci. 91, 163-166.

Patel, P. and A. Wallace, 1976. P-fertility and mixed salinity on growth and Ca, Mg, Na, P and Cl-concentration of tomato, corn and Sudan grass grown in sand culture. Comm. Soil Sci. Plant Anal. 7, 375-385.

Schleiff, U. and A. Fink, 1976. Untersuchungen zur Bedeutung des Ernahrungszustandes von Kulturpflanzen auf ihre Salztoleranz. Z. Pflanzenern. U. Bodendke. 3, 281-292.

Shaviv, A. and J. Hagin, 1993. Interaction of salinity and enhanced ammonium and potassium nutrition in wheat. In: Optimization of Plant Nutition, Kluwer Academic. Publ. 597-601.

Sonneveld, C. 1988. The salt tolerance of greenhouse crops. Neth. J. Agr. Sci. 36, 63-73.

Sonneveld, C. and A.M.M. Van der Burg, 1991. Sodium chloride salinity of vegetable crops in soilless culture. Neth. J. Agr. Sci. 39, 115-122.

Wilcox, L.V. 1955. Classification and use of irrigation waters. US Dept. Agr. 969.