SALINIZATION OF SOILS

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Summary

Most irrigation water contains some salts. After irrigation, the water added to the soil is used by the crops or evaporates directly form the moist soil. The salt, however, is left behind the soil. Therefore, unless removed, it accumulates in the soil. This phenomenon is called salinization. Salts in the irrigation water or soil cause an adverse effect on crop production.

To sustain production of crops, irrigation procedures need to be adjusted to control the salts in the soil, as well as controlling the salt concentration in the irrigation water. Electrolytic conductivity, cation exchange capacity, sodium adsorption ratio and other physico-chemical parameters, are used for assessing the salinity of soil and water.

In order to mitigate the effects of salinization to maintain agricultural productivity, several measures have been practiced. The rise of groundwater is mainly caused by the capillary effect of the soil. Irrigation methods to avoid capillary rise have been developed. The most widely used method to improve salinity is leaching. Also, salt-

tolerant crops are developed with the help of biotechnology, in order to be able to thrive in a saline environment.

1. Introduction

Normally, soil is rich in salts because the parent rock of the soil contains ionic substances. Seawater is another source of salts in low-lying area along the coast. A very common source of salts in irrigated soils, however, is the irrigation water itself. Most irrigation water contains some salts. After irrigation, the water added to the soil is used by the crops or evaporates directly form the moist soil. The salt, however, is left behind in the soil. Therefore, unless removed, it accumulates in the soil. This phenomenon is called salinization. A white layer of dry salt is sometimes observed on very salty soil. Salty groundwater may also contribute to salinization. When the water table rises, the salty groundwater may reach to the uppermost stratum, thus, to the root zone. Soil which contains excessive amounts of salt is often referred as salty or saline soil. Soil or water which has a high concentration of salt is said to have high salinity.

2. Causes of salinization and saline soil

In many places in the world, the productivity of soil has deteriorated because of an excess of salt has accumulated in the soil around the plant root zone. Large-scale soil salinization has mostly occurred in arid and semi-arid regions. Soil affected by salt also widely exists in sub-humid and humid (i.e. high rainfall) regions. Saline soil is particularly frequent in coastal areas since the soil in those areas is exposed to seawater. Even if the water is low in salinity, the salinity in the soil will increase if the water is used for irrigation for a long time because the trace amount of salt gradually accumulates.

Excessive salinity of the soil surface and the root zone are typical properties of saline soils. The main source of salts in soil is exposed bedrock in geologic strata in the Earth's crust. Salts are gradually released from the bedrock after becoming soluble through physical and chemical weathering such as hydrolysis, hydration, dissolution, oxidation, and carbonation. The released salts dissolve into the surface water or groundwater. As the water with dissolved salts flows from humid regions to less humid or arid regions, salts in the water are gradually concentrated.

The most dominant ions at the place where salts become soluble by weathering are carbonate and bicarbonate of calcium, magnesium, potassium and sodium, if carbon dioxide exists. At first, the salinity of the water is low, but as the water flows from a humid area to a less humid area, it becomes higher as the water evaporates. As the salts in the water are further concentrated, salts with lower solubility start to precipitate. In addition, due to other mechanisms such as ion exchange, adsorption, and the difference of mobility, the concentrations of chemical substances dissolved in the water gradually shift; this always results in increased concentration of chloride and sodium ions in water and soil.

2.1. Classification of saline soil

Saline soil is usually categorized into the following three types, saline, sodic, and alkaline sodic soil.

Saline soil contains a lower amount of sodium absorbed onto soil particles. This type of soil is often seen in sandy soil containing lower amounts of clay and organic matter. Saline soil in deserts is usually of this type.

Sodic soil contains a large amount of sodium absorbed onto soil particles. This type of soil is often seen in soil that contains large amounts of clay.

Alkaline sodic soil is a type of sodic soil that is highly alkaline with the pH value more than 8.5. This type of soil contains higher amounts of carbonate and bicarbonate which can be hydrolyzed to alkalize the products. This soil type has also been called “alkaline soil”. Excessive amounts of carbonate and bicarbonate salts may be brought into soil with groundwater by capillary effect or by irrigation water, or may be formed from soil particles themselves.

2.2. Inhibition of plant growth

The growth of a plant is inhibited by salts when the concentration in the soil around the root zone exceeds the plant's salt-tolerance. Excessive salinity in water causes growth inhibition, partial dwarfism, and lower yield, depending on the salinity level. The direct result of excessive salinity on plants is increase of the osmotic pressure in the root zone; this retards the absorption of groundwater by the plant roots.

In addition to the influence of osmotic pressure, the plant might suffer from the excessive concentration and excessive intake of ions which may be toxic for the plant. This may further inhibit the absorption of essential nutrients.

There is no definitive concentration limit of salinity with which plants are unable to grow. As salinity increases, however, plant growth is inhibited, developing chlorosis, and ultimately causing death. Tolerance to salt in soil is significantly different between plant species. Salt tolerance is evaluated by the difference between the yield in saline soil and that in non-saline soil.

Salinity	**Category and notes**
Less than 0.5 mS cm^{-1} Less than 250 μS cm^{-1} Less than 160 ppm Less than 160 mg L^{-1}	Low salinity water. In the case of improved saline soil, this type of water can be used as irrigation water for most types of agricultural land and for all kinds of crops.
0.7-2.25 mS cm^{-1} 250 - 750 μS cm^{-1} 160 - 480 ppm 160 - 480 mg L^{-1}	Brackish water. If appropriately leached, this type of water can be used for agriculture. Salt-tolerant plants can grow without special salinity adjustment.
0.75 -2.25 mS cm^{-1} 750 - 2250 μS cm^{-1} 480 - 1440 ppm 480 - 1440 mg L^{-1}	High salinity water. This type of water cannot be used for irrigation without drainage facilities. Land with enough drainage capacity can be used to grow only salt-tolerant plants under special salinity control.
More than 2.25 mS cm^{-1}	Extremely high salinity water. This type of water is

More than 2250 μS cm^{-1} More than 1440 ppm More than 1440 mg L^{-1}	inappropriate for irrigation water in general. However, it can be used in specific conditions. If soil has good permeability and high drainage capacity, only salt-tolerant plants can grow after leaching.

Table 1. Categories of salinity of irrigation water

If the soil in which the adverse effect is observed is mixed with water and then the water is analyzed, the salt concentration and the electrolytic conductivity (EC) will be more than 0.02 normality (N) and more than 2 mS cm^{-1}, respectively.

When salt affects the growth of most plants, these parameters are likely to be more than 0.04 N and more than 4 mS cm^{-1}. In sodic and clay soil there is a deterioration in physical properties such as drainage capacity and air permeability, which result in growth inhibition.

Crops affected by salt exhibit lower physiological activity including photosynthesis and transpiration (see Table 1). According to the classification established by US Salinity Laboratory, soil with more than 7.5 mS cm^{-1} of EC significantly affect crops; only salt-tolerant plants can grow in this type of soil.

2.3 Salinity and osmotic pressure

Osmosis is the process of water movement from less saline water to more saline water through a semi-permeable membrane (Figure 1). The less saline water permeates the membrane to the more saline water until the salinities in both sides become balanced against the osmotic pressure which pulls water through the membrane.

Semi-permeable membranes do not allow ions through them except water molecules. Theoretically, water can permeate the membrane to both sides, but more water molecules in the less saline side move to the more saline side because the amount of water molecules in the more saline side is smaller than that in the less saline side.

As a result, the water level in the less saline side becomes lower while that in the more saline side becomes higher. The difference of the water levels pushes the less saline water. Ultimately, the differential pressure balances the salinities on both sides.

Because the positive pressure balances the salinities, the negative pressure is inversely generated on the less saline side and it pulls water outside the membrane. This negative pressure is called osmotic pressure.

The osmotic pressure is also expressed as atmospheric pressure. The equation expressing the relationship between salinity and osmotic pressure is the following.

$$\begin{aligned}\text{Osmotic pressure (OP)} &= \text{Salinity (mg L}^{-1}) \times 0.000563\\ &= \text{Salinity (mS cm}^{-1}) \times 0.36 \qquad (1)\end{aligned}$$

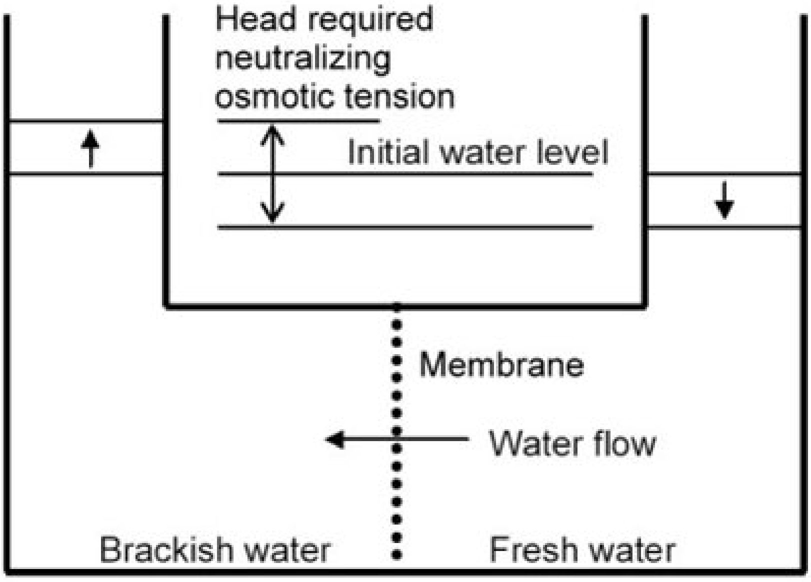

Figure 1. Osmosis and osmotic pressure

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Biographical Sketches

Hideyasu Fujiyama is Professor of Agriculture at Tottori University, where he has been on faculty since 1996. He was admitted to Osaka University in 1969 and received the Bachelor Degree of Pharmacy in 1973. Then, he continued his research at Hokkaido University and obtained the Master Degree in Agriculture in 1976. From 1976, he served as a Research Associate at the Faculty of Agriculture, Tottori University, then as Associate Professor from 1989. A Doctoral Degree from Hokkaido University was conferred on him in 1987.

His domain of research is salinity and eutrophication; it includes the difference in mechanism of salinity hazards between plant species, the growth improvement of salt-stressed plants by chemical methods, the effect of acid rain on nutrient absorption and growth of plants, the dynamics of elements in water and sediments in eutrophic lakes, and the remediation of eutrophic lakes using the nutrient absorption ability of plants.

Yasumoto Magara is Professor of Engineering at Hokkaido University, where he has been on faculty since 1997. He was admitted to Hokkaido University in 1960 and received a degree of Bachelor of Engineering in Sanitary Engineering in 1964 and Master of Engineering in 1966. After working for the same university for four years, he moved to the National Institute of Public Health in 1970. He served as the Director of the Institute. From 1984 he worked for the Department of Sanitary Engineering, then the Department of Water Supply Engineering. He obtained a Ph.D. in Engineering from Hokkaido University in 1979 and was conferred an Honorary Doctoral Degree in Engineering from Chiangmai University in 1994. Since 1964, his research subjects have been in environmental engineering and have included advanced water purification for drinking water, control of hazardous chemicals in drinking water, planning and treatment of domestic waste including human excreta, management of ambient water quality, and mechanisms of biological wastewater treatment system performance. He has also been a member of governmental deliberation councils of several ministries and agencies including Ministry of Health and Welfare, Ministry of Education, Environmental Agency, and National Land Agency. He performs international activities with JICA (Japan International Cooperation Agency) and World Health Organization. As for academic fields, he plays a pivotal role in many associations and societies, and has been Chairman of Japan Society on Water Environment.

Professor Magara has written and edited books on analysis and assessment of drinking water. He has been the author or co-author of more than 100 research articles.