Presented at
International salinity conf.
Texas Tech, Lubbock, Texas
16-20 August 1976

CROP SALT TOLERANCE: EVALUATION OF EXISTING DATA

E. V. Maas and G. J. Hoffman 1/

INTRODUCTION

Salinity is perhaps the most important problem affecting irrigation agriculture in the world. It has been estimated that salinity limits crop production on 4×10^7 ha, or one-third of the world's irrigated land. In addition, millions of hectares of potentially irrigable land could become saline if put into production. It is imperative, therefore, that we provide the best salt-tolerance data available for crop selection and management decisions in these areas.

The U.S. Salinity Laboratory has conducted considerable research on plant salt tolerance, and the data compiled (Bernstein, 1964b; and U.S. Salinity Laboratory Staff, 1954) have been cited and used throughout the world. Since then, additional data have been obtained and innumerable publications have appeared dealing with salt tolerance. To provide current assessment of the relative tolerance of agricultural crops, we recently completed an extensive review and evaluation of the past 30 years' literature (Maas and Hoffman, 1976). Those data are presented graphically in this paper so that the relative tolerance among crops can easily be seen. The criteria required to express salt tolerance and the factors that influence and limit the use of these data are briefly discussed.

SALT TOLERANCE CRITERIA

Salt tolerance of agricultural crops typically is expressed as the decrease in yield associated with a given level of soil salinity as compared with yield under non-saline conditions (Berg, 1950; Bernstein, 1964b; Bernstein, 1974; de Forges, 1970; and U.S. Salinity Laboratory Staff, 1954). Acquisition of reliable salt-tolerance data requires appropriate measures of both soil salinity and plant response so that reductions in crop yield can be correlated with increases in salinity.

The primary salinity factors influencing plant growth are the kind and concentration of salts present in the soil solution. The predominate soluble ions in saline soils and waters are sodium, calcium, magnesium, bicarbonate, chloride, and sulfate. Except where ratios of these ions are extreme, most plants respond to salinity as a function of the total salt concentration or osmotic potential of soil water without regard to the salt species present (Bernstein, 1961). Nevertheless, some herba-

1/ U.S. Salinity Laboratory, Riverside, California.

ceous plants and most woody species are susceptible to specific ion toxicities. For example, many fruit and berry crops are susceptible to chloride and sodium injury. Boron, an essential element for plant growth, is often found in saline soils at concentrations toxic to many plants. The maximum permissible levels of chloride, sodium, and boron in soil saturation extracts for some crops have been published (Bernstein, 1974). Occasionally, salinity induces nutritional imbalances or deficiencies that cause decreased growth and plant injury not attributable to osmotic effects alone (Bernstein, 1964a; and Bernstein and Hayward, 1958). Sulfate-induced calcium deficiency is one common example. Obviously, the relationship between total soluble salts in the root medium and crop yield must be corrected for these special cases.

Salt concentration in soils usually is determined by measuring the electrical conductivity of a soil saturation extract (EC_e) obtained from the active root zone (U.S. Salinity Laboratory Staff, 1954). The electrical conductivity of a solution is directly proportional to its concentration of soluble salts and, within limits, EC_e can be related to the EC of the soil water. For many soils, the soluble-salt concentration of the soil solution at field capacity is about twice that at saturation. Although EC_e can be routinely and reproducibly determined in the laboratory, in situ measurements of soil water salinity obviously are preferable. These measurements are now possible by using either salinity sensors (Oster and Ingvalson, 1967; and Oster and Willardson, 1971) or the four-electrode resistance probe (Rhoades and Ingvalson, 1971; and Rhoades, 1975).

Since salt distribution in the soil usually varies in both space and time, it is also important to know when and where to take salinity measurements. Except under irrigation with high-leaching fractions, salinity profiles are usually highly nonuniform, with concentrations ranging from about that of the irrigation water near the soil surface to many times higher at the bottom of the root zone. As a result of evapotranspiration and drainage, the salt concentration also changes with time between irrigations; consequently, irrigation frequency influences the magnitude of these changes.

Most salt-tolerance data were obtained where salinity was maintained essentially uniform throughout the root zone by irrigating soil plots or sand cultures with saline waters and high-leaching fractions. These conditions minimize the ambiguity encountered when interpreting results obtained from nonuniform salinity profiles. However, applying these data to field conditions where the distribution of salt is neither uniform in depth nor constant with time is difficult and requires knowledge of how plants respond to varying salinity. Assuming that plants respond primarily to the soil water salinity in that part of the root zone with the highest total water potential, then time-integrated salinity measured in the zone of maximum water uptake should correlate best with crop response. Under high-frequency irrigation, this zone corresponds primarily to the upper part of the root zone where soil salinity is influenced mostly by the salinity of the irrigation water (Bernstein and Francois, 1973). With infrequent irrigation, the zone of maximum water uptake becomes larger as the plant is forced to extract increasingly saline water from increasingly greater depths.

The only agronomically important plant criterion for establishing salt tolerance is the commercial yield of the crop. Vegetative growth, although often used, is not always a reliable guide for predicting fruit or seed production. Grain yields of rice (Pearson, 1959) and corn (Kaddah and Ghowail, 1964) may be greatly reduced without appreciably affecting straw yield. With some other crops, e.g., barley, wheat, cotton, and some tolerant grasses, seed or fiber production is decreased much less than vegetative growth (Ayers, Brown, and Wadleigh, 1952; and unpublished USSL data). For root crops, storage-root yields may be decreased much more than that of tops or fibrous roots (Hoffman and Rawlins, 1971; and Lunin, Gallatin, and Batchelder, 1963).

FACTORS INFLUENCING SALT TOLERANCE

Salt tolerance is a relative value based upon the climatic and cultural conditions under which the crop was grown. Salt tolerance lists published by the U.S. Salinity Laboratory (Bernstein, 1964b; Bernstein, 1974; and U.S. Salinity Laboratory Staff , 1954) represent relative tolerance when crops are grown under conditions simulating cultural and management practices recommended for commercial production in the southwestern United States. Absolute tolerances that reflect predictable inherent physiological responses by plants cannot be determined because many interactions among plant, soil, water, and environmental factors influence the plant's ability to tolerate salt.

Plant sensitivity to salinity often varies from one growth stage to the next (Maas and Hoffman, 1976). For example, barley, corn, rice, and wheat are more sensitive during emergence and early seedling growth than during germination and later stages of growth and grain development. In contrast, sugarbeet and safflower are most sensitive during germination. To avoid problems at sensitive stages of growth, one must know the salt tolerance at these specific stages for some crops and use appropriate management practices to reduce salinity. Although salt tolerance is usually reported as single value for a crop, several examples of varietal differences are now known (Maas and Hoffman, 1976). Interestingly, these crops (e.g., bermudagrass, bromegrass, bentgrass, barley, rice, wheat, soybean, birdsfoot trefoil, and berseem clover) belong to either the Gramineae or Leguminosae families. Perhaps as crops are developed from an increasingly diverse genetic base, even more variability will be found. Rootstocks must be considered in evaluating salt-tolerance differences among tree and vine crops. Salt tolerance of avocado, citrus, grapes, and many stone-fruit trees is related to the ability of rootstocks to exclude chloride.

Soil fertility interacts with salinity to affect the apparent tolerance of many crops. These interactions and how they affect interpretations of salt tolerance data have been discussed by Bernstein, Francois, and Clark (1974). Crops generally seem more salt tolerant when grown with poor rather than with adequate fertility, but only because yields are depressed more by inadequate nutrition under non-saline than under saline conditions. Although fertilization increases yields on infertile saline soils, it usually has no effect on relative salt tolerance because it increases yields proportionately more on comparable non-saline soils. Unless salinity causes specific nutritional problems, fertilization in excess of that required for non-saline soil usually has little beneficial effect and may, in fact, aggravate salt injury (Bernstein, Francois, and Clark, 1974). Other soil factors that may influence crop salt tolerance include soil matric potential, leaching fraction, poor soil aeration, and a shallow water table.

Climatic conditions often influence plant response to salinity. Many crops appear less salt tolerant when grown in a hot, dry climate than in a cool, humid one (Magistad, Ayers, Wadleigh, and Gauch, 1943). Hoffman and co-workers (Hoffman and Rawlins, 1971; and Hoffman, Rawlins, Garber, and Cullen, 1971) found that high atmospheric humidity tended to increase salt tolereance, especially that of salt sensitive crops. Controlled-environment studies indicate that air pollution may increase the apparent salt tolerance of many crops. For example, alfalfa grown at ozone concentrations often prevalent in several agricultural areas, yields were highest at moderate salinity levels that normally reduce growth (Hoffman, Maas, and Rawlins, 1975). Because some crops are affected more by air pollutants when grown under non-saline than under saline conditions, they may seem more salt tolerant in air-polluted areas.

SALT TOLERANCE EVALUATIONS

The most difficult task in evaluating crop salt tolerance data is accounting for the many factors that may influence the plant's response to salinity. A review of the literature reveals that many experimental procedures have been used for determining salt tolerance. Experiments have been conducted in soil, sand, and water cultures; in field, small plots, greenhouse, and growth chambers; and under nearly every conceivable environmental condition. Salination methods have differed, as have ways of measuring and reporting salinity levels in the root medium. Likewise, plant response to salinity has been measured in several ways and at various stages of growth and development. In many experiments, important variables were either not measured or reported, or were uncontrolled.

Notwithstanding the difficulties in evaluating and normalizing the extensive data published worldwide, we have compiled and reviewed all available salt tolerance data from the past 30 years to present our best assessment of the relative salt tolerance of agricultural crops (Maas and Hoffman, 1976). In general, only those data correlating crop yield to the total soluble salts in the root medium were considered. Sodic soil conditions, specific ion toxicities, and nutritional effects were not evaluated. Unfortunately, vegetative growth had to be used for some tree and vine crops because of the lack of yield data. Experiments without adequate control of the factors influencing salt tolerance and papers that failed to mention these factors were not considered in the salt tolerance evaluations. For ease in interpretation, all salinity values were converted to EC_e and all yield data were converted to a relative basis, with the yield of the control treatment assigned a value of 100.

The salt tolerance data for 61 crops are presented in Figures 1-8. In general, crop yields were not decreased significantly until a threshold salinity level was exceeded, and then yields decreased approximately linearly as salinity increased beyond the threshold. The few exceptions to this were of minimal concern because deviations from linearity occurred in the lower part of the curve where yields were commercially unacceptable. The salt-tolerance curve for each crop was obtained by calculating a linear regression equation for the yield data beyond the threshold from each individual experiment. When more than one experiment was considered for determining the salt tolerance of a crop, the slope and intercept values for the various experiments were averaged. In some cases, inclusion or exclusion of data required subjective judgment. Because of the limited salinity range tested in some studies, data from some experiments could be used only to establish threshold salinities and those from others only to determine slope.

Relative yield (Y) at any given soil salinity (EC_e) can be calculated by the equation

$$Y = \frac{100\ (EC_0 - EC_e)}{EC_0 - EC_{100}}$$

where EC_{100} is the salinity threshold value (EC_e where Y = 100) and EC_0 the salinity at zero yield (EC_e where Y = 0). The values for EC_{100} and EC_0 for a given crop can be taken from the appropriate figure. Using alfalfa as an example, EC_{100} = 2 mmho/cm and EC_0 = 15.7 mmho/cm from Figure 3; therefore, at a soil salinity of 5.4 mmho/cm, the relative yield, Y = 100(15.7 - 5.4)/(15.7 - 2.0) = 75%.

A qualitative salt tolerance rating for each crop is also indicated by the shaded areas in the figures. Four divisions were selected to correspond with commonly used terminology ranging from sensitive to tolerant (Fig. 1). The division boundaries for these qualitative ratings approximate the slopes of the linear curves that represent most of the crops reported. With few exceptions the linear salt tolerance curve for each crop remained within one division. Where the salt tolerance curve crosses division boundaries, the crop is rated based on its tolerance at salinity levels where yields are commercially acceptable. Because of insufficient data to determine curves for some crops, only qualitative salt tolerence ratings could be assigned and these are listed in Table 1.

Table 1: Qualitative salt tolerance rating of crops lacking sufficient data for quantitative rating.

Crop Salt Tolerance Rating			
Sensitive	Moderately Sensitive	Moderately Tolerant	Tolerant
Apple	Bentgrass	Bromegrass	Wildrye, Altai
Avocado	Millet, Foxtail	Canarygrass, seed	Wildrye, Russian
Lemon	Rhodesgrass	Olive	
Okra	Timothy	Safflower	
Raspberry		Sorghum	
		Wheatgrass, slender	

The salt tolerance evaluations presented here agree remarkably well with data published from this Laboratory (Bernstein, 1964b; and Bernstein, 1974) even though new and additional experimental data were used for many crops. Only the tolerance of garden beet and bermudagrass changed significantly and both seem less tolerant than previously reported. The threshold salinities of corn, grape, and spinach dropped slightly as compared with extrapolated values from Bernstein's evaluations (Bernstein, 1974), whereas threshold salinities of cotton, soybean, and wheat increased about 1 mmho/cm. Several new crops were added to the list but quantitative evaluations of a few others were not included because the data were equivocal.

In summary, we again emphasize that these data do not represent absolute salt tolerances independent of other factors. Instead, they furnish a guide to relative tolerances among various crops. Whereas absolute tolerance vary with climate, cultural practices, and other variables, relative tolerance should apply to most conditions.

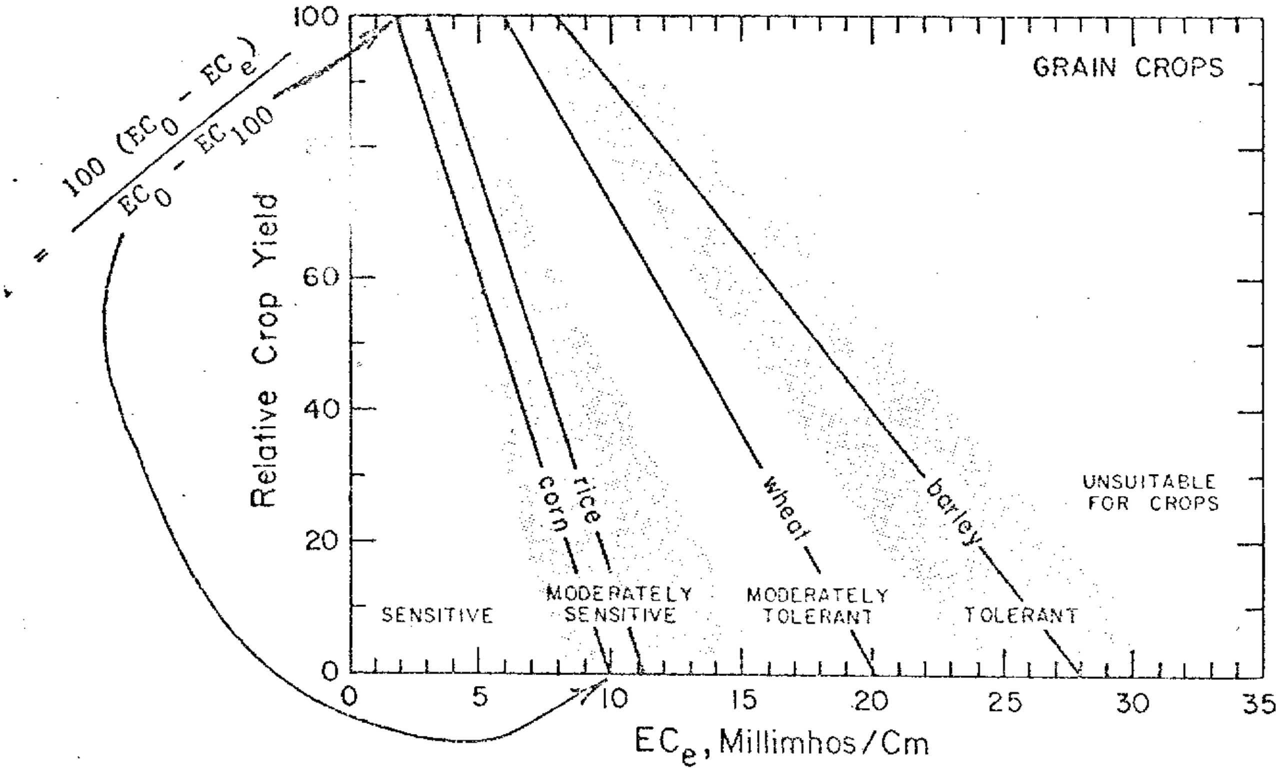

Figure 1: Salt Tolerance of Grain Crops

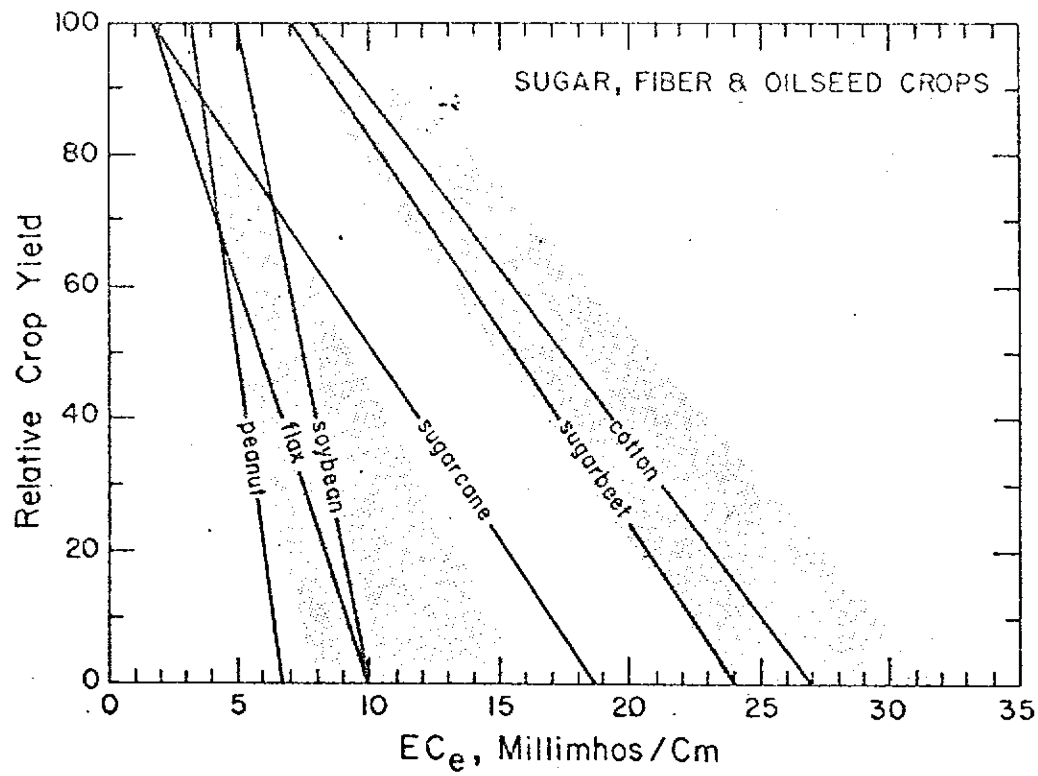

Figure 2: Salt Tolerance of Sugar, Fiber and Oilseed Crops

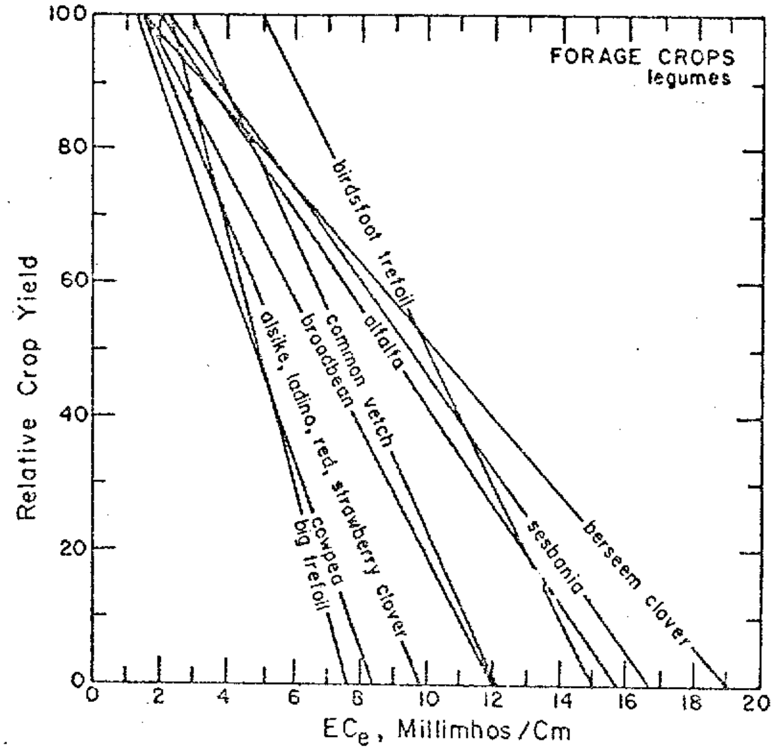

Figure 3: Salt Tolerance of Forage Crops - Legumes

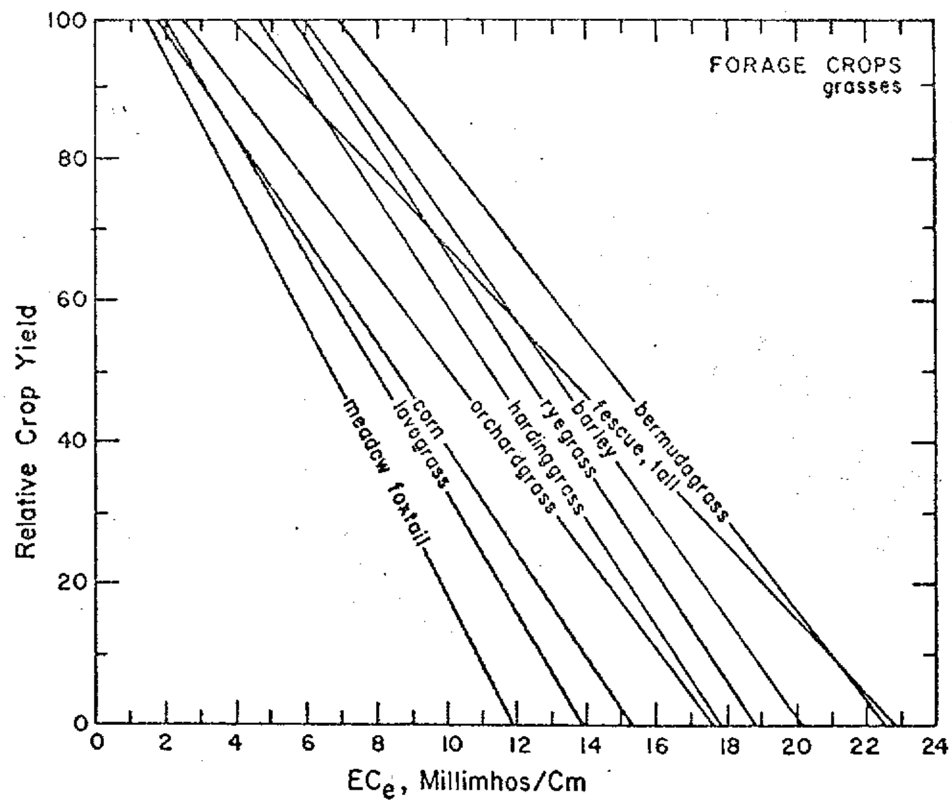

Figure 4: Salt Tolerance of Forage Crops - Grasses

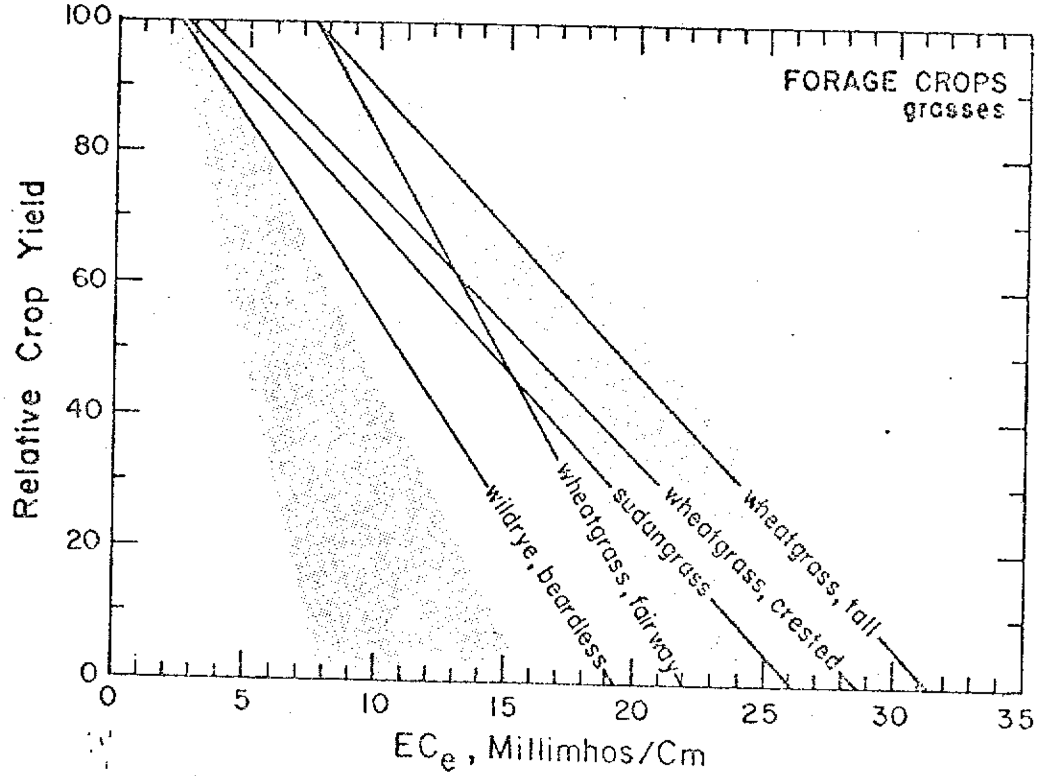

Figure 5: Salt Tolerance of Forage Crops - Grasses

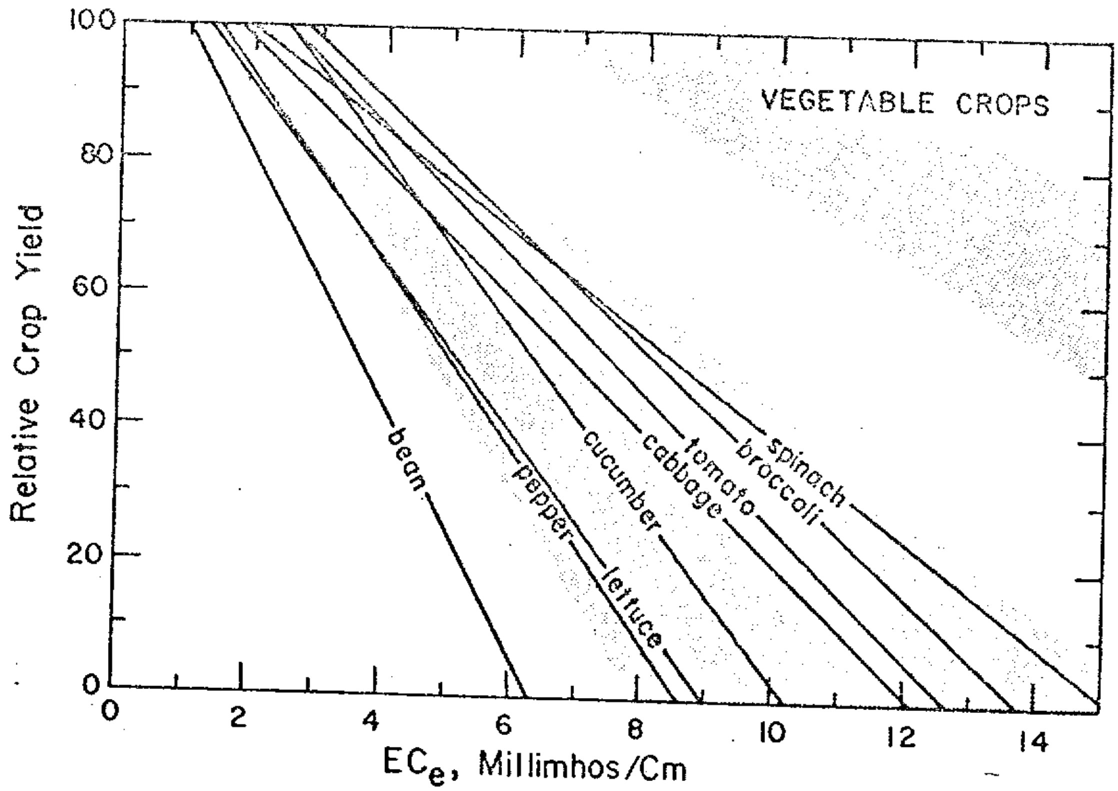

Figure 6: Salt Tolerance of Vegetable Crops

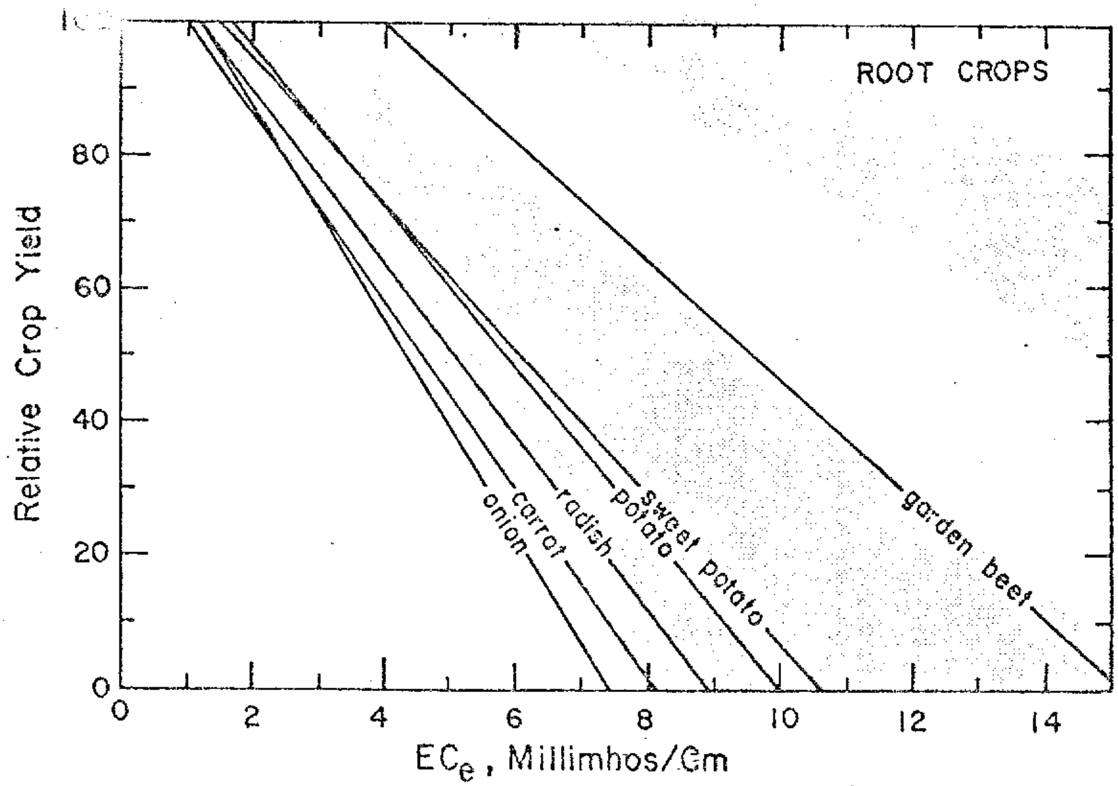

Figure 7: Salt Tolerance of Root Crops

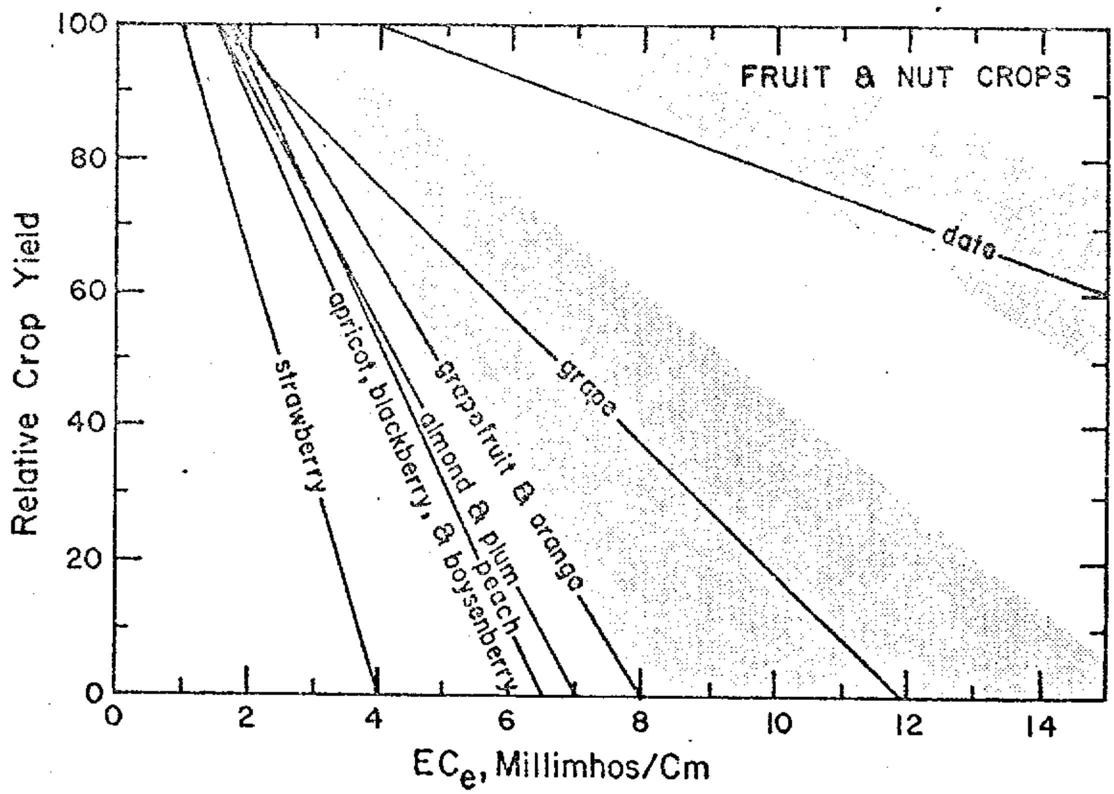

Figure 8: Salt Tolerance of Fruit and Nut Crops

REFERENCES

Ayers, A. D., J. W. Brown, and C. H. Wadleigh. 1952. Salt tolerance of barley and wheat in soil plots receiving several salinization regimes. Agron. J. 44:307-310.

Berg, C. V. D. 1950. The influence of salt in the soil on the yield of agricultural crops. Fourth Intl. Cong. Soil Sci. Trans. 1:411-413.

Bernstein, L. 1961. Osmotic adjustment of plants to saline media. I. Steady state. Am. J. Bot. 48:909-918.

Bernstein, L. 1964a. Effects of salinity on mineral composition and growth of plants. Proc. 4th Intl. Colloquium Plant Analysis and Fert. Problems (Brussels) 4:25-45.

Bernstein, L. 1964b. Salt tolerance of plants. U.S. Dept. Agr. Inf. Bull. 283. 23 pp.

Bernstein, L. 1974. Crop growth and salinity. In: Jan van Schilfgaarde (ed.), Drainage for agriculture. Agronomy 17:39-54. Am. Soc. Agron., Madison, Wisconsin.

Bernstein, L. and L. E. Francois. 1973. Leaching requirement studies; sensitivity of alfalfa to salinity of irrigation and drainage waters. Soil Sci. Soc. Am. Proc. 37:931-943.

Bernstein, L., L. E. Francois, and R. A. Clark. 1974. Interactive effects of salinity and fertility on yields of grains and vegetables. Agron. J. 66:412-421.

Bernstein, L. and H. E. Hayward. 1958. Physiology of salt tolerance. Annu. Rev. Plant Physiol. 9:25-46.

de Forges, J. M. 1970. Research on the utilization of saline water for irrigation in Tunisia. Nature and Resources VI:2-6.

Hoffman, G. J., E. V. Maas, and S. L. Rawlins. 1975. Salinity-ozone interactive effects on alfalfa yield and water relations. J. Environ. Qual. 4:326-331.

Hoffman, G. J. and S. L. Rawlins. 1971. Growth and water potential of root crops as influenced by salinity and relative humidity. Agron. J. 63:877-880.

Hoffman, G. J., S. L. Rawlins, M. J. Garber, and E. M. Cullen. 1971. Water relations and growth of cotton as influenced by salinity and relative humidity. Agron. J. 63:822-826.

Kaddah, M. T. and S. I. Ghowail. 1964. Salinity effects on the growth of corn at different stages of development. Agron. J. 56:214-217.

Lunin, J., M. H. Gallatin, and A. R. Batchelder. 1963. Saline irrigation of several vegetable crops at various growth stages. I. Effect on yields. Agron. J. 55:107-110.

Maas, E. V. and G. J. Hoffman. 1976. Crop salt tolerance - current assessment. (Submitted to J. Irrig. and Drainage, Div. Am. Soc. Civil Eng.).

Magistad, O. C., A. D. Ayers, C. H. Wadleigh, and H. G. Gauch. 1943. Effect of salt concentration, kind of salt, and climate on plant growth in sand cultures. Plant Physiol. 18:151-166.

Oster, J. D., and R. D. Ingvalson.. 1967. In situ measurement of soil salinity with a sensor. Soil Sci. Soc. Am. Proc. 31:572-574.

Oster, J. D., and L. S Willardson. 1971. Reliability of salinity sensors for the management of soil salinity. Agron. J. 63:695-698.

Pearson, G. A. 1959. Factors influencing salinity of submerged soils and growth of Caloro rice. Soil Sci. 87:198-206.

Rhoades, J. D., and R. D. Ingvalson. 1971. Determining salinity in field soils with soil resistance measurements. Soil Sci. Soc. Am. Proc. 35:54-60.

Rhoades, J. D. 1975. Measuring, mapping and monitoring field salinity and water table depths with soil resistance measurements. Proc., Expert Consultation on Prognosis of Salinity and Alkalinity, Rome, Italy, June 1975. (In press).

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U.S. Dept. Agr. Handbook 60. 160 pp.