SOIL SALINITY AND ALKALINITY[1]

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Salt-affected soils contain soluble salts dissolved in the soil solution in amounts sufficiently high to impede growth of food and fiber crops. These salts consist in general of calcium, magnesium, and sodium associated with chloride, sulfate, and bicarbonate with lesser amounts of phosphate, nitrate, and boron (borate). If the soluble salts are neutral salts (not a preponderance of sodium and carbonates), the soil is referred to as a saline soil. But if the soil solution is rich in sodium salts, the soil tends to adsorb sodium and thus becomes sodic or alkaline. Details of saline and sodic soils will be discussed later in this lecture.

SOURCE OF SOLUBLE SALTS

The source of the soluble salts in soils is usually from ground and surface waters rather than from the weathering of the soil minerals. Irrigation water such as the Colorado River water used in southern California contains approximately one ton of salt in each acre foot of water applied. Growers frequently applied 4 to 5 acres feet of water per year and thus 4 to 5 tons of salts. If drainage is impeded, the irrigated soils become highly saline. If

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[1]Presented April 13, 1982: University Extension Course entitled Applied Technology for Citrus Production.

the ground water table rises to within 5 or 6 feet from the surface, the ground water rises to the surface by capillarity and evaporates leaving the transported salts in the soil. Eventually the soil becomes saline. Other sources of salts include fertilizers and, if close to the Coast, marine drift.

SALINE SOILS

Extent

An accurate estimate of the total land area under cultivation that is salt-affected (saline) is impossible to make because of the dynamic nature of irrigated soils. Within the USA, approximately one-third of the irrigated acreage is saline. Undoubtedly, large percentages of irrigated lands throughout the world are salt-affected, particularly in the arid zones. For example, about 350 million acres are salt-affected in Asia. Vast areas of saline soils are found in semi-arid and arid regions of USSR, China, Iran, Iraq, India, and Pakistan. There are over 130 million acres of salt-affected soils in South America, 120 million in Africa, and 35 million acres in Australia. Perhaps up to 50% of the irrigated soils in Mexico are salt-affected to the extent that crop yields are restricted. In California, saline soils are common in the irrigated valleys.

Definitions

Under conditions leading to the accumulation of soluble salts within the root profile, yields of crops are not only influenced by the concentration of soluble salts in the soil solution, factors such

as crop species, climate, irrigation water composition, and irrigation-drainage management come into play. However, generalizations are necessary for classification of salt-affected soils.

Kearney and Schofield (1936) considered a saline soil as any soil containing 0.1% or more of soluble salts. This characteristic ($\geq$ 0.1% soluble salts) has been used extensively throughout the world to classify saline soils. The measurement is made conveniently with a conductivity bridge and, in general, plants respond to salinity independently of the composition of the salts dissolved in the soil water. That is, an electrical conductivity reading (EC) translates to a given yield decrement regardless of the salt species present. The criticism of the Kearney-Schofield measurement is that it does not reflect the effect of texture differences. As example, a 0.1% salt level for a sandy loam would be far more harmful to plants than this level in a clay loam soil because of the greater water holding capacity of the latter soil.

Saturation Extract Important

In 1942, Schofield proposed the use of the saturation extract analysis for diagnosing salt-affected soils. The procedure entails saturating soil with distilled water, then extracting the soil water by vacuum extraction. The extracted solution is referred to as the saturation extract. Measurement of the EC of the extract gives a measure of salinity which can be used to estimate the potential damage to various crop species. Schofield defined a saline soil as a soil having an EC_e value of 4.0 mmho/cm or higher. This definition is universally used. Many crop species have been calibrated against EC_e values. As examples, Schofield proposed the following:

Threshold EC_e Value	Crop Species
mmho/cm	
$\leq$ 2.0	very sensitive crops
2 - 4	sensitive crop
4 - 8	semi-tolerant
8 - 16	tolerant

The advantages of the saturation extract technique are: (1) it is readily reproducible, (2) there is a relationship between the moisture content at saturation and field moisture, and (3) the extract is used for assessment of sodicity (alkalinity). The most important argument for using this technique is that EC_e values have been calibrated against a wide variety of crop plants throughout the world (Maas and Hoffman, 1977).

Some useful conversion factors:

EC_e (mmho/cm) x 10 = meq/liter

EC_e (mmho/cm) x 0.36 = osmatic potential (bars)

EC_e (mmho/cm) x 640 = mg/liter (ppm)

EC_e (mmho/cm) = dS/m

Other Measurements

Other measurements of salt salinity include *in situ* measurements with salt sensors, 4 prong probes and magnetic detection. Dr. Rhoades of the U.S. Salinity Laboratory is one of the leading scientists developing instruments for measuring salinity *in situ*.

The Salinity Profile

Soil salinity exerts a depressing effect on growth of plants to various degrees depending upon parameters such as: (1) the plant species, (2) irrigation water composition, (3) irrigation-drainage management, and (4) climate. Maas and Hoffman (1977) have summarized salt tolerance data for many crop species. A major problem is that of collecting a representative soil sample for assessing salinity. The salinity tolerance of plants may vary depending upon the stage of growth that the plant is exposed to salinity. The distribution of soil salinity within the root profile and with time has a strong influence upon the effect that soluble salts have on plants. The ideal measurements of soil salinity would consist of EC_E (EC of the saturation paste extract) measurements by horizons of the root system a number of times during the active growing period of the crop. These data could be averaged to have a single measure of the effective salinity profile. On the assumption that the root system absorbs 40, 30, 20, and 10% of its water respectively from the first-, second-, third-, and fourth quarter of the rootzone, we can estimate soil salinity on an averaged basis, knowing the leaching fraction and EC_{iw} (salinity of the irrigation water).

Rootzone Interval	Relative Concentration of Saturation Extract*		
	Leaching Fraction		
	0.05	0.10	0.20
Top Quarter	0.65	0.64	0.62
Entire Root System	2.79	1.88	1.29

*Compared to that of the irrigation water.

As an approximation, the average rootzone salinity (expressed as $\overline{EC}_e$) is 1.5 x EC_{iw}; this assumes a leaching fraction of 0.15.

Plants integrate the length of time that they are exposed to salinity, hence it is necessary to have soil samples or measurements taken at enough times during the active growing season to have representative EC_e values which can be averaged. With an average EC_e value, one can use the Maas-Hoffman equation to estimate yield

$$Y = 100 - B\ (EC_e - A)$$

SODIC SOIL

Sodic soil (alkali) is defined as a soil that contains an exchangeable sodium percentage (ESP) value of $\geq$ 15. Although the threshold value of 15% was arbitrarily selected, soil structure characteristics begin to change as the ESP approaches 15, i.e., infiltration, permeability, soil strength, bulk density, porosity, etc. Field crops do not suffer directly from sodium *per se*; rather their growth is impaired by the development of soil structure

unfavorable to root development, water uptake, aeration, etc.

There are a number of parameters which influence the accumulation of exchangeable sodium in soils. Such parameters include clay species and content, organic matter content, irrigation-drainage regime (leaching fraction), and composition of the irrigation water.

The chemical analysis of the saturation extract of soil may be used to assess sodicity. The sodium adsorption ratio (SAR) is a reflection of the ESP.

$$SAR_e = \frac{Na}{(Ca+Mg)^{\frac{1}{2}}} \quad \text{mmol/liter}$$

With irrigation waters containing a relative abundance of bicarbonate (HCO_3), it may be necessary to calculate the SAR adjusted for precipitation of carbonates.

$$SAR_{adj} = SAR_{iw} [1 + (8.4 - pH_c)]$$

The term within the brackets varies from 0 to 3 depending upon the properties of the irrigation water. The lecture on water quality covered the calculation of pH_c,

$$pH_c = (pK_2' - pK_c') + p(Ca+Mg) + p(alk)$$

and the lower the pH_c value, the greater the tendency of the water to precipitate calcium and magnesium upon entering the soil and thus cause an increase in the sodicity of the soil water.

Two models currently in use are

Exchangeable Na surface $ESP_s = \frac{1}{2} SAR_{iw} [1 + (8.4 - pH_c)]$

bottom profile $ESP_b = k\ ESP_s$ where k equals 2.06,

1.36, 1.03, or 0.83 for LF values

of 0.1, 0.2, 0.3, and 0.4

The physical properties of soil irrigated with waters of different electrolyte and sodicity levels vary greatly. At low electrolyte concentrations, soils tend to disperse and lose their structure at low ESP levels ($\leq$ 10); conversely, at a fixed ESP level, say 15, dispersion does not occur if the electrolyte concentration is maintained above 10 meq/liter.

BORON SOILS

Soils containing more than 1.0 mg boron per liter of saturation extract or soil solution contain excessive concentrations of boron for fruit crops. As with salinity, there is a wide range of tolerance that is dependent upon the crop species (see table below).

Crop Species	Threshold B_{SE} (mg B/liter)
Sensitive	0.3 - 1.0
Moderately sensitive	1.0 - 5.0
Tolerant	5.0 - 20

Boron usually accumulates in soils through use of irrigation waters containing excessive concentrations of boron (> 1.0 mg B/ℓ). However, lateral seepage or upward movement of ground waters containing excessive amounts of boron also leads to the accumulation of harmful amounts of boron.

The boron toxicity hazard may be determined by analyzing the saturation extract from boron.

RECLAMATION

Reclamation of saline soils requires leaching with a suitable water. Drainage must be adequate. Sprinkler irrigation is more effective than flood irrigation.

A sodic soil may be reclaimed through leaching provided a source of soluble calcium is available, i.e., gypsum.

High boron soils can be leached, usually 2 to 3 times more water than that needed for saline soils is required.