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influence of excessive Cl, SO_4, HCO_3, Na, Ca, Mg, K, NO_3.

Specific Ion Effects:

The influence of excessive concentrations of specific salts on the plant growth is an extremely complex subject involving many fundamental principles of plant nutrition. Ions that are frequently found in excess in saline soils include chloride, sulfate, bicarbonates, sodium, calcium and magnesium. Less frequently encountered in excessive amounts are potassium and nitrate. The effects of all these ions on plant growth have been investigated by comparing plant response to solutions of different salts.

Before considering specific toxic effects caused by excessive concentrations of soluble salts, other effects of certain ions deserve some attention. Although, sodium and chloride are not essential plant nutrients but they may stimulate the productivity of certain crops even when present in relatively small concentrations in normal soils. But in saline soils, chloride and sodium ions occur in much higher concentrations than normal conditions. Under such situations, the high osmotic pressure of the soil solution tends to obscure specific effects of sodium or chloride on crop yields and quality.

Sodium:

Plants species vary greatly in the amounts of sodium that they may accumulate and many species tend to exclude sodium from their leaves, although they may accumulate it in their stems or roots. Sodium in the soil may exert important secondary effects on plant growth through adverse structural modifications of the soil. Thus, if exchange complex contains appreciable amounts of sodium, the soil may become dispersed and puddle, thereby causing poor aeration and low water availability. This is especially true in fine textured soils. If the exchange complex becomes more than 40-50 % saturated with sodium, nutritional disturbances may occur.

It has been observed from the experiments that the addition of calcium and sometimes magnesium to alkali soils can improve plant growth very markedly with an associated increase in the uptake of these added elements by plants. The effects of increasing levels of exchangeable sodium on cationic accumulation varied among species and were related to inherent specificity of the species in accumulating the several cations. In general, increasing the exchangeable sodium percentage of the substrate resulted in a decreased accumulation of calcium, magnesium and potassium in the plants.

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Calcium:

The effect of high concentrations of calcium ions in saline soil solutions varies with the species. Some species are more tolerant to added calcium salts than of other neutral salts. Moderate concentrations of calcium chloride are highly toxic to stone fruits and it appears that this toxicity is associated with an accumulation of chloride in leaves. This chloride accumulation is more pronounced in the presence of excess calcium ions than when sodium occurs in excess.

Magnesium:

High concentrations of magnesium in the substrate are frequently more toxic to plants than concentration of other neutral salts. This toxicity of magnesium may be alleviated by the presence of relatively high concentrations of calcium ions in the substrate.

Potassium:

Although the occurrence of high concentration of potassium in the soil solution is rare, the toxic effects of high potassium have been observed. There is evidence to indicate that toxicity of high potassium like that of high magnesium may be lessened when balanced by high calcium concentrations. High concentrations of potassium may also induce magnesium deficiency and iron chlorosis.

Sulfate:

Specific sensitivity of plants to high sulfate concentrations has been noted for a number of crops and it appears that such sensitivity is related to the tendency of high sulfate concentrations to limit the uptake of calcium by plants. Associated with this decrease in calcium are increases in the absorption of sodium and potassium so that harmful effects of high sulfate in the substrate may be related to a disturbance of optimum cationic balance within the plant.

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MANAGEMENT OF SALT-AFFECTED SOILS

Management of salt-affected soils can be done by following certain measures. These measures can be divided into two categories, i.e. measures for the management of reclaimed salt-affected soils, i.e. normal soils, and measures for the management of salt-affected soils.

Management of reclaimed soils

General measures for prevention of salination in reclaimed salt-affected soils aim to protect the soils from the development/reoccurrence of salt build up. These measures include:

1) maintenance of a downward balance of movement of salts and water
2) reduction in the replenishment of the ground waters and ingress of salts into irrigated areas
3) reduction in ground water evaporation

1) Measures for maintaining a downward balance of salt and water movement in the soils

Wherever natural drainage is available or artificial drainage has been provided, prevention of salination can be done if the balance of movement of moisture (water) is maintained downward in the soil profile, i.e. more water is applied than the amount of water moving upward in the soil profile under evapo-transpiration forces. This can be achieved by the use of irrigation depth greater than the consumptive use of crops or by including such crops in the rotations which require excess irrigation depth (high delta water crops).

2) Measures for reducing the replenishment of ground waters and ingress of salts into irrigated areas

a) Planned, rationed water utilization: Planned water utilization can be practiced in accordance with the nature of the soil, the depth of the ground waters, the type of agricultural crops grown and the type of economy in each irrigation system. This effort makes it possible to reduce the ingress of water and easily soluble salts into the irrigated territory by as much as 20-30 % of the head water intake. However, this requires the equipment for water measurement and control.

b) Water usage according to weather conditions: A study of the autumn, winter, spring and summer weather forecasts should be done so that in the wet period of time no watering is done.

c) Control of surplus irrigation: Surplus irrigation water must never be spread in any part of the irrigated area and flood water has to be controlled.

d) Control of seepage: Seepage must be kept to a minimum. The losses in areas where the canals and water courses are not lined may be as high as 45 %. It is necessary to line the canals and water courses to control the conveyance losses as much as possible. Good results may be obtained in the initial stages by coating with clay materials.

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e) *Remodelling of ancient irrigation systems:* Many of the ancient irrigation systems have [illegible] rebuilt. Some canals lack the requisite hydrotechnical equipment, are meandering and too long. Meas[ures] are needed to reconstruct these systems according to the requirements of modern agriculture.

f) *Provision of water for domestic purposes:* The use of irrigation canals for the delivery of water for domestic purpose during the period without irrigation must be avoided to control water seepage. For this purpose, special canals, storage ponds or wells have to be constructed.

g) *Field leveling:* The fields must be carefully levelled under conditions where surface irrigation methods are used. This practice improves water-use efficiency.

h) *Correct planning for rice growing:* Rice requires huge amount of irrigation water. If a greater part of an area is under rice cultivation, a sharp rise in the ground water may occur. Rice growing areas must be specially selected. They must lie at some distance from the main areas of irrigated land, and have good artificial drainage. Some areas, like the Indus Plains of Pakistan, are suitable only for rice growing because of the large volume of irrigation water available only during the summer.

3) **Measures for reducing ground water evaporation**

Ground water can move from the lower depths to the surface soil where water evaporates and leaves behind salts. The following measures can help reduce the ground water evaporation.

a) *Plant cover over the field:* To reduce ground water evaporation, it is necessary to keep a plant cover over the field. This is especially important in irrigated farming. Plant cover provides shade to the field, act as a mulch and thus reduce surface evaporation.

b) *Improvement of soil structure:* A granular water-resistant soil structure weakens the capillary rise and thus reduces the evaporation. Soil structure can be improved by the addition of organic matter (green manure), deep ploughing, cultivation in relation to irrigation schedule, and avoid overflowing of water after which the soil forms a crust upon drying.

c) *Tree plantation along roads and canals:* Strip afforestation slows down the speed of winds and increases the air humidity thereby reducing the evaporation. On the other hand, the water consumption of trees is very high, thus the water table is maintained/lowered.

d) *Use of ground water for irrigation:* Some ground waters having salt concentrations under permissible limits can be used for irrigation. This practice lowers the water table and decreases direct evaporation.

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Management of salt-affected soils

Management of salt-affected soils can be divided into different aspects including leaching requirement, selection of salt tolerant crops, irrigation practices, fertilization, and planting techniques.

Leaching requirement

Leaching requirement (LR) may be defined as the fraction of the irrigation water that must pass through the root zone to control soil salinity at a specified level. This is the ratio of the equivalent depth of drainage water (D_{dw}) to the equivalent depth of irrigation water (D_{iw}). Similarly, LR can be calculated from the knowledge of the concentration of salts in irrigation water (EC_{iw}) and the permissible level of salt concentration in the drainage water (EC_{dw}). To illustrate the significance of the LR, consider first the simplest possible case:

$$LR = D_{dw} / D_{iw} = EC_{iw} / EC_{dw} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

Leaching requirement may be expressed as a fraction or as percentage. The calculations for LR are made under the assumed conditions, viz. uniform areal application of irrigation water, no rainfall, no removal of salts in the harvested crop, no precipitation of soluble salts in the soil, and a steady-state water flow. With these assumptions, moisture and salt storage in soil, depth of root zone, cation exchange reactions, and drainage conditions of soil are not taken into considerations. On the other hand, it is assumed that the soil drainage will permit the specified leaching.

For field crops where a value of EC_{dw} = 8 dS m^{-1} can be tolerated, the formula for calculating LR would be

$$LR = D_{dw} / D_{iw} = EC_{iw} / EC_{dw} = EC_{iw} / 8$$

For irrigation waters with EC values of 1, 2, 3, and 4 dS m^{-1}, respectively, the LR will be 13, 25, 38, and 50 %. These are the maximum values because rainfall, removal of salts by crops, and precipitation of salts in soils are seldom zero. The predicted value of LR may reduce if these factors are properly taken into consideration.

Some care must be taken into consideration while using equation 1, to make sure that the condition of steady-state or longtime average is understood. As an average over a longtime, the EC of irrigation water used in equation 1 should be weighted average for the conductivities of the rain water (EC_{rw}) and irrigation water (EC_{iw}) as given in the following equation:

$$EC_{(rw+iw)} = (D_{rw}\, EC_{rw} + D_{iw}\, EC_{iw}) / (D_{rw} + D_{iw}) \quad \ldots\ldots\ldots\ldots \quad (2)$$

where D_{rw} and D_{iw} are the depths, respectively of rain water and irrigation water entering the soil. In order to keep the soil salinity from exceeding a specified value, information regarding the consumptive use of water is necessary if the LR concept is to be used for determining either the depth of irrigation water that must be applied or the minimum depth of water that must be drained. The depth of irrigation water (D_{iw}) is related to consumptive use (D_{cw}) and the depth of drainage water (D_{dw}) by the equation:

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$$D_{iw} = D_{cw} + D_{dw} \quad \ldots\ldots\ldots\ldots \quad (3)$$

(14)

Using equation 1 to eliminate D_{dw} from equation 3 gives:

$$D_{iw} = D_{cw} / (1 - LR) \quad \ldots\ldots\ldots\ldots \quad (4)$$

Expressing the LR in equation 4 in terms of conductivity ratio in equation 1 gives:

$$D_{iw} = [EC_{dw} / (EC_{dw} - EC_{iw})] \, D_{cw} \quad \ldots\ldots\ldots\ldots \quad (5)$$

The depth of irrigation water (D_{iw}) is thus expressed in terms of the EC of irrigation water, consumptive use and salt tolerance of a crop. The crop salt tolerance is taken into account by the selection of the permissible values of EC of the drainage water or EC of the soil saturation extract.

Crop selection for salt-affected soils

In salt-affected soils, the judicious selection of crops that can produce satisfactory yields under saline conditions may make the difference between success or failure. The salt tolerance of a plant can be defined as the plant's capacity to endure the effects of excess salts in the medium of the root growth. The salt tolerance of a crop may be appraised according to three criteria:

1. The ability of the crop to survive on salt-affected soils
2. The acceptable yield of the crop on salt-affected soils, mostly 50 % reduced yield.
3. The relative yield of the crop on a salt-affected soil as compared with its yield on a normal soil under the similar growing conditions.

The salt tolerance of a plant is not an exact value. It depends on many factors, viz. environmental and edaphic factors (soil fertility, physical condition of soil, salt distribution in soil profile, irrigation practices, climate) and biological factors (stage of growth, varieties and rootstocks).

Table Salinity and sodicity tolerance of some crop species*

Crop	Tolerance to salinity	Tolerance to sodicity
Barley (*Hordeum vulgare*)	Tolerant	Moderately tolerant
Bean (*Phaseolus vulgaris*)	Sensitive	Sensitive
Corn (*Zea mays*)	Moderately sensitive	Sensitive
Cotton (*Gossypium hirsutum*)	Tolerant	Moderately tolerant
Kallar grass (*Leptochloa fusca*)	Tolerant	Tolerant
Rice (*Oryza sativa*)	Sensitive	Tolerant
Sesbania (*Sesbania aculeata*)	Moderately tolerant	Tolerant
Wheat (*Triticum aestivum*)	Moderately tolerant	Moderately tolerant

*These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary, depending on climate, soil conditions, and cultural practices.

Corn (MS)
Rice (ST)

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Fertilization

Salinity, sodicity and their combination produce unfavourable nutrient ratios in host soils. Excess of Na^+ and deficiency of many macro- and micro-nutrients are common in sodic and saline-sodic soils. The prominent factors responsible for low nutrient availability and mobility in sodic soils are high soil pH and poor soil physical conditions due to dispersed soil matrix because of Na^+ dominance. For this reason, special fertilizer management practices are needed for optimum crop production.

Salt-affected soils generally have low organic matter and N. Green-manuring of sesbania species has been an established practice for years to increase soil N and decrease salinity/sodicity hazard. In sodic soils during reclamation with chemical amendments, some N loss may occur along with leaching of soluble salts and Na^+. It is generally recommended that rice and wheat crops grown on sodic soils should have 25% extra N applied over the rates recommended for nonsodic soils of a particular region.

Sodic and saline-sodic soils usually have higher available phosphorous than the normal soils because higher concentrations of Na_2CO_3 results in the formation of soluble Na_3PO_4. On the basis of some studies, it has been concluded that the sodic soils after reclamation did not require additional P fertilizer for 4 to 5 years. Similarly, it has been suggested that a 50 % reduction in the recommended dose of P may be done for a rice-wheat rotation grown up to three years after reclamation without yield loss.

Increasing soil sodicity nearly always results in a deficiency of Ca concentration in the soil. Fertilizers containing Ca (calcium nitrate, single superphosphate) or producing physiological acidity (ammonium sulphate, urea) perform better than the equivalent rates of Ca-free or physiologically neutral materials. Some studies also show that application of Zn containing fertilizer (zinc sulphate) improved crop yields on salt-affected soils particularly in rice growing areas.

Generally, it is recommended that application of fertilizers, except P containing fertilizers, to the salt-affected soils should be done at higher rates (15-20 %) than the normal soils in any agro-ecological zone.

Planting techniques

In selecting crops for salt-affected areas, particular attention should be given to the salt tolerance of crops during the germination stage because poor germination leads to a poor crop stand. This problem is complicated by the fact that some crop species which are tolerant during the later stages of growth may be sensitive during to salinity during germination. Under field conditions, it is possible by the modification of planting practices to minimize the tendency of salts to accumulate around the seed and to improve the stand of crops those are sensitive to salts during germination.

Seeds of a crop sprout only when they are placed so as to avoid excessive salt build-up around them. The pattern of salt build-up changes with the shape of the bed on which seeds are grown.

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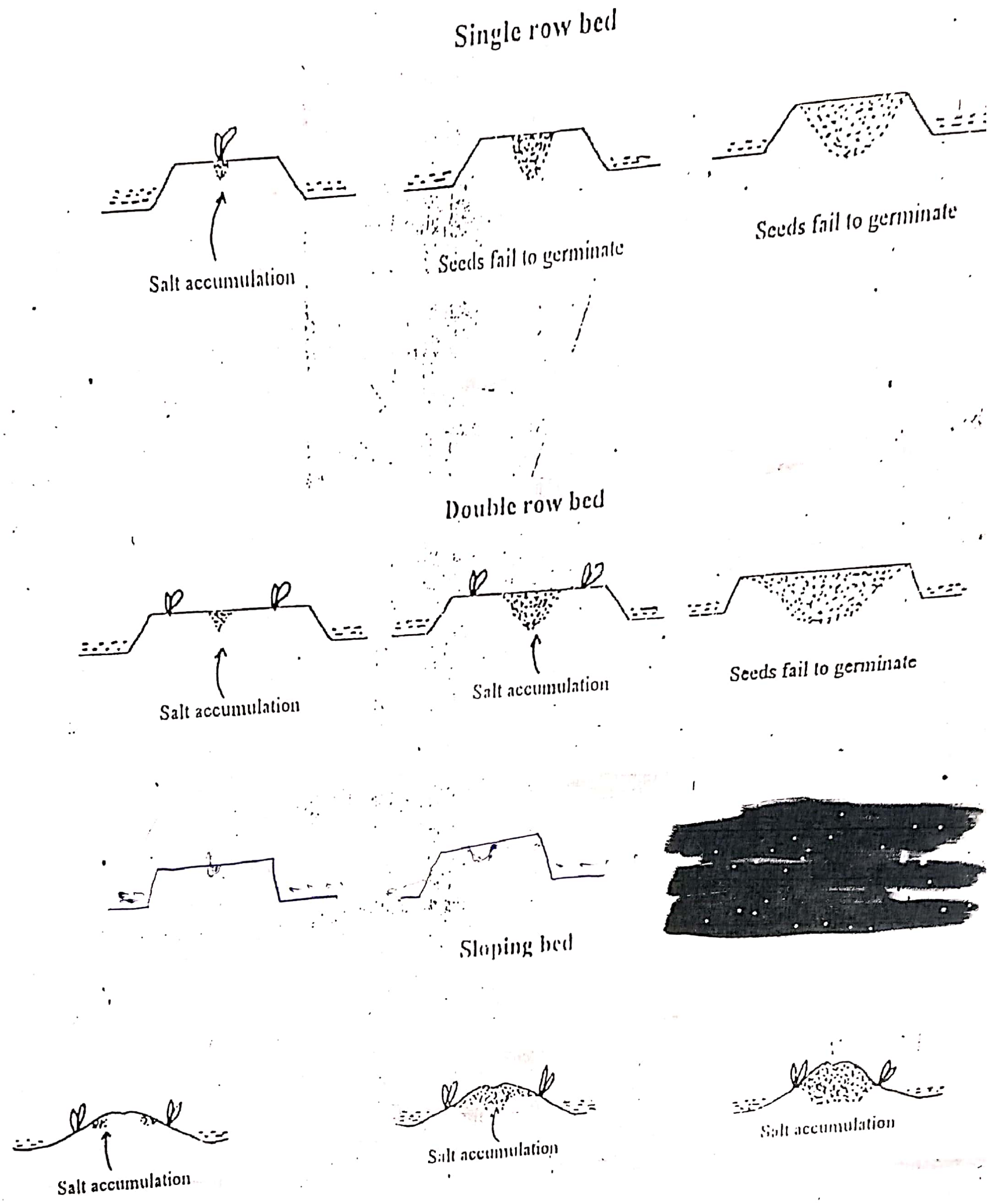
Soil salinity at planting time

4 dS m⁻¹ — 8 dS m⁻¹ — 16 dS m⁻¹



- ✓ ridge sowing for wheat
- ✓ ~~one~~ seedling per hill → rice ↑ seedling / hill
- ✓ holes for trees, add compost date palm, guava.

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