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Saline Soil and Their Management

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Outline

- Introduction to salt affected soil
- **Categorisation** of salt affected soil
- **Causes** of salinity
- Causes of poor crop growth in saline soils
- **Evaluation/ Appraisal** of salinity problem
- **Management strategies for combating SALINIZATION**



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Salt affected soils:

Geographical distribution of salt affected soils in India:

4 major tracts where salt affected soils occurring in India are as follows:

1. **Semi-arid Indo-Gangetic alluvial tract** (Punjab, Haryana, UP, Delhi, parts of Bihar)
2. **Arid tract** of Rajasthan and Gujrat
3. **Arid and semi-arid tract of central and Southern states** principally of the irrigated areas
4. **Coastal-alluvial soil**

State wise distribution of Saline and Alkali soils in India

- | | |
|----------------------|-------------------------|
| 1. U.P-----1.295 mha | 7. Maharastra—0.534 mha |
| 2. Gujrat—1.214 | 8. Orissa---0.404 |
| 3. W.B----0.850 | 9. Karnataka----0.404 |
| 4. Rajasthan—0.728 | 10. M.P----0.21 |
| 5. Punjab- 0.688 | 11. AP----0.04 |
| 6. Haryana---0.526 | |



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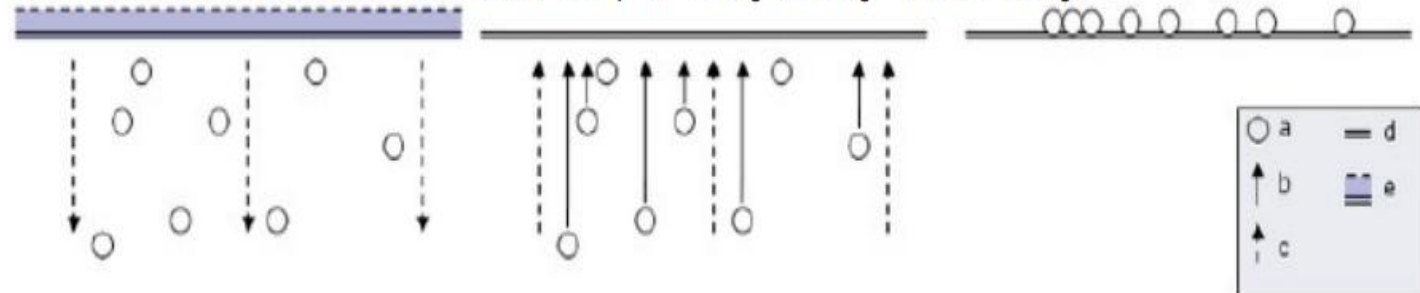
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2



3

The major **cations** concern in saline soils and waters are Na^+ , Ca^{2+} , Mg^{2+} , and K^+ , and the primary **anions** are Cl^- , SO_4^{2-} , HCO_3^- , CO_3^{2-} , and NO_3^- .



Rain or irrigation, in the absence of leaching, can bring salts to the surface by capillary action



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Categorisation of salt affected soils:

1. Saline
2. Sodic/ Alkali soil
3. Saline-Sodic soil

1. Saline soil

a) Physico-Chemical Characteristics

- i) **EC** of the saturation soil extract is more than $4 \text{ dSm}^{-1} (>4)$
- ii) **pH** of the soil is less than 8.5 (< 8.5)
- iii) **ESP** is less than 15 (<15)

b) Physical Characteristics

- i) **Soil Structure**- Usually good
- ii) **Infiltration rate**- High
- iii) **Soil Aeration**- Good

c) **Colour**- Usually white



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2. Sodic Soil (Black-alkali soil)

a) Physico-Chemical Characteristics

- i) **EC** of the saturation soil extract is less than 4 dSm^{-1} (<4)
- ii) **pH** of the soil is more than 8.5 (> 8.5)
- iii) **ESP** is higher than 15 (>15)

b) Physical Characteristics

- i) **Soil Structure** - very poor
(soil is in highly dispersed condition)
- ii) **Infiltration rate** - very poor
- iii) **Soil Aeration** - very poor

c) **Colour**- Usually black

(O.M. dissolves at high pH appearing black colour)



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3. Saline-Sodic Soil

a) **Physico-Chemical Characteristics**

- i) **EC** of the saturation extract is higher than 4 dSm^{-1} (>4)
- ii) **pH** of the soil is lower than 8.5 (< 8.5)
- iii) **ESP** is higher than 15 (>15)

b) **Physical Characteristics**

- i) **Soil Structure** - good
 - ii) **Infiltration rate** - good
 - iii) **Soil Aeration** - good
- c) **Colour**- Usually **white**



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Causes of Salinity in soil

1. **Primary source of salts** in soil is from **rock weathering**. During weathering process soluble salts are formed. Solute movement with water is the determining factor in soil salinization process.
2. **Fluctuating depth of ground water** or WT leads to soil salinity.
3. In **arid region less rainfall** available to leach the salt and **high rate of evaporation** causes concentration of salts in soil at various layer.
4. Coastal Area: Due to **inundation of sea water**.
5. **Irrigation water** containing high concn. of soluble salts (Na salts) leads to soil salinity.
6. Due to **drainage restriction**, reduces permeability of soil.



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The presence of salinity in soil and water can affect plant growth in **three** ways:

The presence of salinity in soil and water can affect plant growth in three ways:

- (1) it can increase the osmotic potential and hence decrease water availability;
- (2) it can induce specific-ion effects by increasing the **concentration of ions** with an inhibitory effect on biological metabolism;

And

- (3) it can diminish soil-water permeability and soil aeration by adversely affecting **soil structure**. The adverse effects of soil salinity on plant growth and productivity varies with the type of plant being grown



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Causes of poor crop growth in saline soil:

(i) High osmotic pressure of the soil soln:

(a) it can increase the osmotic potential and hence decrease water availability; Because of high O.P plant root find difficulty in absorbing high quantity of water and it is due to presence of soluble salts in soil.

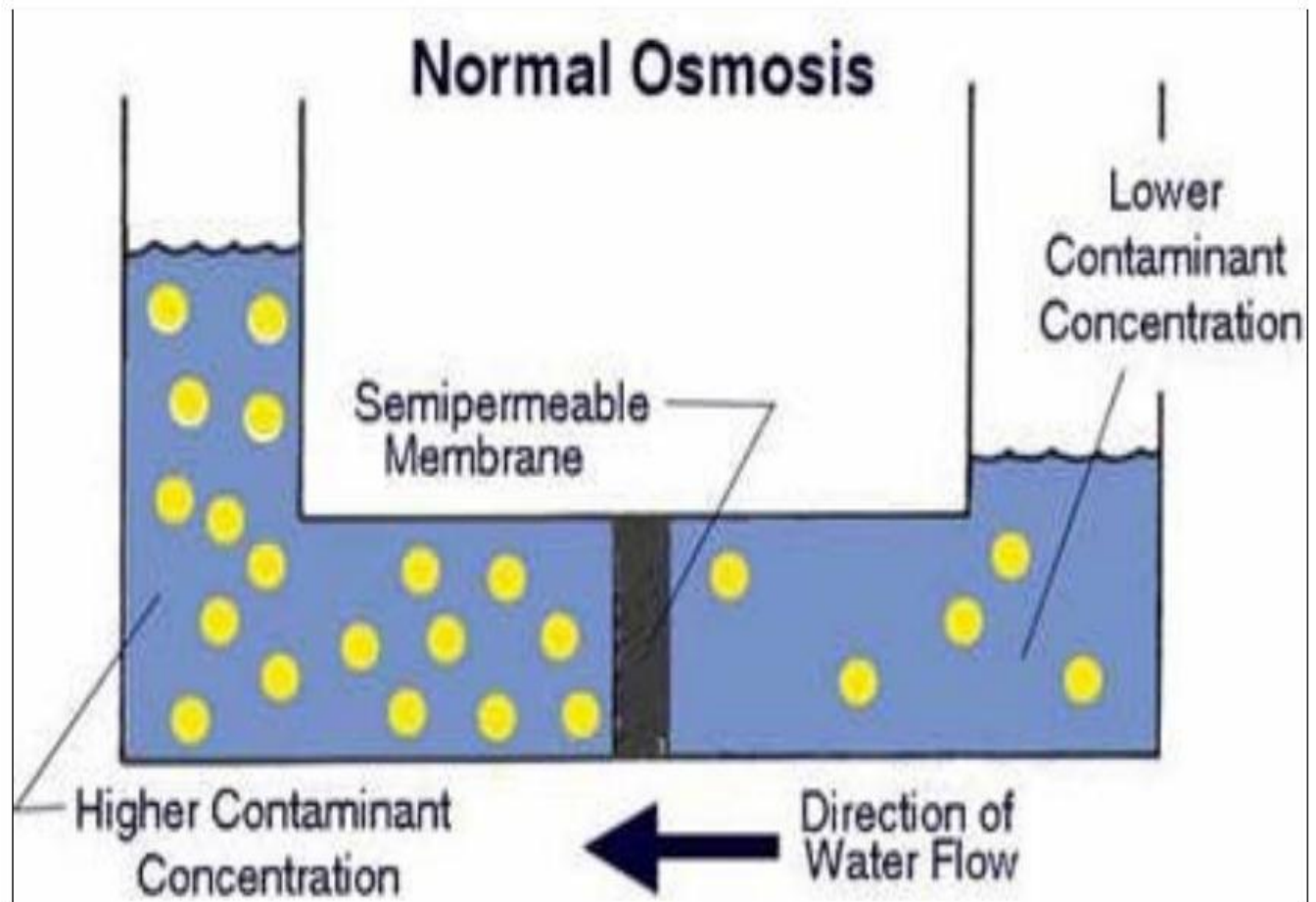
(b) The osmotic effect increases the potential forces that hold water in the soil and makes it more difficult for plant roots to extract water. During dry period, salt in soil soln. may be so concentrated as to kill plants by pulling water from them (exosmosis).

(c) Due to high salt concn. plants have to spent more energy to absorb water and smaller quantity of energy is left for growth in function, seriously affected in cell elongation, leaves become deep green colour, cell becomes flaccid and loss turgidity of the cell.



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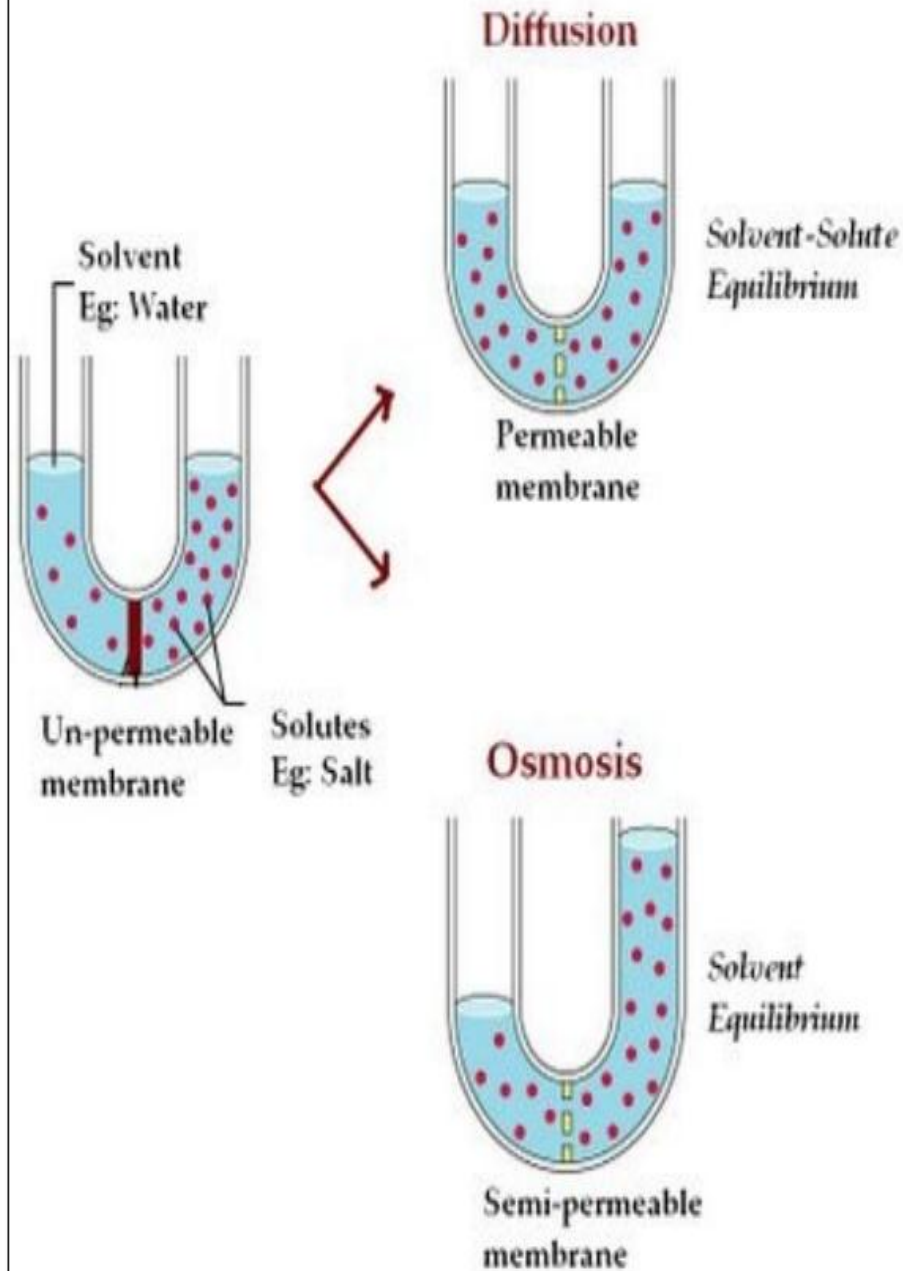


it is the movement of water across a selectively permeable membrane from an area of high **water potential** (low **solute** concn.) to an area of low **water potential** (**high solute concn.**). It may also be used to describe a physical process in which any solvent moves, without input of energy, across a semipermeable membrane



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Osmotic Pressure.ex



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(2) Specific-ion effects:

If growth depression is due to excessive concentrations of the specific ions, rather than to osmotic effects alone, it is called "**specific ion toxicity**"

(a) **at low concn:** NaHCO_3 and soluble borates become toxic

NaHCO_3 : its harmful effect is more likely to be due to the consequences of **high pH** it brings about. Phosphate, Fe, Zn and Mn become unavailable to the plant at high pH value and **soil structure** tends to become **water unstable** bringing about conditions of low water permeability and poor aeration

Borate: Citrus: Irrigation water should contain **B** less than 0.75 mg L^{-1}
Sugarbeet, Lucerne, Cotton, Date palm- crop growth will be hampered if water containing **B** @ $4-6 \text{ mg/L}$

(b) **At High concn:** some ions have toxic effects at high concn.
Fruit plants can tolerate sufficient amount of SO_4^{-2} but not Cl^- (Sensitive)
Flax and grasses: sensitive to high concn. of SO_4^{-2}



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(3) Nutritional Imbalance:

(i) HCO_3^- induced Fe deficiency –

Fe is pptd due to presence of high bicarbonate

(ii) Na^+ induced Ca deficiency-

The specific effects of Na on plant physiological processes include **antagonistic effects on Ca** uptake and shows Ca deficiency. This is because **Na^+ displaces Ca^{2+} from membranes, rendering them nonfunctional.**

(iii) Mg induced Ca deficiency-

High concentrations of competitive cations such as Na^+ , K^+ and Mg^{2+} have been shown to **displace cell membrane-associated Ca^{2+}** . The **greater antagonistic effect of Mg^{2+}** compared to Na^+ is due to its **greater membrane binding constant**. Due to its greater binding constant, **Mg^{2+} more readily displaces Ca^{2+} from the plasma membrane** at lower concns (and salinities) than Na^+ , resulting in a greater growth reduction and corresponding **Ca deficiency**.



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Evaluation/Appraisal of salinity problem:

(i) **Percentage of water soluble salts** in soil

(ii) **Osmotic pressure** of the soil soln. should measure

(iii) **EC** of the saturated soil soil extract

(iv) **Concentration of water soluble Boron:**



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(i) Percentage of water soluble salts in soil;

From a measure of EC of the saturation extract, the total soluble salts in the soil can easily be calculated by the following eqn:

$$P_{ss} = (P_{sw} \times P_w) / 100 = (0.064 \times EC_e \times 10^3 \times SP) / 100$$

P_{ss} - % salt in soil

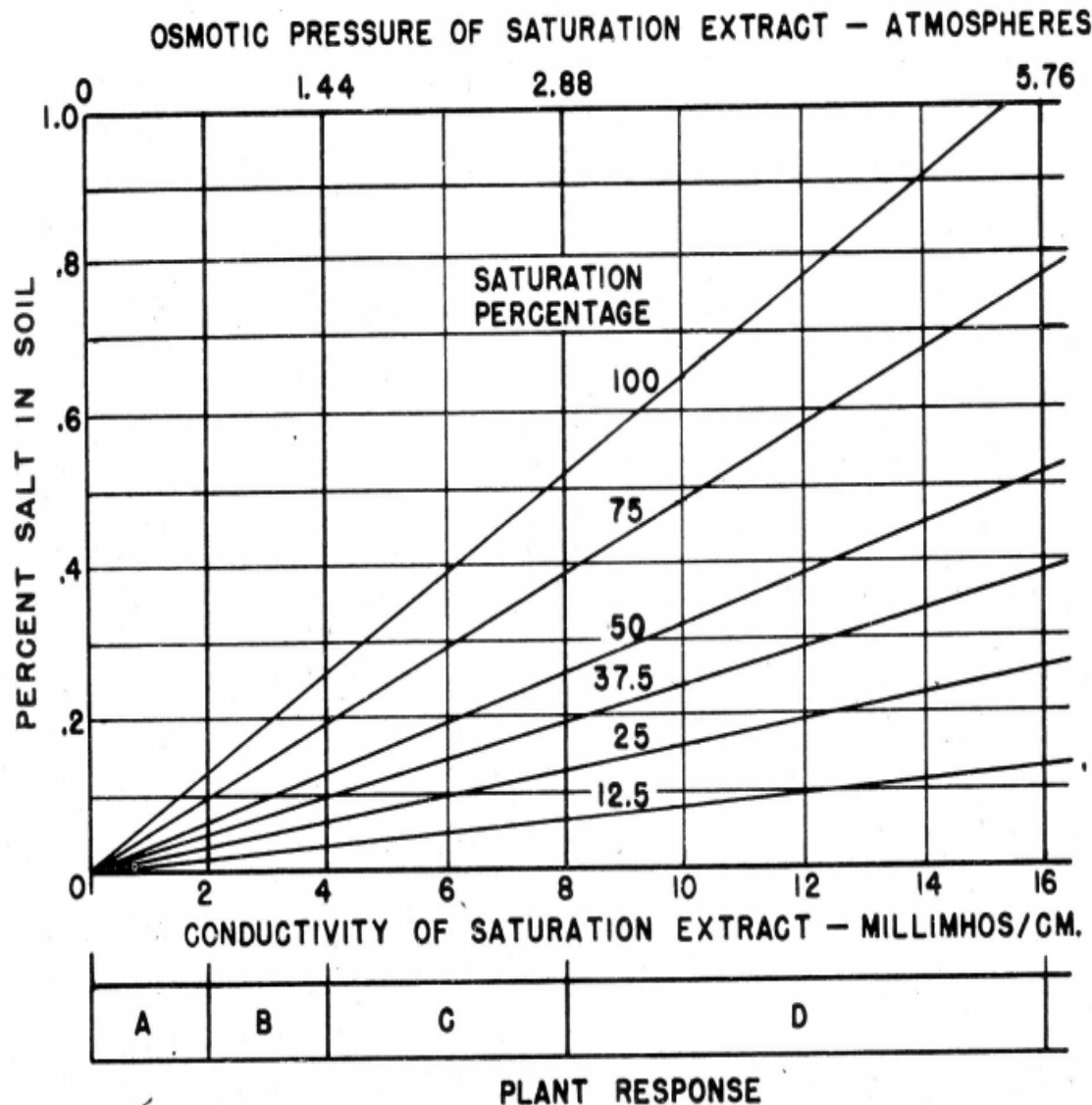
P_{sw} - % salt in water or saturation extract;

P_w - % water in soil or SP



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at $EC, \times 10^3 = 4$, nearly all crops make good growth and for a soil with a **satn %** of **75**, as seen in the diagram, this corresponds to a salt content of about **0.2 percent**.

On the other hand, **0.2 percent salt in a sandy soil** for which the **saturation percentage is 25** would correspond to $EC, \times 10^3 = 12$, which is too saline for good growth of most crop plants.

Relationship between electrical conductivity of soil solution and salt content (the numbers in the plot represent grams of water that are needed to saturate 100 g of soil (it takes 12.5 g of water to saturate 100 g of sand and 100 g of water to saturate 100 g of clay.



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(ii) Osmotic pressure of the soil soln

Osmotic pressure of the soil soln is closely related to the rate of water uptake and the growth of plants in saline soils. O.P. of soil soln is usually calculated from the freezing point depressions as follows:

$$\text{O.P.} = 12.06 \Delta T - 0.021 \Delta T^2 \quad (\Delta T = \text{depression of freezing point})$$

It should be measured in Field capacity moisture regime

In another way, Osmotic pressure can be measured by EC of the saturation extract

$$\text{O.P.} = 0.36 \text{ EC}$$

O.P. = bar or atm. Pressure

$$\text{OP (bars)} \approx \text{EC (dS m}^{-1}\text{)} \times (-0.36)$$

$$\text{EC} = (\text{dS/m})$$

O.P. = Osmotic potential

Colligative properties are properties of solutions that depend on the number of molecules in a given volume of solvent and not on the properties/identity (e.g. size or mass) of the molecules.

Colligative properties include:

lowering of vapor pressure;

elevation of boiling point;

depression of freezing point and

osmotic pressure (π) $\pi V = nRTi$

J. H. van't Hoff:



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(iii) EC of the saturated soil soil extract

EC values (dS/m)	Plant response
0-2	Salinity effects mostly negligible
2-4	Yield of sensitive crop may be restricted
4-8	Yield of many crop restricted
8-16	Only tolerant crops can grow satisfactorily
>16	Unsatisfactory

iv) Concentration of water soluble Boron:

The determination of **water soluble boron** concentration is also an another criteria for characterisation of saline soils. The critical limits of B concn for the plant growth is given below:

Boron conc (ppm)	Plant response
< 0.7	safe
0.7-1.5	Marginal
> 1.5	Unsafe



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Reclamation of Saline soil:

(i) Removal of excess salt by good quality irrign water:

Ponding and intermittent ponding is more efficient in leaching of salts.

For the success of leaching water table must be sufficiently low

(ii) Drainage of the soluble salts at surface and subsurface region:

Surface drainage is for draining of excess run off

Subsurface drainage for lowering the WT

(iii) Proper water mangement of cropping system are important for crop pdn.

Salt Balance:

It is the balance between the amount of salt leaving into the soil through irrigation water . While flushing care must be taken so that the salt balance becomes always positive. In this background a term is used which is known as **Leaching Requirement (LR)**.

LR----- it is defined as the fraction of irrigation water passing out or drained out through the root zone and expressed as

$$\frac{EC_{iw}}{EC_{dw}} = \frac{d_{dw}}{d_{iw}} = \text{leaching requirement (LR).}$$



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Salt balance

A complete salt balance for an irrigated soil in a given time interval can be written as

$$S_p + S_{iw} + S_r + S_d + S_f = S_{dw} + S_c + S_{ppt}$$

the cumulative contribution of S_p (atmospheric inputs), S_r (residual soil salts), S_d (salt released by weathering) and S_f (fertilizer salts) is usually small when compared with S_{iw} (salts in the irrigation water) and tends to be balanced by S_c (crop removal of salt). Usually, the effect of S_{ppt} (precipitation of carbonates and sulphates in the soil) has been discounted and management practices have concentrated on the relationship between S_{iw} and S_{dw} (salt removed in drainage water). This approach leads to the simplified equation

$$EC_{iw} \times d_{iw} = EC_{dw} \times d_{dw}$$

where the subscripts **iw** and **dw** refer to irrigation and drainage water, respectively, d is the volume of water applied per unit area (in mm), and EC measures the salt concentration. Rearranging Equation gives

$$\frac{EC_{iw}}{EC_{dw}} = \frac{d_{dw}}{d_{iw}} = \text{leaching requirement (LR)}$$



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The most common approach to salinity management is to maintain a prescribed *leaching requirement* (LR), defined as

$$LR = \frac{D_{dw}}{D_{iw}} = \frac{EC_{iw}}{EC_{dw}} \quad (11.10)$$

where EC_{dw} and EC_{iw} are the electrical conductivities (salt concentrations) of the drainage and irrigation waters, and D_{iw} and D_{dw} are the amounts of irrigation and drainage water. The relationship is based on the assumptions that a salt balance exists (i.e., that $EC_{iw} D_{iw} = EC_{dw} D_{dw}$) and that the plant is a perfect semipermeable mem-

Validity of eqn 11.10 depends on 3 assumptions

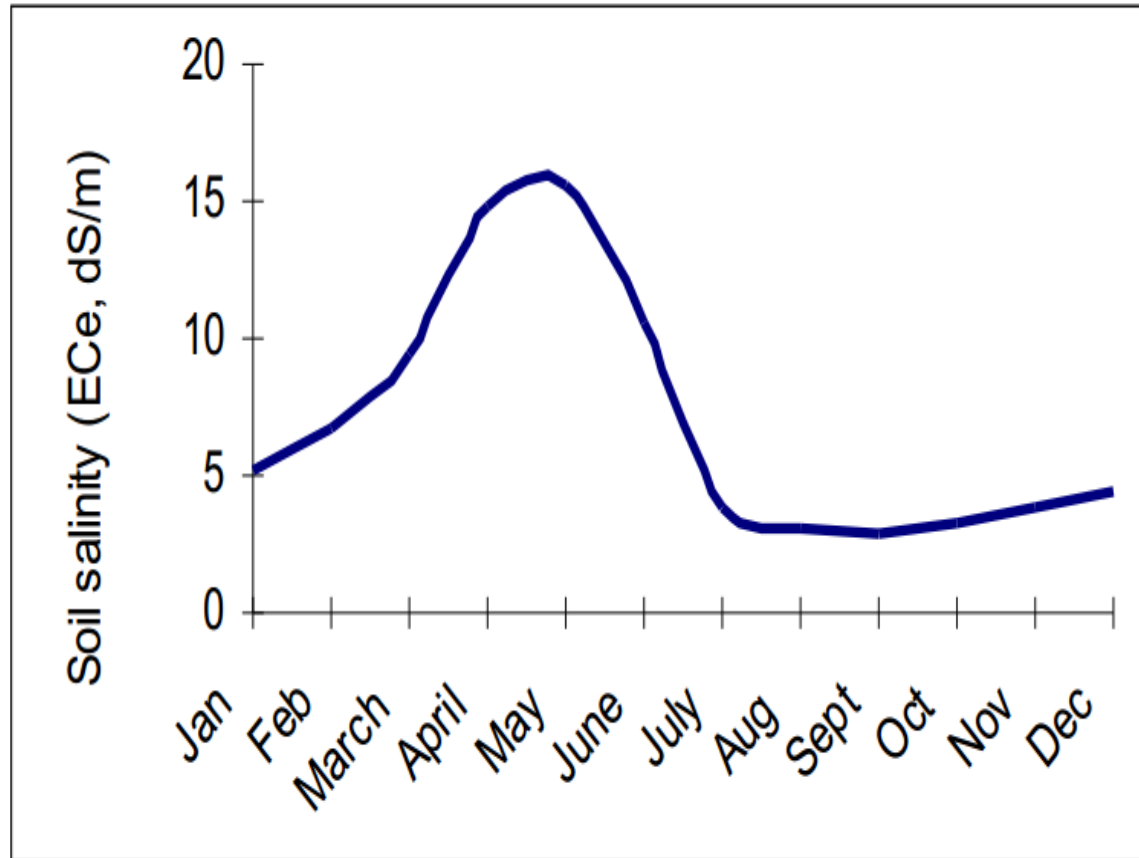
- (i) Plant roots are assumed to have perfectly semipermeable membrane, i.e., it allows only water to enter into the cell but not salts
- (ii) There should not be any precipitation of the soluble salts
- (iii) There will not be any release of soluble salts from the soil

$$TDS \text{ (mg L}^{-1}\text{)} \approx (EC \text{ (dS m}^{-1}\text{)}) \times 640$$



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Variation in soil salinity in different months of the year



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Biological:

- Organic matter application
- Mulching
- Green manuring
- Tree plantation
- Blue-green algae
- Saline agriculture

Hydraulic:

- Flushing
- Leaching
- Improving irrigation / drainage
- Safe disposal of saline waters

Salt-affected Soil

Chemical:

- Amendment
- Soil conditioning
- Mineral fertilizer

Physical/mechanical:

- Scraping
- Land levelling
- Subsoiling
- Sanding
- Improving planting techniques

Other considerations:

- Legal and environmental aspects
- Socioeconomic aspects
- Extension services
- Operation and maintenance

Integrated management practices for the reclamation of salt-affected soils.



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Management strategies

for combating SALINIZATION

1. Soil Management:

- **Maintenance of satisfactory fertility levels**, pH and structure of soils to encourage growth of high yielding crops;
- **Maximization of soil surface cover**, e.g. *use of multiple crop species*;
- **Mulching** exposed ground to help retain soil moisture and reduce erosion
- **Crop selection**, e.g. **use of deep-rooted plants** to maximise water extracn.
- Using crop rotation, **minimum tillage, minimum fallow periods**

2. Water Management:

- **Efficient irrigation of crops**, soil moisture monitoring and accurate determination of water requirements;
- **Choice of appropriate drainage** according to the situation:
 - a. **Surface drainage** systems to collect and control water entering and/or leaving the irrigation site;
 - b. **Subsurface drainage** systems to control a shallow water table below the crop root zone;
 - c. **Biodrainage**: the use of vegetation to control water fluxes in the landscape through evapo-transpiration.
- **Adequate disposal of drainage water** to avoid contamination of receiving waters and the environment.



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3 imp. methods used to remove soluble salts from the root zone.

- (i) **Scraping:** Removing the salts that have accumulated on the soil surface by mechanical means
- (ii) **Flushing:** Washing away the surface accumulated salts by flushing water over the surface is sometimes used to desalinize soils having surface salt crusts.
- (iii) **Leaching:**

This is by far the most effective procedure for removing salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. **Leaching is effective when the salty drainage water is discharged through subsurface drains that carry the leached salts out of the area under reclamation.** Leaching may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage, i.e. the ponded water drains without raising the water table.

Leaching should preferably be done when the soil moisture content is low and the groundwater table is deep.

In some parts of India for example, leaching is best accomplished **during the summer months** because this is the time when the water **table is deepest** and the soil is dry. This is also the only time when large quantities of fresh water can be diverted for reclamation purposes.



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2. Various management practices based on reducing the salt zone for seed germination and seedling establishment:

The **early seedling establishment and tillering phase** are generally the most sensitive stages to salinity. Any management practice that could provide an environment of reduced salt concentration during these stages would mitigate the salinity effects and benefit the crop by promoting plant densities and early seedling growth. A number of approaches have been used.

2.1. Scraping and removal of surface soil: Due to continuous evaporation the salt concentration is the highest in the surface soil. The **top soil** can be **scraped and transported out of the field**. The practice has been used in many areas of the world (Qureshi et al., 2003).

2.2. Pre-sowing irrigation with good quality water: Where available, irrigation with **good quality water prior to sowing helps leach salts** from the top soil. This helps in promoting better seed germination and seedling establishment. The benefits of this practice were documented in a long-term study by Goyal et al (1999 a,b).



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2.3. Appropriate use of ridges or beds for planting:

The impact of salinity may be minimized by **appropriately placing the seeds (or plants) on ridges.**

Where exactly the seeds should be planted on the ridge or bed will depend on the irrigation design.

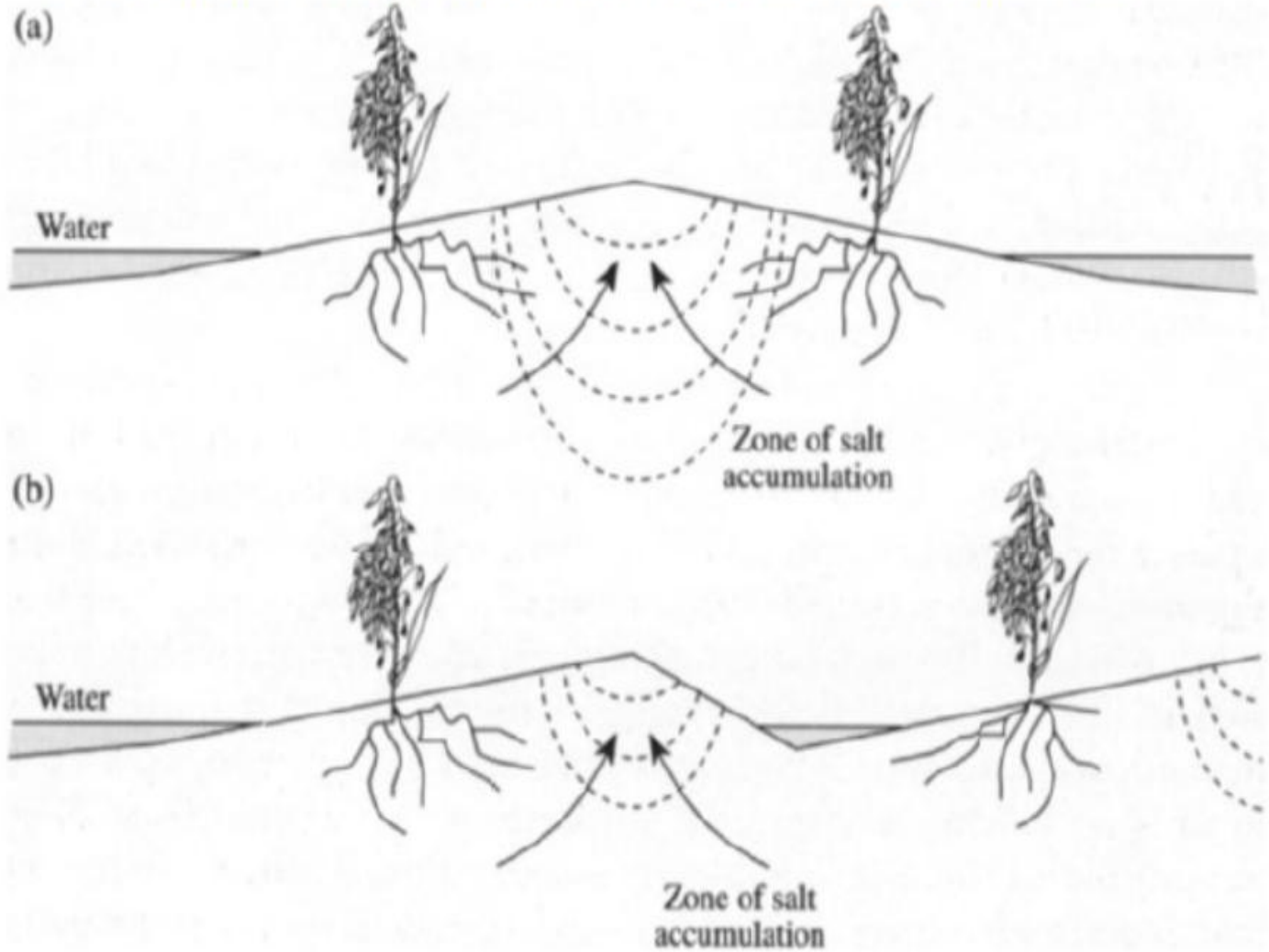
- If the crop planted on ridges would be **irrigated via furrows** on both sides of the ridge, it is better to **place plants on the ridge shoulders** rather than the ridge top because water evaporation will concentrate more salts on the ridge top or center of the bed.
- If the **crop is irrigated via alternate furrows**, then it is better to plant only on **one shoulder of the ridge closer to the furrow that will have water.**



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Sloping beds may be slightly better on highly saline soils because seed can be planted on the slope below the zone of salt accumulation.



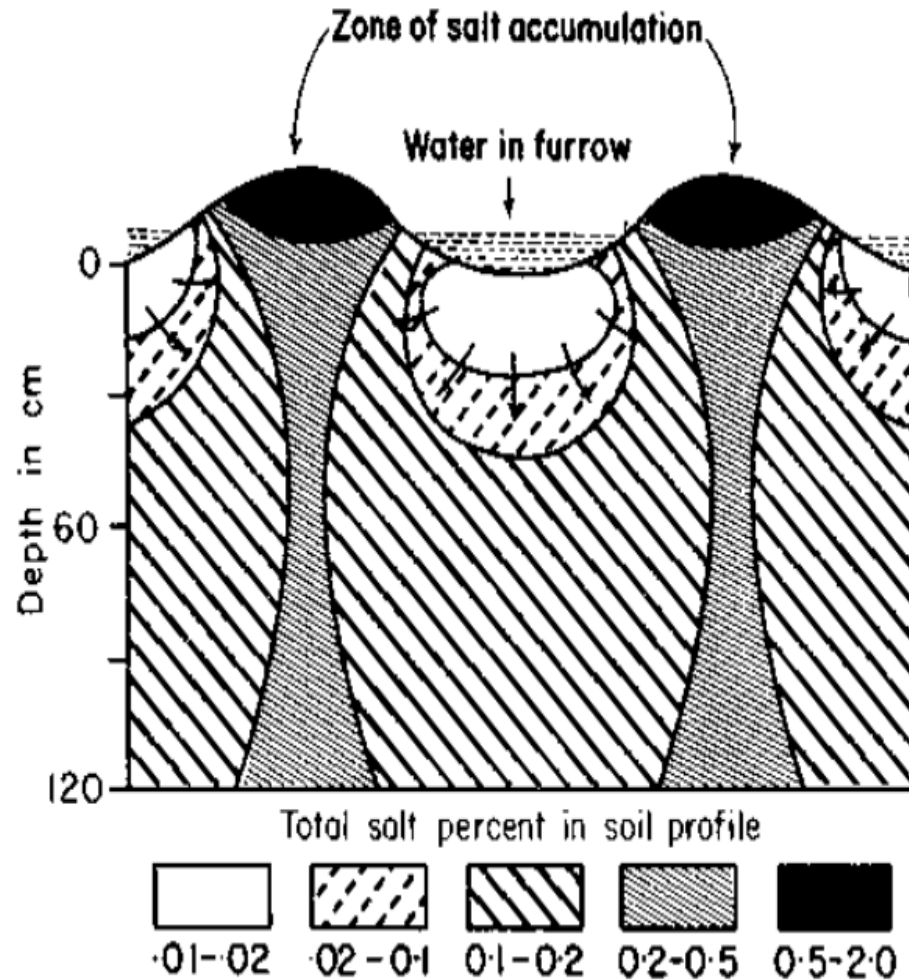
Microtopography of ridge and furrow systems designed to avoid salinity damage to crops: (a) paired crop rows on broadly sloping ridges, (b) single crop rows on asymmetric ridges (from White 1987)



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Certain modifications of the furrow irrigation method including planting in single/double rows or **on sloping beds**, are helpful in getting better stands under saline conditions. With **double beds**, most of the salts accumulate in the centre of the bed **leaving the edges relatively free of salts**.



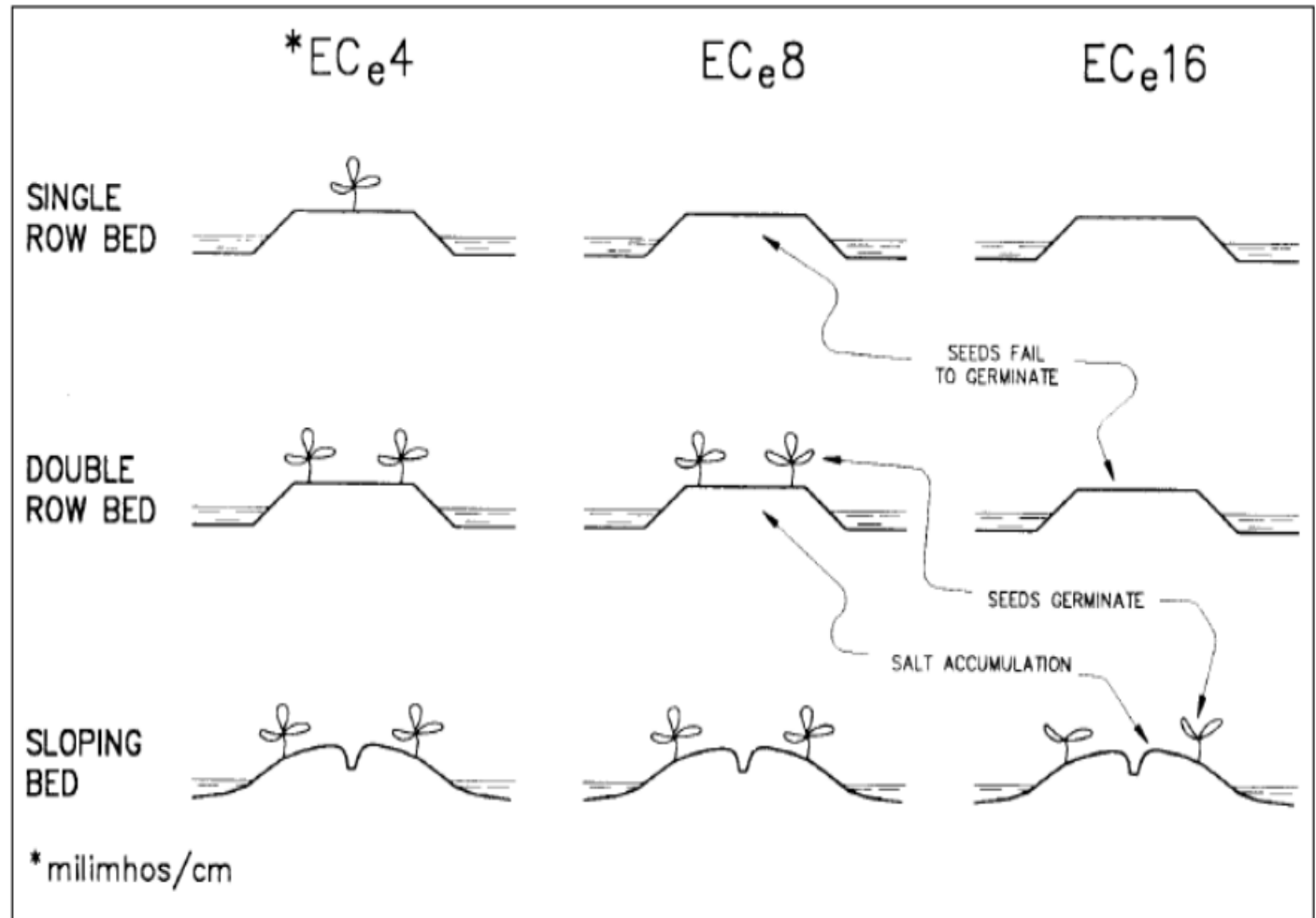
The pattern of salt built up depends on bed shape and irrigation method.

Seeds sprout only when they are placed so as to avoid excessive salt build up around them (Bernstein et al., 1955)



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Pattern of salt build-up as a function of seed placement, bed shape and irrigation water quality.



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3. General management practices to reduce the impact of soil salinity on crop performance: In addition to the management practices mentioned above, the following approaches may help reduce salinity impacts.

3.1. Mulching:

Mulching with crop residue, such as straw, reduces evaporation from the soil surface which in turn reduces the upward movement of salts. Reduced evaporation also reduces the need to irrigate. Consequently fewer salts accumulate.

3.2. Deep Tillage:

Accumulation of salts closer to the surface is a typical feature of saline soils. Deep tillage would mix the salts present in the surface zone into a much larger volume of soil and hence reduce its concentration and impact. Many soils have an impervious hard pan which hinders in the salt leaching process. Under such circumstances “chiseling” would improve water infiltration and hence downward movement of salts.



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Soil type and average root zone leaching fraction

Soil type	Average root zone LF
Sand	0.6
Loam	0.33
Light clay	0.33
Heavy clay	0.2

leaching fraction (LF) of the soil under irrigation, i.e. the proportion of applied water moving below the root zone.

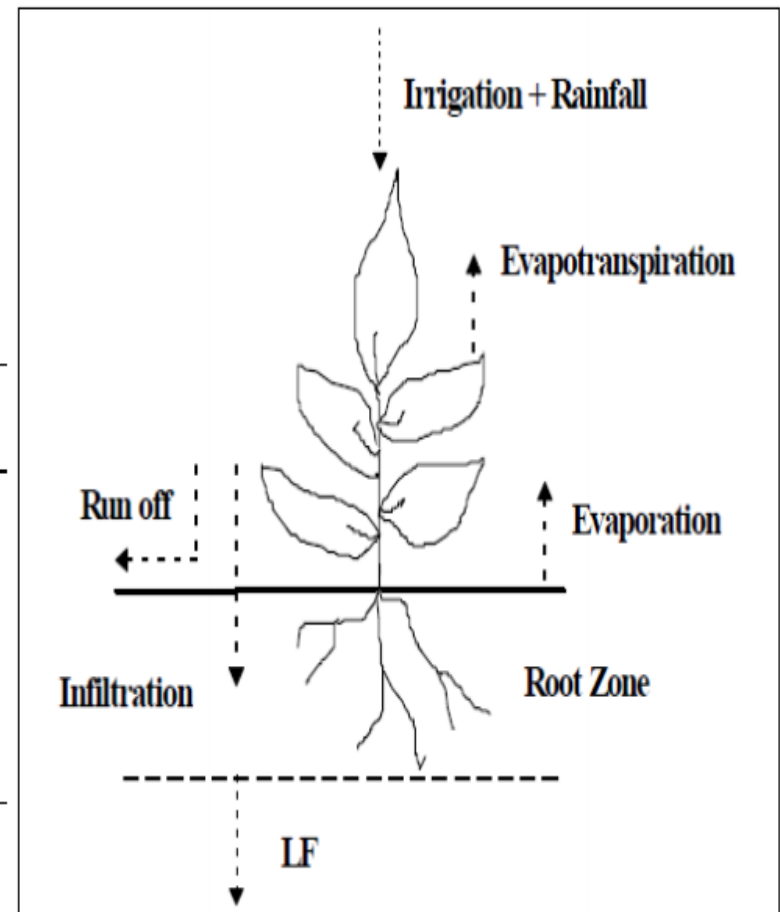


Figure 2—Diagram of the leaching fraction (LF) concept



3.3. Incorporation of Organic matter :

Incorporating crop residues or green-manure crops improves soil tilth, structure, and improves water infiltration which provides safeguard against adverse effects of salinity. In order for this to be effective, regular additions of organic matter (crop residue, manure, sludge, compost) must be made.

Table 2. Leaching requirement for typical irrigation waters in California as related to salt tolerance of crop (taken from J.D. Oster, G.J. Hoffman and F.E. Robinson, California Agriculture, October 1984).

Salinity of applied water (dS/m)	Leaching requirement			
	Sensitive crop	Moderately sensitive crop	Moderately tolerant crop	Tolerant crop
0.05 (freshwater canal)	0.01	0.01	0.01	0.01
0.3 (California aqueduct)	0.05	0.02	0.02	0.02
1.3 (Colorado River)	0.14	0.07	0.04	0.02
5.0 (reused drainage)	not possible	0.27	0.15	0.10



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Conservation farming practices to control soil salinity

- **Reducing summer fallow**
- **Using conservation tillage**
- **Adding organic matter to the soil**
- **Planting salt-tolerant crops
(eg., rapeseed and cabbage)**



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Pond excavation



Land shaping



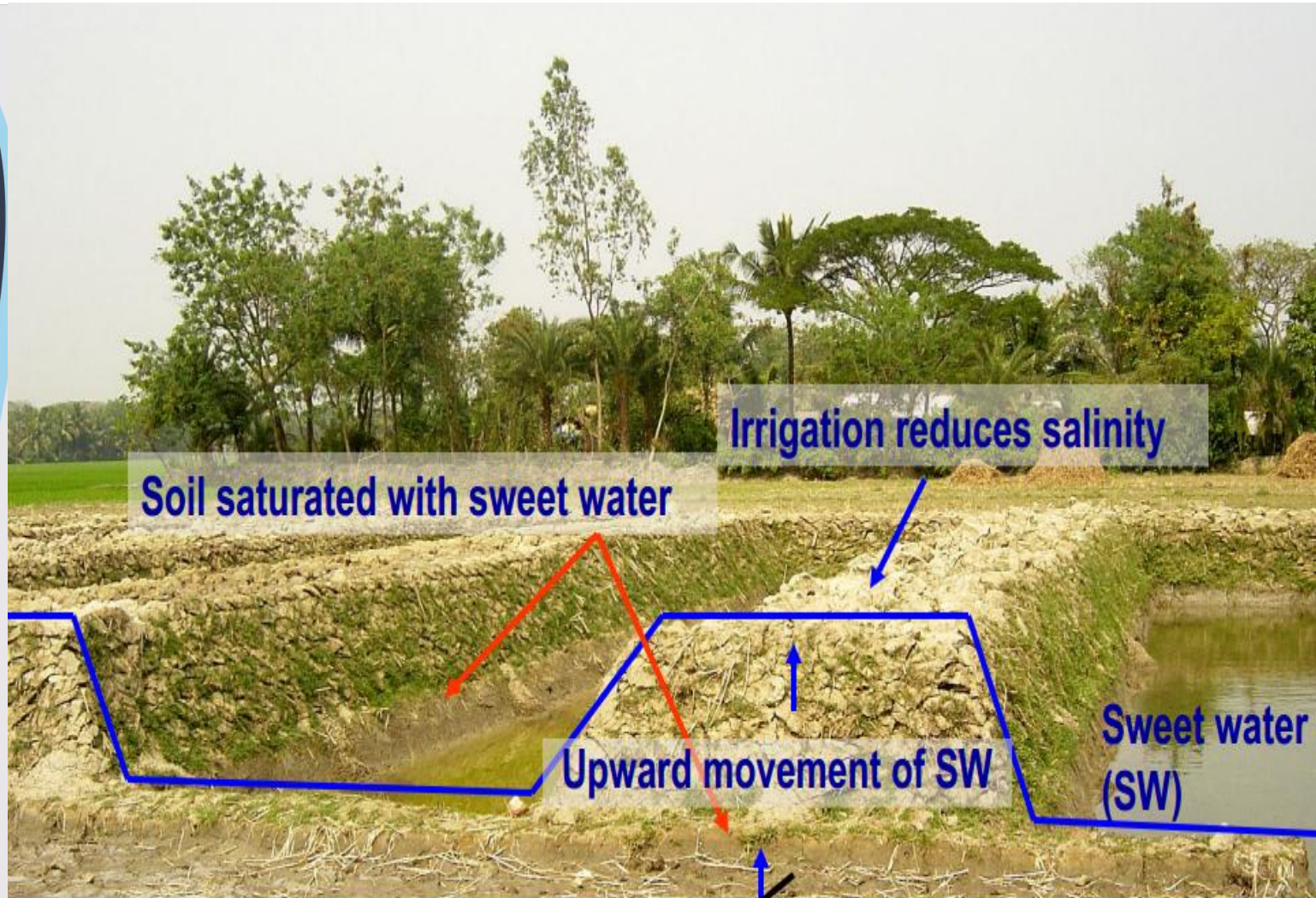
Land shaping





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Soil saturated with sweet water

Irrigation reduces salinity

Upward movement of SW

**Sweet water
(SW)**

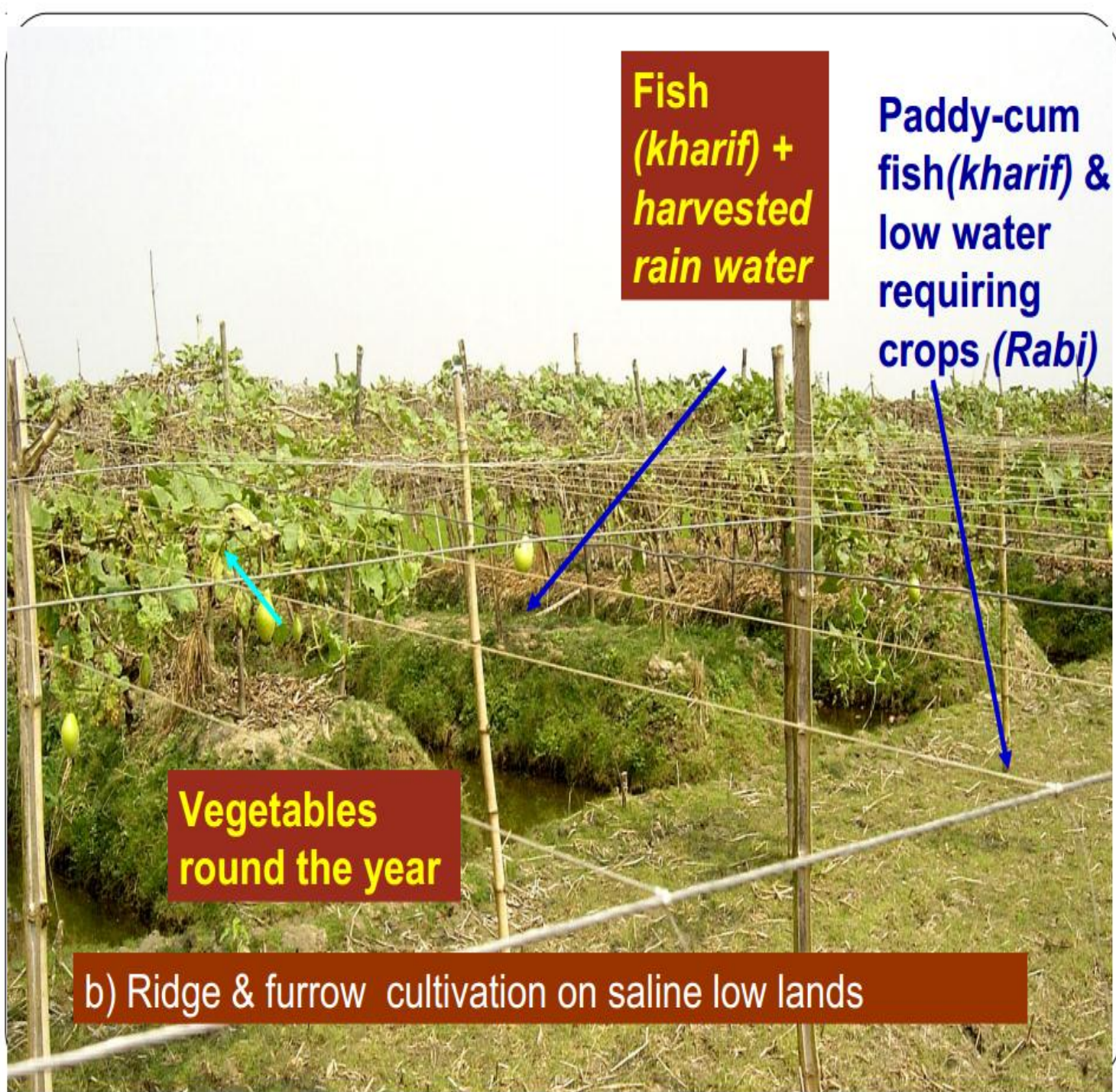
No upward movement of brackish water

Reduce effect of degradation due to land shaping



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**Fish
(kharif) +
harvested
rain water**

**Paddy-cum
fish(kharif) &
low water
requiring
crops (Rabi)**

**Vegetables
round the year**

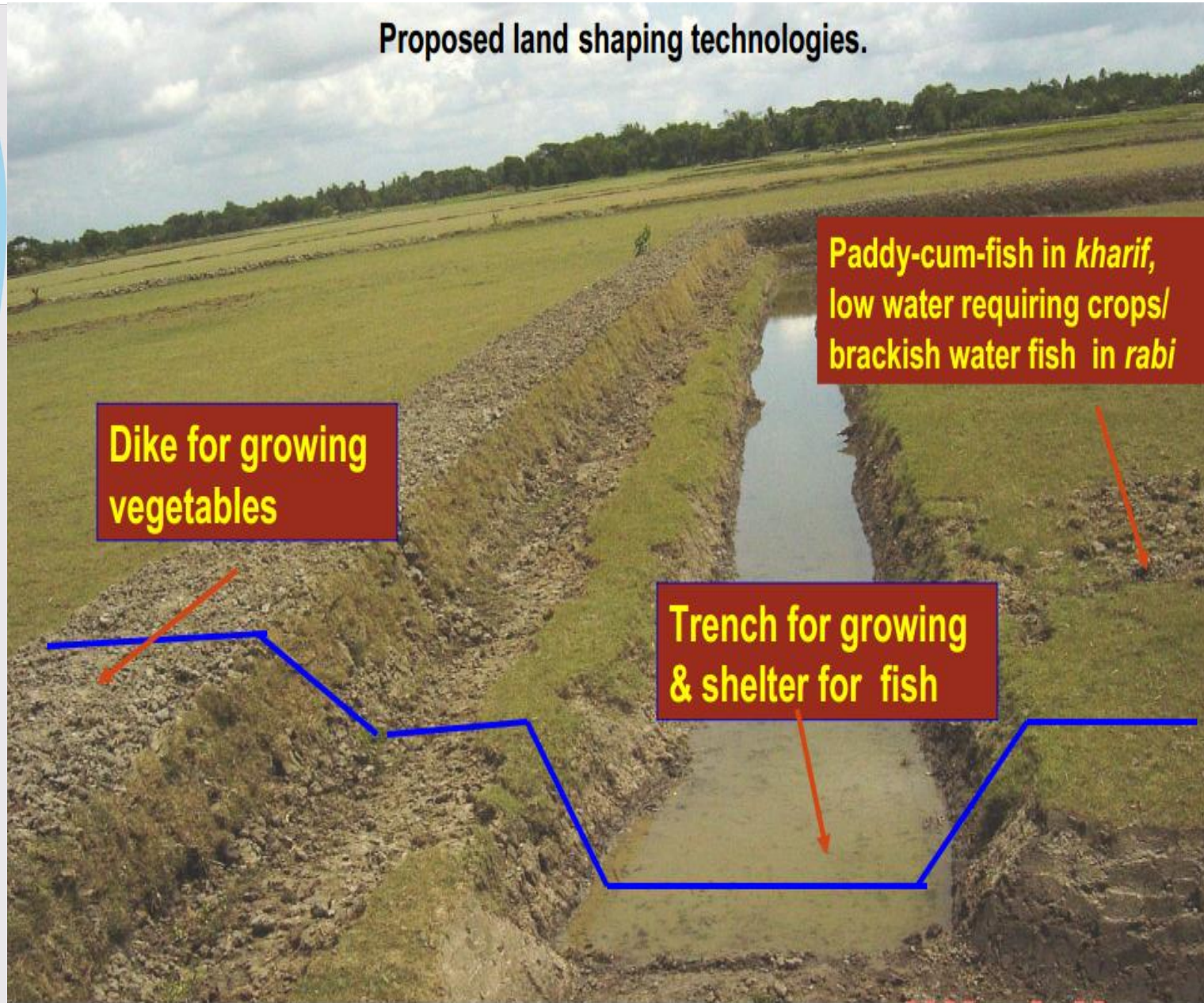
b) Ridge & furrow cultivation on saline low lands



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Proposed land shaping technologies.



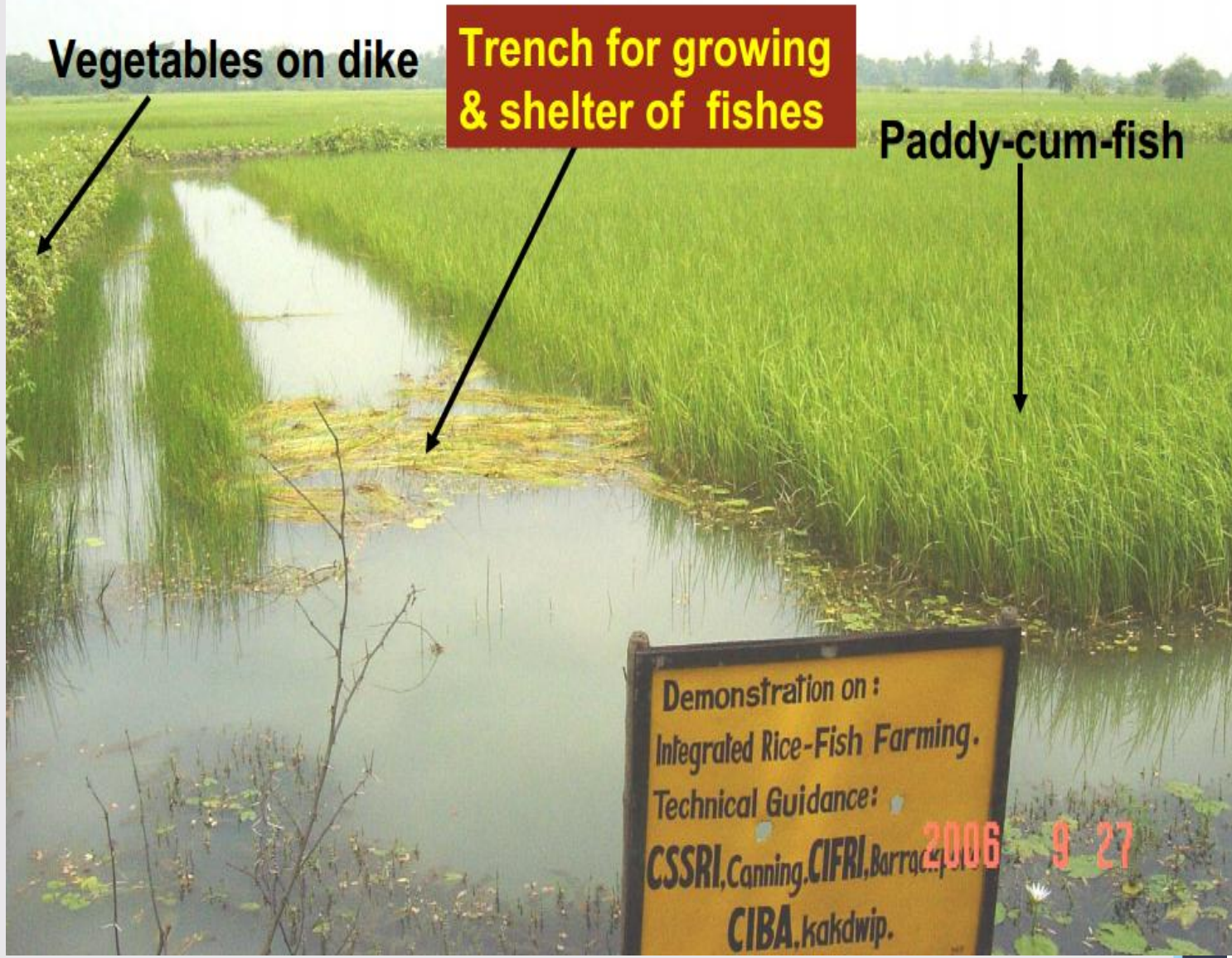
c) Land shaping for paddy cum-fish cultivation

c) Land shaping for paddy cum-fish cultivation..



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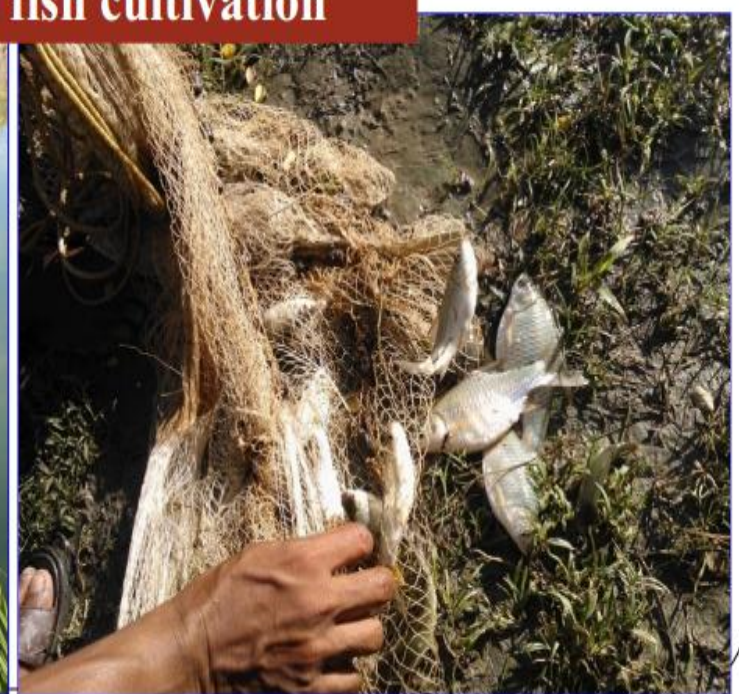
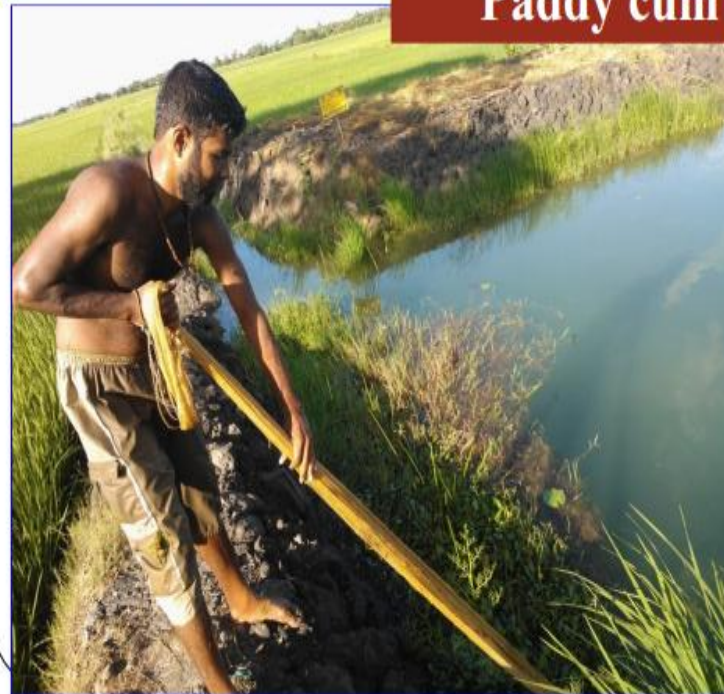


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Paddy cum fish cultivation





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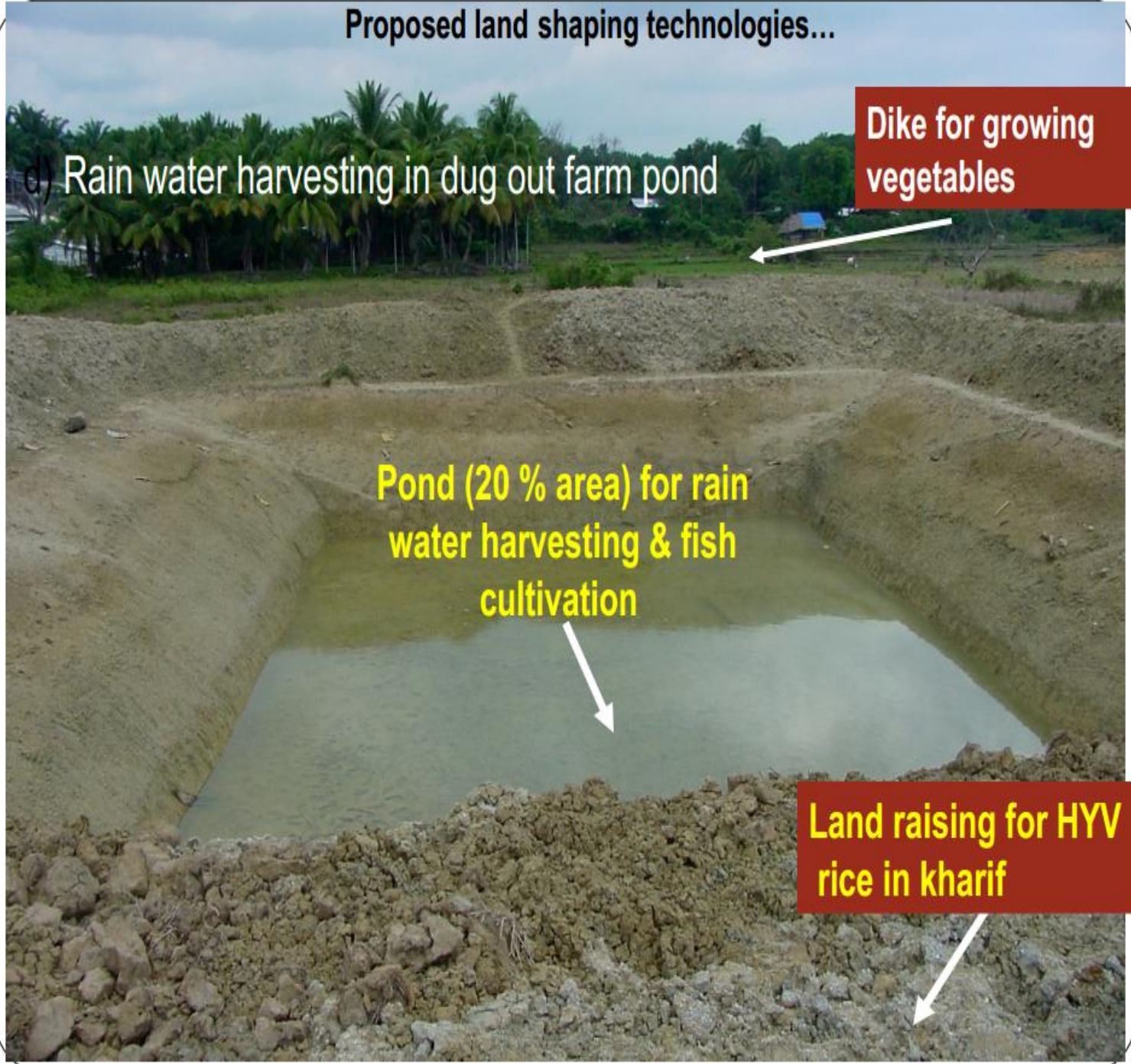
Proposed land shaping technologies...

d) Rain water harvesting in dug out farm pond

Dike for growing vegetables

Pond (20 % area) for rain water harvesting & fish cultivation

Land raising for HYV rice in kharif





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Proposed land shaping technologies



Bitter gourd (*kharif*)



Beans (*kharif*)

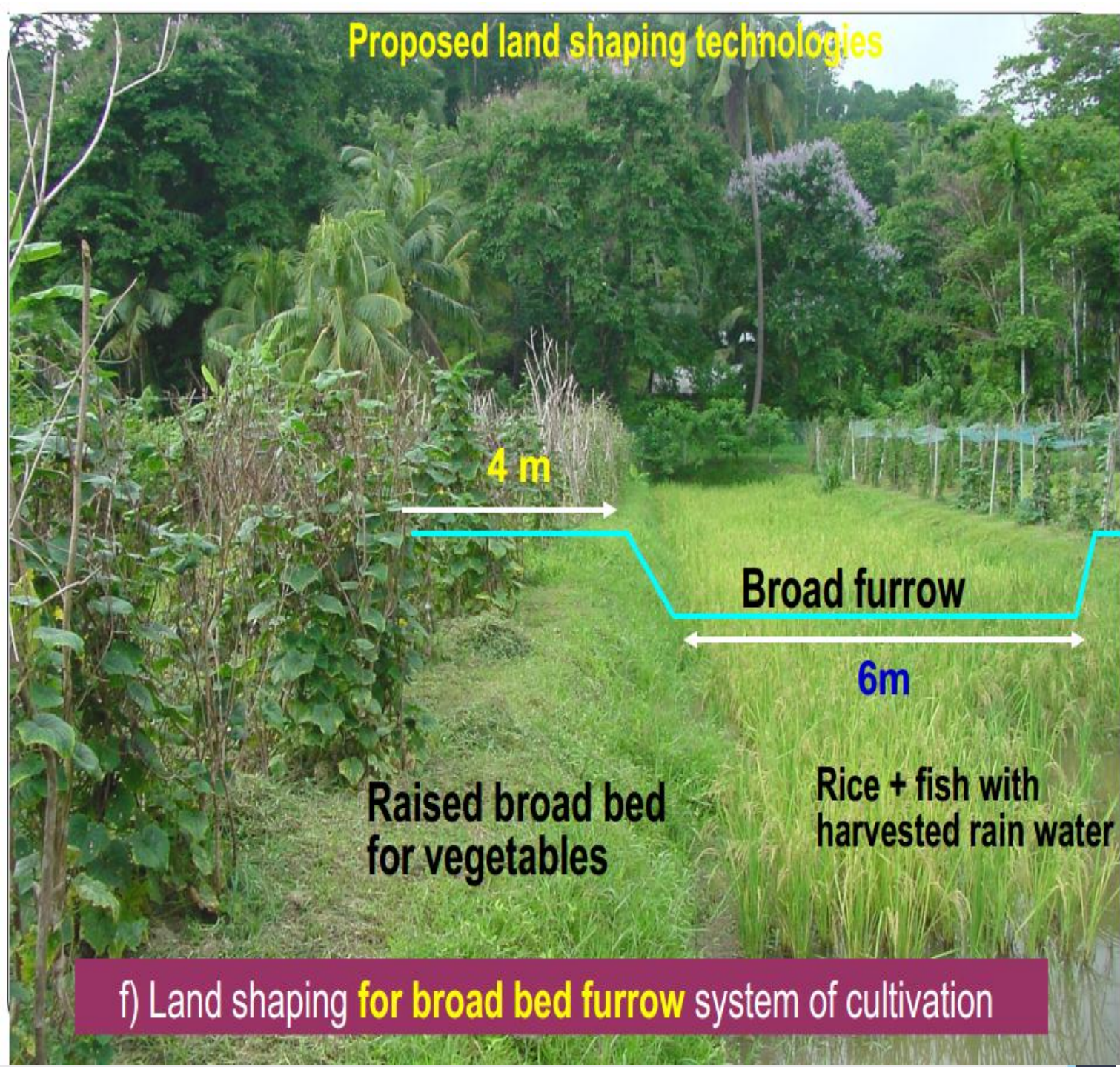
e) Land shaping for growing vegetables round the year (high to medium land)



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Proposed land shaping technologies



f) Land shaping **for broad bed furrow** system of cultivation



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Tolerance of some crops to saline conditions. Salinity expressed as EC.

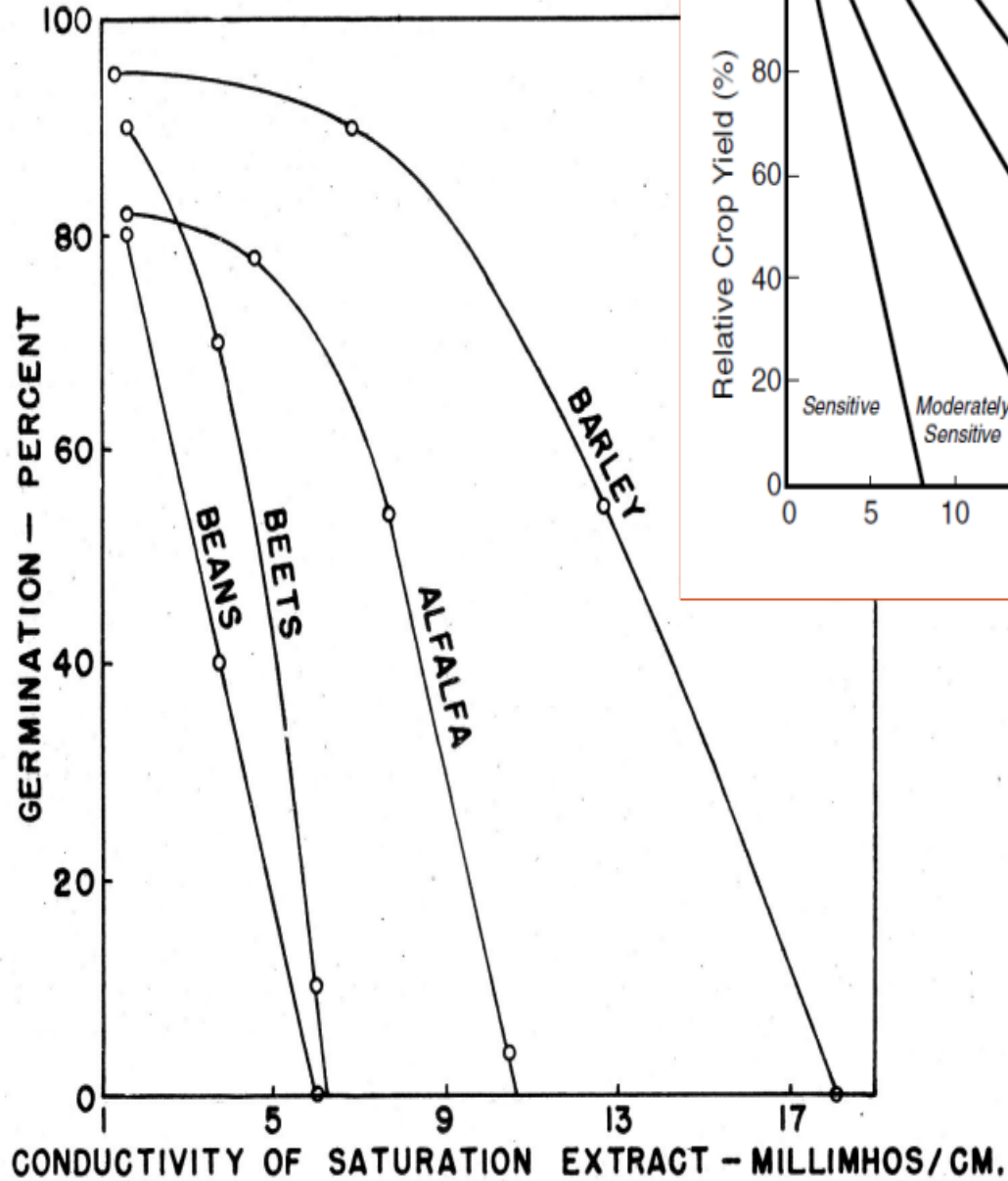
Sensitive (0-4 dS m⁻¹)	Moderately Tolerant (4-6 dS m⁻¹)
Almond	Corn
Bean	Grain Sorghum
Clover	Lettuce
Onion	Soybean
Potato	Tomato
Tolerant (6-8 dS m⁻¹)	Highly Tolerant (8-12 dS m⁻¹)
Fig	Barley
Oats	Cotton
Pomegranate	Olive
Sunflower	Rye
Wheat	Wheatgrass

Brady, N.C., 2002, *The Nature and Properties of Soils*, New Jersey, USA, Prentice Hall.

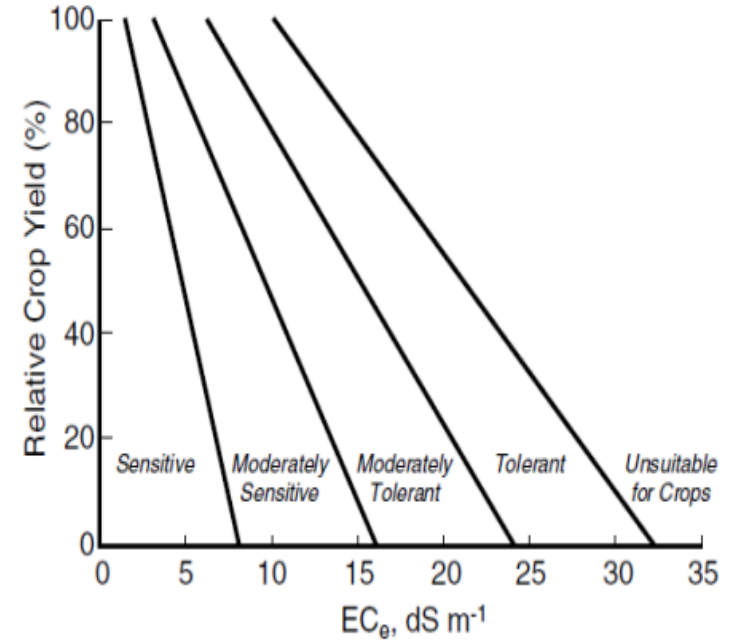


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Crop Selection





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How much salt is added to the soil in an irrigation event for a given amount of irrigation water with a given amount of salinity?

$$L_s = 1/100 L_w \times C_s$$

L_s : salt accumulated in soil (kg/ha)

L_w : hydraulic load (mm),

C_s : salt concentration in the water (mg/l)

Q. Calculate how much salt is added to a land with 100ha area, 1000 mm irrigation with the following characteristics:

- Irrigation amount (D_i) = 1000 mm/year
- Land area (A) = 100 ha
- Water salinity (C_s) = 1.25 dS/m

Ans: $L_s = 1/100(1000\text{mm})(1.25 \times 640\text{mg/L}) = 8000 \text{ kg/ha}$

$W_s = 8000 \times 100\text{ha} = 800000\text{kg} = 800 \text{ ton}$



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Mulching :

During periods of high evapotranspiration between the two irrigations and during periods of fallow there is a tendency for the leached salts to return to the soil surface.

Soil salinization is particularly **high** when the **water table is shallow** and the **salinity of groundwater is high.**

Any practices that **reduce evaporation from the soil surface** and/or **encourage downward flux of soil water** will help to control root zone salinity

Cropping sequences:

which include crops such as **rice, berseem and those requiring frequent irrigations reduce salinity effectively, where drainage is adequate.** Therefore knowledge of the **expected salt balance of the root zone under various crop rotations** will be extremely helpful in planning the best cropping sequences during and after reclamation (Massoud, 1976).

Tillage:

is another mechanical operation that is usually carried out for seed bed preparation and soil permeability improvement but **if it is improperly executed it might turn a salty soil horizon and bring it closer to the soil surface**



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For example, the total molarity of cations or anions can be estimated:

$$\text{Total cations (mmoles(+))/liter} \approx \text{EC (mS cm}^{-1}\text{)} \times 10$$

$$\text{Total anions (mmoles(-))/liter} \approx \text{EC (mS cm}^{-1}\text{)} \times 10$$

or, the quantity of "total dissolved solids" (TDS) in the form of soluble salts can be approximated:

$$\text{TDS (mg/liter)} \approx \text{EC (mS cm}^{-1}\text{)} \times 640$$

These equations are likely to apply reasonably well to soil solutions of different ionic compositions unless the pH indicates the solution to be very acid or very alkaline.