SUMMARY AND CONCLUSION

A field survey based study entitled “Studies on quality parameters of underground water with reference to availability of micronutrient in soil plant system in water logged area of Hanumangarh” was carried out. The salient findings of investigation presented (Maps-11, Figures-25 and Tables 53) and discussed in the preceding chapters are summarized as below. Conclusions derived from the results of this investigation are also presented in this chapter.

5.1 Characterization of underground irrigation water

5.1.1 The pH and EC of irrigation water samples of Hanumangarh district varied from 7.47 to 9.52 and 0.61 to 5.96 dS m\(^{-1}\), respectively in September, 2006 and 7.32 to 9.02 and 0.66 to 6.15 dS m\(^{-1}\), respectively in March, 2007.

5.1.2 Highly significant positive correlations were observed between EC with SAR and adj. SAR of irrigation water in both the seasons.

5.1.2 The SAR and RSC values of irrigation water samples ranged between 0.96 to 21.31 and nil to 4.20 me L\(^{-1}\), respectively in September, 2006 and 3.36 to 25.00 and nil to 5.60 me L\(^{-1}\), respectively in March, 2007. The SAR had highly significant positive correlation with EC, SSP and adj. SAR while RSC had highly significant positive correlation with SSP and pHc of irrigation water in both the seasons.
5.1.3 The pHc values of irrigation water samples of the area ranged between 6.75 to 8.08 and 6.72 to 8.19 in September, 2006 and March, 2007, respectively. The pHc had highly significant positive correlation with RSC and SSP while its negative correlation with EC of irrigation waters in both the seasons.

5.1.4 The Adj. SAR values of irrigation water samples of the area ranged between 3.11 to 66.01 and 11.12 to 74.40 in September, 2006 and March, 2007, respectively. The adj. SAR had highly significant positive correlation with EC, SAR and SSP of irrigation water in both the seasons.

5.1.5 The SSP values of irrigation water samples of the area ranged between 13.62 to 86.44 and 39.44 to 90.00 in September, 2006 and March, 2007, respectively. The SSP had highly significant positive correlation with clay and organic carbon in soils, RSC, SAR, pHc and adj. SAR of irrigation water in both the seasons.

5.1.6 About 38.89, 42.59, 14.81 and 3.70 per cent water samples had EC 0.2-1.5, 1.5-3.0, 3.0-5.0 and 5.0-10.0 dS m⁻¹, respectively during September, 2006 and 20.37, 57.41, 12.96 and 9.26 per cent water samples had EC 0.2-1.5, 3.0-5.0 and 5.0-10.0 dS m⁻¹, respectively during March, 2007 (Gupta, 1986).

5.1.7 About 92.59, 5.56 and 1.85 per cent water samples had SAR 5-10, 10-20 and 20-30, respectively during September, 2006 and 79.63,
14.81 and 5.56 per cent water samples had SAR 5-10, 10-20 and 20-30 respectively during March, 2007 (Gupta, 1986).

5.1.8 About 81.48, 11.11, 5.56 and 1.85 per cent water samples showed RSC nil, <2.5, 2.5-5.0 and 5-10 me L\(^{-1}\) respectively in September, 2006 and 79.63, 12.96, 5.56 and 1.85 per cent water samples showed RSC nil, <2.5, 2.5-5.0 and 5-10 me L\(^{-1}\), respectively in March, 2007 (Gupta, 1986).

5.2 Classification of irrigation water

5.2.1 According to USSL standards, the irrigation water samples were classified into five classes viz., C\(_2\)S\(_1\), C\(_3\)S\(_1\), C\(_4\)S\(_1\), C\(_4\)S\(_2\) and C\(_4\)S\(_3\) in September, 2006 and six classes viz., C\(_2\)S\(_1\), C\(_3\)S\(_1\), C\(_3\)S\(_2\), C\(_4\)S\(_1\), C\(_4\)S\(_2\) and C\(_4\)S\(_3\) in March, 2007 (Here C denotes EC while S denotes SAR).

5.2.2 On the basis of EC and Adj. SAR, the irrigation water samples were categorized into 13 classes viz., A\(_1\)C\(_1\), A\(_2\)C\(_1\), A\(_3\)C\(_1\), A\(_4\)C\(_1\), A\(_5\)C\(_1\), A\(_1\)C\(_2\), A\(_2\)C\(_2\), A\(_3\)C\(_2\), A\(_4\)C\(_2\), A\(_5\)C\(_2\), A\(_4\)C\(_3\) and A\(_5\)C\(_3\), in September, 2006 and 12 classes in viz., A\(_1\)C\(_1\), A\(_2\)C\(_1\), A\(_3\)C\(_1\), A\(_2\)C\(_2\), A\(_3\)C\(_2\), A\(_2\)C\(_3\), A\(_3\)C\(_3\), A\(_4\)C\(_3\), A\(_5\)C\(_3\) and A\(_5\)C\(_4\) March, 2007.

5.2.3 The irrigation water samples of Hanumangarh district were classified into 4 salinity classes (C\(_1\), C\(_2\), C\(_3\) and C\(_4\)), 3 sodicity classes (S\(_1\), S\(_2\) and S\(_3\)) and 4 alkalinity classes (A\(_0\), A\(_2\), A\(_3\) and A\(_4\)).

5.2.4 On the basis of water quality criteria of Gupta et al. (1994) about 50.00 per cent underground water samples were free from salinity...
and alkalinity and were found suitable for irrigation to all the crops under agro-climatic conditions of IGNP irrigated north west plain zone of Hanumangarh district (Rajasthan), whereas, 33.33 per cent underground water samples were found marginally saline, 3.70 per cent showed the salinity and high SAR saline 5.56 per cent. Marginally alkaline, alkaline and highly alkaline water samples were found 3.70, 1.85 and 1.85 per cent, respectively during September, 2006. During March, 2007, 33.33 per cent underground water samples were free from salinity and alkalinity and 38.89 per cent under ground water samples were found marginally saline and 1.85 per cent showed the salinity and 16.67 per cent high SAR saline, 3.70 per cent marginally alkaline and 5.55 per cent highly alkaline and none water sample was found alkaline, respectively.

5.3 Seasonal variations in characteristics of irrigation water

The increase in EC, SAR and RSC values of irrigation water of Hanumangarh district after monsoon period were of the tone of 13.39, 29.36 and 0.51 per cent, respectively, which shows improvement in the quality of underground irrigation water after monsoon period.

5.4 Soil Characterization

5.4.1 Physical parameters

5.4.1.1 The soils of Hanumangarh district were found sandy loam, clay loam and loamy sand in texture. In general, soils of the study area are mostly sandy loam in nature.
5.4.1.2 The sand, silt and clay content of surface and subsurface soils of Hanumangarh district ranged between 47.2 to 88.0, 45.0 to 86.9 and 0.40 to 14.6 during September, 2006 and 4.1 to 15.4, 5.9 to 34.7 and 6.8 to 35.4 per cent during March, 2007.

5.4.1.3 Highly significant negative correlation were found between sand with silt and clay contents of soils in both surface and subsurface soils in both the seasons.

5.4.2 Chemical parameters

5.4.2.1 The pH of soils of the study area varied from 7.84 to 9.52 and 7.82 to 9.76 in September, 2006 and 7.80 to 9.63 and 7.86 to 9.24 in March, 2007 for surface and subsurface soils, respectively. Most of the soils (92.13 per cent) of the study area were found alkaline in nature.

5.4.2.2 A significant positive correlation was obtained between pH of subsurface soils and pH of irrigation water.

5.4.2.2 Electrical conductivity of the soil ranged from 0.12 to 1.27 and 0.14 to 1.20 dS m\(^{-1}\) in September, 2006, 0.06 to 3.36 and 0.05 to 2.02 in March, 2007 for surface and subsurface soils, respectively. Highly significant positive correlation was obtained between EC\(_2\) of soils and SAR in both surface and sub-surface soils in both the seasons. Similarly lightly significant correlation was also obtained between EC\(_2\) of soils and ESP in both surface and sub-surface soils in both the seasons.
5.4.2.3 The CaCO₃ status of soils of study area ranged between 2.20 to 27.60 and 2.20 to 28.40 per cent for surface and subsurface soils, respectively in September, 2006 and 3.20 to 35.20 and 4.40 to 33.60 per cent in March, 2007.

5.4.2.4 The SAR of soils of Hanumangarh district varied from 0.50 to 4.99 and 1.44 to 4.83 in September, 2006, 0.74 to 8.12 and 0.78 to 6.42 in March, 2007 in the surface and subsurface soils, respectively.

5.4.2.5 The ESP of soils of Hanumangarh district varied from -0.52 to 5.75 and 0.86 to 5.54 in September, 2006, -0.17 to 9.68 and -0.10 to 7.58 in March, 2007 in the surface and subsurface soils, respectively.

5.4.2.6 The SSP of soils of Hanumangarh district varied from 20.69 to 71.33 and 52.07 to 69.49 in September, 2006, 50.23 to 78.56 and 51.43 to 75.06 in March, 2007 in the surface and subsurface soils, respectively.

5.4.3 Salinity and sodicity indices of soils

5.4.3.1 The calculated values of the salinity and sodicity indices for soils of Hanumangarh district are 1.04 and 2.87 for surface, 1.04 and 2.92 for subsurface soils during September, 2006 and 1.09 and 2.90 for surface and 1.04 and 2.92 for subsurface soils during March, 2007. Thus, these soils have no salinity and moderate alkalinity problem.

5.4.3.2 On the basis of EC and pH of surface and subsurface soils, soils of Hanumangarh district were classified into three salinity and
sodicity groups as suggested by Sehgal et al. (1987). The majority of surface (37.00%) and subsurface (44.49%) soils fell under the VsSt (very slight salinity and strong sodicity), whereas, only 29.63 and 31.48 per cent under the VsS (very slight salinity and slight to negligible sodicity) and 33.33 and 24.07 per cent under VsM (very slight salinity and moderate sodicity) groups, respectively in September, 2006 and during March, 2007, surface (61.11%) and subsurface (66.67%) soils fell under the VsM (very slight salinity and moderate sodicity), groups 12.96 and 12.96 per cent under the VsS (very slight salinity and slight to negligible sodicity) and only 22.22 and 18.52 per cent under VsSt (very slight salinity and strong sodicity), respectively.

5.4.4 Fertility parameters

5.4.1 The organic carbon content of these soils generally have been found low. The values of organic carbon ranged from 0.14 to 0.57 and 0.14 to 0.47 per cent for surface and sub surface soils, respectively in September, 2006 and 0.06 to 0.45 and 0.00 o 0.39 per cent in March, 2007.

5.4.2 The organic carbon content was found to have significant and positive correlation with Fe and Cu.

5.4.3 The calculated values of the fertility indices for soils of study area are 1.03 and 1.00 for organic carbon in September, 2006, 1.00 and 1.00 in March, 2007 in surface and subsurface soils, respectively.
5.4.5 Soil micronutrient

5.4.5.1 About 66.67 and 64.81 per cent surface and subsurface samples in September, 2006, 55.56 and 77.78 per cent samples in March, 2007 were found deficient in available iron while, 33.33 and 35.19 per cent samples in September, 2006, 44.44 and 22.22 per cent samples in March, 2007 were found sufficient in available iron in surface and subsurface soils, respectively.

5.4.5.2 About 83.33 and 85.19 per cent samples in September, 2006, 77.78 and 77.78 per cent samples in March, 2007 were found deficient in available Mn. 16.67 and 14.81 per cent samples in September, 2006, 22.22 and 22.22 per cent samples in March, 2007 were found sufficient in available manganese in surface and subsurface soils, respectively.

5.4.5.3 About 77.78 and 74.07 per cent samples fell in the category of deficient, 1.85 and 7.41 per cent samples fell in marginal, 20.37 and 18.52 per cent samples fell in the category of sufficient in available zinc content in the surface and subsurface soils, respectively in September, 2006 while, 74.07 and 77.78 per cent samples fell in the category of deficient, 5.56 and 20.37 per cent samples fell in marginal, 20.37 and 1.85 per cent samples fell in the category of sufficient in available zinc content in the surface and subsurface soils, respectively in March, 2007.
5.4.5.4 Copper was found sufficient in all the surface and subsurface soil samples for both the seasons of the studied area.

5.4.5.5 The soil and plant nutrients are positively correlated with each other.

5.4.6 Plant micronutrient

5.4.6.1 The range value of iron content in plants of Hanumangarh district was found 24.4 to 219.40 ppm in September, 2006, while, in March, 2007, the range value of available iron content in plants was found 22.2 to 180.8 ppm.

5.4.6.2 The range value of manganese content in plants of Hanumangarh district was found 5.0 to 50.6 ppm in September, 2006, while, in March, 2007, the range value of available manganese content in plants was found 3.8 to 48.2 ppm.

5.4.6.3 The range value of zinc content in plants of Hanumangarh district was found 12.0 to 33.6 ppm in September, 2006, while, in March, 2007, the range value of available zinc content in plants was found 11.0 to 27.8 ppm.

5.4.6.4 The range value of copper content in plants of Hanumangarh district was found 5.6 to 10.48 ppm in September, 2006, while, in March, 2007, the range value of available copper content in plants was found 5.20 to 8.40 ppm.
5.4.6.5 About 67.69 and 32.31 per cent plant samples in September, 2006, 66.67 and 33.33 per cent samples in March, 2007 were found deficient and sufficient in iron, respectively.

5.4.6.6 About 83.08 and 16.92 per cent plant samples in September, 2006, 77.14 and 22.86 per cent samples in March, 2007 were found deficient and sufficient in Mn, respectively.

5.4.6.7 About 84.62 and 15.38 per cent plant samples in September, 2006, 93.33 and 66.67 per cent samples in March, 2007 were found deficient and sufficient in zinc, respectively.

5.4.6.8 Copper was found sufficient in all plant samples for both the seasons of the studied area.

CONCLUSION

The majority of irrigation water samples of the studied area were found in good and marginally saline classes. However, the soils of the area had shown very slight salinity to moderate salinity problem. Fertility status of the soils belongs to low for organic carbon. Among the micronutrients only copper was observed sufficient.

Identification of major management units based on soil and irrigation water characteristics

On the basis of study of soil and water characteristics, it can be inferred that salinity and alkalinity of soils and saline irrigation water are
the principle constraints affecting crop production in the area. Hence, the following management units can be formed-

Unit –I : High SAR saline water - very slight salinity and strong alkaline soils (HSS-Vs.St.)

Unit –II : High SAR saline water - very slight salinity and moderate alkaline soils (HSS-Vs.M.)

Unit –III : Highly alkaline water - very slight salinity and strong alkaline soils (HA-Vs.St.)

Unit -IV : Highly alkaline water – very slight salinity and moderate alkaline soils (HA – Vs.M.)

The details of management practices are as follows -

**Unit – I HSS-Vs.St.**

1. Light and frequent irrigation should be applied to keep the plant root zone moist.

2. Sprinkler or drip irrigation may be better methods to reduce the salinity and sodicity hazards and scarcity of water.

3. Addition of organic manures like farm yard manure (FYM), compost, green manuring etc. at least once in a three years for sustaining crop production.

4. Foliar application of micronutrients especially iron and zinc, because soil application may not be much beneficial as soils are alkaline in nature.
5. Establishment of silivopastoral system and adoption of stubble mulching, strip cropping, field bunding and increased stands of beneficial trees.


7. Periodic monitoring of gypsum application and removal of accumulated salts is necessary.

8. Gypsum application @ 50% gypsum requirement (G.R.) in the powdered form about 10-15 days before sowing and it should be mixed thoroughly in the soil up to the depth of 10-15 cm soil.

9. Proper land leveling, bunding and deep ploughing of the field should be done to ensure uniform leaching of salts.

10. Fertilizers should be applied @ 1.25 times of the recommended dose along with 10 tonnes of FYM per hectare.

11. As a safe guard against poor germination and mortality, reduced inter/intra row spaces, use 10-25 per cent more seed rate than the recommended one.

**Unit – II HSS – Vs.M.**

1. Proper land leveling, bunding and deep ploughing of the field should be done to ensure uniform leaching and drainage of water.
2. Gypsum should be applied @ 50 per cent G.R. in the powder form about 10-15 days before sowing and it should be mixed thoroughly in the soil upto the depth of 10-15 cm.

3. Pearl millet (RHB- 60, MH- 419, HHB-60) can be grown after arrival of good monsoon rains and minimum supplemental irrigation should be given.

4. In *rabi*, after application of 5 tonnes FYM and 2 tonnes gypsum per hectare barley (Ratna, RL-345, K-169), mustard (Pusa Bold, CS-416) can be grown.

5. 25 per cent higher seed rate and recommended dose of nitrogen and phosphorus should be applied.

6. Periodic monitoring of gypsum application and removal of accumulated salts is necessary.

7. Light and frequent irrigation should be applied to keep the plant root zone moist.

8. Sprinkler or drip irrigation may be better methods to reduce the salinity and sodicity hazards and scarcity of water.

9. Addition of organic manures like FYM, compost, green manuring etc. at least once in a three years for sustaining crop production.

10. Foliar application of micronutrients especially iron and zinc, because soil application may not be much beneficial as soils are alkaline in nature.

11. Establishment of silivopastoral system and adoption of stubble mulching, strip cropping, field bunding and increased stands of beneficial trees.
1. Proper land leveling, bunding and deep ploughing of the field should be done to ensure uniform leaching and drainage of water.

2. Apply additional dose of gypsum according to RSC neutralization along with 50 per cent G.R.

3. Fertilizers should be applied @ 1.25 times of the recommended dose along with 10 tonnes of FYM per hectare.

4. 10-25 per cent more seed than recommended seed rate should be shown as a safe guard against poor germination

5. Pearlmillet (MH – 419, RHB – 90, HHB -60), clusterbean (H -75), mustard (Bio – 902, Pusa Bold, Kranti and T-59) can be grown after good monsoonal rains and minimum supplemental irrigation should be given.


7. For better germination, seed should be presoaked in 1% CaCl₂ solution for 16 hours before sowing

8. Nitrogenous fertilizers should be applied in split doses through Calcium Ammonium Nitrate (CAN), ammonium sulphate and phosphorus through single super phosphate.

9. Foliar application of micronutrients especially iron and zinc, because soil application may not be much beneficial as soils are alkaline in nature.

336
Unit- IV HA-VsM

1. Proper land leveling, bunding and deep ploughing of the field should be done to ensure uniform leaching and drainage of water.

2. Apply additional dose of gypsum according to RSC neutralization along with 50 per cent G.R.

3. Fertilizers should be applied @ 1.25 times of the recommended dose along with 10 tonnes of FYM per hectare.

4. For better germination, seed should be presoaked in 1% CaCl₂ solution for 16 hours before sowing.

5. Nitrogenous fertilizers should be applied in split doses through CAN, ammonium sulphate and phosphorus through single super phosphate.

6. Low water requiring and alkali tolerant crops such as pearl millet, mustard, barley should be grown.

7. Periodic monitoring of salt in soil is necessary.

8. Foliar application of micronutrients especially iron and zinc, because soil application may not be much beneficial as soils are alkaline in nature.

Management of micronutrients deficiency in plants

Though adequate amount of any micronutrient may be present in saline and alkali soils but the availability of that nutrient to the growing plant is less because of salinization and alkalinization. Besides this, pH of saline and alkali soils is more than 7.0 that is alkaline in nature which reduces the availability of cationic micronutrients due to the formation of...
their insoluble hydroxides and carbonates. Due to these reasons, majority of the soil samples of the area were found deficient in micronutrients except copper. The following management practices are suggested for overcoming deficiency of plant micronutrients -

1. As a first step towards overcoming deficiency, an assessment of available micronutrient content in the soils of studied area was carried out and on the basis of results, mapping of micronutrient deficient area was done.

2. The concentration of iron in the plant tissue with the increase in manganese in the culture medium/soil and vice versa. Iron deficiency has been found to be identical with manganese excess and iron excess with manganese deficiency. It is the level of these nutrients and not their ratios, are important in the context of crop yields. Balance application of manganese and iron should be given in the deficient soils before sowing.

3. Following addition of manganese fertilizer, the readily available manganese decreases with increase in time and moisture level, but reducible manganese was not affected. Transportation of added manganese to non-exchangeable form was more quicker in sandy soil than in heavy and medium soils. It is inferred that clay surface does not play any important role in the transformation but aeration along with some soil factors seem to be effective in transforming manganous Mn to higher oxidation states.

4. Ferrous sulphate, ferric sulphate, ferrous carbonate, ferrous oxide, ferrous ammonium sulphate, Fe-DTPA, Fe-EDTA, Fe-EDDHA, Fe-HEDTA, Lignin sulphonate, Methoxy phenylpropane complex,
polyflavonoid should be applied in iron deficient soil before sowing of crop along with recommended dose of NPK fertilizers.

5. Manganese sulphate, manganous oxide, manganese carbonate, manganese chloride, manganese phosphate, manganese oxide, manganese fritis, Mn-EDTA, Manganese methoxyphenyl propane should be applied in manganese deficient soil before sowing of crop along with recommended dose of NPK fertilizers.

6. Zinc sulphate, zinc oxide, zinc chloride, zinc carbonate, zinc ammonium phosphate, zinc fritis, Zn-EDTA, Zn-HEDTA, Zn-NTA, Zn-Lignin sulphonate, Zn-poly flavonoid, Zn-humic acid and Zn-fulvic acid should be applied in zinc deficient soil before sowing of crop along with recommended dose of NPK fertilizers.

7. The deficiency of zinc, iron and manganese can also be corrected in standing crops by spraying 0.5 to 1.0 per cent solutions of zinc sulphate, ferrous sulphate and manganese sulphate, respectively on crops.

8. The spray can be repeated after 15 days interval if deficiency of these micronutrients is further observed.

In horticultural crops (ber, kinnow) the deficiency of these micronutrients can be met out by soil application as well as foliar application.

**General Suggested management practices for sustainable crop production**

These management practices can be dealt under the following headings –
(I) Water

Crop growth with saline water is adversely affected with saline water and it is primarily due to excess salts or osmotic pressure of soil solution resulting in reduced availability of water to plants. It may also be due to excessive concentration and absorption of individual ions like chloride, sodium, boron etc. The detrimental effect of salinity includes poor germination, reduced initial growth, resulting in smaller plants. Continuous use of saline water without adequate leaching of salts make the soil saline while continuous use of sodic water without using amendments and adopting management practices make the soil alkaline.

The water falling in the category—good, can be used safely in all types of soils and crops. The water that is marginally saline can be used in the area having coarse textured soil. The ground water categorized as marginally alkaline, can be used effectively with gypsum application. The water categorized as saline, high SAR-saline and highly alkaline are not suitable for normal irrigation.

However, American cotton (RST-9) and Desi cotton (RG8 and HD-123), wheat (Raj.3077), barley (BL-2) and mustard (Kranti) can be grown after good monsoon rains with supplemental irrigation with poor quality water as and when required.

(i) Cultural practices

In general, cultural practices like land leveling, grading, smoothing, dry seeding followed by quick post-sowing, irrigation with saline water,
placement of seeds at right place and in right direction, increases the crop performance under salinity constraint. Application of organic manures and crop residues, mitigate the adverse effect of saline water apart from increasing the efficiency of the applied inorganic fertilizers. Light and frequent irrigation minimizes the accumulation of salts whereas longer irrigation intervals induce salinity in upper layer of soil.

(ii) Crop and varieties

When salt accumulate in root zone in excessive amount, the crop suffers from water stress for a significant period of time leading to reduction in yield. Under this situation, less water requiring and short duration crops are found suitable Salt tolerant crops and varieties, as mentioned below should be grown in proper sequence-

<table>
<thead>
<tr>
<th>Crop</th>
<th>Genotypes / varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desi Cotton</td>
<td>RG-7, HD-123</td>
</tr>
<tr>
<td>American cotton</td>
<td>RST-9</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>HHB-60, MH-419, RHB-90</td>
</tr>
<tr>
<td>Clusterbean</td>
<td>HG-75, RGC-978, GAUG-3, Durgapura Safed, GAUG-14, RGC-471</td>
</tr>
<tr>
<td>Castor</td>
<td>RCH-1</td>
</tr>
<tr>
<td>Wheat</td>
<td>Raj-3077, KRL-1-4, K-65</td>
</tr>
<tr>
<td>Barley</td>
<td>BL-2, RS-17 and RS-6</td>
</tr>
</tbody>
</table>
(iii) Conjunctive use of water

Saline water in conjunction with good quality water can be used if one or two irrigation of good quality water is applied at the initial stages rather than at later stages.

In cyclic mode, one or two irrigation with canal water at early stage of plant growth is followed by saline water at later stages compared to all irrigation with saline water. Thus it consists in mixing saline water with good quality water so that EC and SAR could be reduced to a desired extent. This would increase the total quantity of water available for irrigation but at the same time saves good quality of water.

(iv) Irrigation management

The frequency of irrigation markedly affects the response to saline water. Increasing frequency of irrigation with saline water by surface irrigation add the salt load of soil, provided the quantity of water applied for each irrigation is also simultaneously adjusted according to crop water need, which is possible only by use of sprinkler and other micro irrigation systems like drip or trickle. In these systems, salt build up in the vicinity of root zone remains always lower than for surface irrigation, and the difference increases with the increase of salinity of irrigation water.

Further, the sprinkler irrigation with saline water during periods of high humidity, such as nights, greatly reduces or eliminates the problem of salt damage. The sprinkler system is more effective in leaching of saline
soils, as leaching efficiency is higher under sprinkler due to controlled rate of application and movement of water through micro pores.

Thus light and frequent irrigation should be applied to keep the soil moist.

(II) Saline and alkaline soils

Several physical, chemical and biological soil management measures help facilitate the safe use of saline water in crop production. Some important ones in this regard are: tillage, deep ploughing, sanding, use of chemical amendments & soil conditioners, organic & green manuring and mulching.

(i) Tillage

Tillage is a mechanical operation that is usually carried out for seedbed preparation, soil permeability improvement, to break up surface crusts and to improve water infiltration. If tillage is improperly executed, it might form a plough layer or bring a salty layer closer to the surface. Sodic soils are especially subject to puddling and crusting; they should be tilled carefully and wet soil conditions are avoided. Heavy machinery traffic should also be avoided. More frequent irrigation, especially during the germination and seedling stages, tends to soften surface crusts on sodic soils and encourages better stands

(ii) Deep ploughing

Deep ploughing refers to depths of ploughing from about 40 to 150 cm. It is most beneficial on stratified soils having impermeable layers lying
between permeable layers. In sodic soils, deep ploughing should be carried out after removing and reclaiming the sodicity, otherwise it will cause complete disturbance and collapse of the soil structure. Deep ploughing upto 60 cm, loosens the aggregates, improves the physical condition of these layers, increases soil-water storage capacity and helps control salt accumulation when using saline water for irrigation. Crop yield can markedly be improved by ploughing to this depth every three or four years. The selection of the right plough types (shape and spacing between shanks), sequence, ploughing depth and moisture content at the time of ploughing should provide good soil tilth and improve soil structure. Special equipment can even invert whole soil profile or break up substrata as deep as 2.5 m that impede deep percolation, so that many adverse physical soil conditions associated with land, irrigated with saline water can be modified in order to improve leachability and drainability.

(iii) Sanding

Sanding is used in some cases to make a fine textured surface soil more permeable by mixing sand into it, thus a relatively permanent change in surface soil texture is obtained. When properly done, sanding results in improved root penetration and better air and water permeability which facilitates leaching of saline sodic water when surface infiltration limits water penetration. The method can be combined with initial deep ploughing.
(iv) Chemical amendments

Chemical amendments are used to neutralize soil reaction, to react with calcium carbonate and to replace exchangeable sodium by calcium. This decreases the ESP and should be followed by leaching for removal of salts derived from the reaction of the amendments with sodic soils. They also decrease the SAR of irrigation water if added in the irrigation system. Gypsum is by far the most common amendment for sodic soil reclamation, particularly when using saline water with a high SAR value for irrigation. Calcium chloride is highly soluble and is a satisfactory amendment especially when added to irrigation water.

(v) Mineral fertilizers

Salt accumulation affects nutrient content and availability for plants in one or more of the following ways: by changing the form in which the nutrients are present in the soil; by enhancing loss of nutrients from the soil through heavy leaching or as in nitrogen, through denitrification, or by precipitation in soil; through the effects of non-nutrient (complementary) ions on nutrient uptake; and by adverse interactions between the salt present in saline water and fertilizers, decreasing fertilizer use efficiency.

Crop response to fertilizer under saline or sodic conditions is complex since it is influenced by many soil, crop and environmental factors. The benefits expected from using soil management measures to facilitate the safe use of saline water for irrigation will not be realized unless adequate, but not excessive, plant nutrients are applied as
fertilizers. The level of salinity may itself be altered by excess fertilizer application as mineral fertilizers are for the most part soluble salts. The type of fertilizer applied, when using saline water for irrigation, should preferably be acid and contain Ca rather than Na taking into consideration the complementary anions present. Timing and placement of mineral fertilizers are important and unless properly applied they may contribute to or cause a salinity problem.

(vi) Organic manure and mulching

Incorporating organic matter into the soil has two principal beneficial effects on soils irrigated with saline water with high SAR and on saline sodic soils: improvement of soil permeability and release of carbon dioxide and certain organic acids during decomposition. This will help in lowering soil pH, releasing calcium by solubilization of CaCO₃ and other minerals, thereby increasing ECₑ and replacement of exchangeable Na by Ca and Mg which lowers the ESP. Growing legumes and using green manure will improve soil structure.

Mulching, to reduce evaporation losses will also decrease the opportunity for soil salinization. When using saline water where the concentration of soluble salts in the soil is expected to be high in the surface, mulching can considerably help leach salts, reduce ESP and thus facilitate the production of tolerant crops. Thus, whenever feasible, mulching to reduce the upward flux of soluble salts should be encouraged.
(vii) Leaching

Leaching of saline soils is essentially a process, where by water of low concentration is applied to displace the soil solution of relatively high concentration. The application of the excess water to pass through the root zone with the aim of pushing the salts below the root zone, while saline soils could be reclaimed through leaching alone, alkaline soils require application of an amendment to replace Na ions by a more favourable ion, the Ca on the exchange complex. Therefore, leaching in amended alkaline soils is not only required to transport the applied chemical constituent of the amendment to the site of exchange, but also to transport the exchanged ion and soluble salts below the root zone. Gypsum and pyrites are applied as amendments to reclaim alkaline soils.

(viii) Salt tolerant crops/varieties

It would be desirable to grow following salt tolerant crops and their varieties-

(i) Bajra – PHB-12, PHB-14, PHB-50, BJ-104
(iii) Barley – Amber, Jyoti, Ajad, DL-88, DL-3, RD-137
(iv) Mustard – T-59, Pusa bold, PR-10

The following alkali tolerant crops and their varieties should be grown -

(i) Bajra – HB-3, PHB-10, PHB-50, HS-1
(ii) Cotton – Kh-33/1146, G-27, J-34, Krisna
(iv) Barley – Vijay, Ratana, DL-88, DL-120, RD-113
(v) Mustard – T-59, RL-18

(IX) Cultural practices

As a safeguard against poor germination and mortality, 10-25 per cent more seed than recommended seed rate should be sown. For better germination, seeds should be presoaked in 3 per cent Na₂SO₄ or 15 per cent common salt solution for 18 hours before sowing. For alkaline soils seeds should be presoaked in 1 per cent CaCl₂ solution for 16 hours to ensure better germination and seed rate should be kept 10-25 per cent more than recommended. Direction of the ridge should be kept North-East to South-West and seed should be sown on the North-East slope of ridges.

(X) Agronomical practices

To keep the land fallow during the monsoon season so that salts accumulated during the winter season are leached out making the soil fit for growing the next winter crop.