Chapter 4
Irrigation Systems and Zones of Salinity Development

Mohammad Zaman, Shabbir A. Shahid, and Lee Heng

Abstract Selection of suitable irrigation systems (drip-surface and subsurface, sprinkler, bubbler, furrow etc.) for irrigated agriculture is one way of improving water use efficiency and to manage root zone salinity. These irrigation systems develop salinity zones differently which needs to be understood for various reasons, such as where to place the seed for good germination and where to apply leaching to maintain the root zone salinity below crop threshold salinity level. In this chapter emphasis have been made to describe various irrigation systems and zones of salinity development under each system. In surface irrigation system (flood, surge, sprinkler, bubbler) the maximum salinity is developed in deeper layers based on the wetting front and the lowest salinity is at the surface. Drip irrigation is often preferred to sprinkler irrigation for species with a high sensitivity to leaf necrosis. In surface drip irrigation salts concentrate along the perimeters of the expanding wetting soil zone, with the lowest salt concentrations occurring in the immediate vicinity of the water source, the highest at the soil surface, and in the very center of any two drippers, i.e. at the boundary of the volume of wetted soil. In the subsurface drip irrigation, the salts continuously buildup at the soil surface through an upward capillary movement from the buried irrigation lines during growing season, therefore the concept of leaching requirement (LR) does not work specially to leach the salts from surface above the buried drip lines. In furrow irrigation system maximum salts accumulate in ridges of soil between the furrows. The salt accumulation in furrow irrigation using different bed shapes (flat top bed, sloping beds) is shown in different figures giving guidelines to the farmers to place seeds in safe zone to accomplish high germination rate. Following the salinity development zones, various methods of salinity management are described. Relative crop salinity tolerance rating is described briefly. Prediction of crop yield in salinized farms compared to non-saline farms is also described using Maas and Hoffman equation.

Keywords Irrigation systems · Sprinkler · Drip · Surge · Salinity development zones · Salinity tolerance · Maas and Hoffman

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1 Introduction

In arid and semi-arid regions, the major constraints to agriculture are water and arable land scarcity, harsh climatic conditions, and poor water use efficiency. This often necessitates the use of saline/brackish water to partially supplement the normal water requirements of crops. In order to minimize the effects of saline water on salinity in the root-zone soil, a suitable irrigation method must be selected, one which does not raise soil salinity hazards. The irrigation method chosen for a particular farm/field is determined by the depth of irrigation water applied, water losses by leaching and runoff, zones of salt accumulation, and the uniformity of applying the irrigation water.

Broadly, surface irrigation systems can be divided into two main classes: ***gravity flow surface irrigation*** (flood, border, surge, furrow, etc.), and '***pressurized flow irrigation***'. The practice of surface irrigation is predominant and covers nearly 95% of the world's irrigated areas. The sustainability of surface irrigation depends on the use of innovative methods, ones which are appropriate for different irrigation systems and result in a wide adoption by farmers. Sprinkler and trickle irrigation together represent the broad class '*pressurized*' irrigation methods. In trickle irrigation, the water is carried in a pipe system to the point of irrigation, where the water is finally made available to the root system for uptake by plants. Surface irrigation can lead to heavy losses through leaching while being conveyed to (and at the point of) the irrigation site.

Each irrigation system develops salinity at a specific soil zone and, thus, needs to be carefully monitored. Shahid (2013) has recently introduced zones of soil salinity development for a range of different irrigation systems. Commonly used irrigation methods and the probable zones of soil salinity development are discussed here. In this context, safe zones with a relatively low salinity are suggested where seeds can be placed for germination, or where seedlings can be transplanted.

The zone of salt accumulation depends on the method of irrigation and seed bed shape. The irrigation systems used include:

- Flood irrigation
- Basin irrigation
- Border irrigation
- Surge irrigation
- Furrow irrigation
- Drip irrigation
  - Surface drip irrigation
  - Subsurface drip irrigation

Soil salinity development, i.e. the location and quantity of salts in each irrigation system is variable. In the flood, basin, border and sprinkler irrigation systems, the net water movement is downward when there is no high water-table. Under such circumstances, surface accumulation of salts is unlikely. Rather, the salt accumulates

Plate 4.1 Basin irrigation of date palm

at deeper soil layers based on the final ‘wetted zone’. Each irrigation cycle dissolves surface salinity and then concentrates those salts at the final wetting zone. Here, then, there is lower surface salinity and an increase in the subsurface salinity.

At the end of each irrigation (flood, basin and border) cycle, the soil dries out and the salts are concentrated, adversely affecting the crop yield. Frequent irrigation may lower the salinity, but it wastes water. Alternatives which improve the efficiency of water use are drip or sprinkler irrigation. In the bubbler type of (basin) irrigation, a small fountain of water is applied to flood small basins dug around the tree base, or on the soil surface adjacent to individual trees. In the GCC countries, this system is commonly used to irrigate date palm trees (Plate 4.1).

This shift from conventional surface irrigation to a more modern irrigation system is costly and requires assurance on a high degree of crop adaptability. However, there are advantages in using modern irrigation system(s), especially when saline/ brackish water must be used under hot desert conditions like that prevail in the Middle East, and parts of Australia and South East Asia. Frequent (twice daily) irrigation maintains a soil moisture level that does not fluctuate appreciably between wet and dry extremes. This residual moisture which remains in the soil between irrigation cycles keeps salts in a dilute solution, making it possible to use saline water – a situation which is problematic when irrigation occurs every second or third day.

Plate 4.2 Sprinkler irrigation in a demonstration plot of salt tolerant grass in Abu Dhabi Emirate

2 Sprinkler Irrigation

With sprinkler irrigation, strong streams of water are sprayed through the air to spread on the soil surface (Plate 4.2). A good sprinkler irrigation (SI) must meet all of the requirements of the crop for water, including evapotranspiration (ET). Irrigation by sprinkler allows efficient and economic use of water and reduces losses through deep percolation of water through the soil. If water applied via SI is in close agreement with crop needs (ET plus leaching), excessive drainage and high water-table problems can be greatly reduced, thus improving salinity control. Sprinkler irrigation can be accomplished through the use of fixed sprinklers or by a continually moving system, such as center-pivot, linear moving laterals, and other forms of travelling sprinklers. Special care should be exercised in selecting nozzle size, operating pressure and sprinkler spacing when using SI on fine textured soil (which will have low intake rates) to ensure uniform water application at low rates.

While sprinkler irrigation will uniformly distribute water, high wind can distort the distribution of water applied, thus affecting water use efficiency. Windbreaks around the edges of the farm can help to reduce the negative effects of strong wind.

The saline water applied with sprinkler can also cause leaf burn (necrosis) through salt injury (Plate 4.3). Leaf necrosis from sprinkler irrigation can occur when sodium exceeds 70 ppm, or chloride exceeds 105 ppm in irrigation water.

Plate 4.3 Salinity diagnostics in a grass field where sprinkler irrigation with saline water has caused necrosis (leaf burn)

Table 4.1 Susceptibility of crops to foliar injury[a] from saline sprinkler water

Na^+ or Cl^- concentrations (meq l^{-1}) which can cause foliar injury			
< 5	5–10	10–20	> 20
Almond	Grape	Alfalfa	Cauliflower
Apricot	Pepper	Barley	Cotton
Citrus	Potato	Corn	Sugar beet
Plum	Tomato	Cucumber	Sunflower
		Safflower	
		Sesame	
		Sorghum	

Source data (Maas 1986)
[a]Foliar injury is influenced by cultural and environmental conditions
Data presented is for general guidelines for day-time sprinkling (cf. Minhas and Gupta 1992)

Thus, quality of water must closely match the leaf burn tolerance of the crop plants. The leaves of many plants readily absorb Na^+, Ca^{2+}, and Cl^- when water is applied through sprinkler system. The susceptibility of foliar injury differs among plant species; it is related to leaves' characteristics and rate of ion absorption rather than salinity tolerance (Maas 1986). However, sprinkler irrigation applied at night, or during periods of high humidity can reduce or eliminate the problem of leaf necrosis. Relative susceptibility of crops to foliar injury (Maas 1986) is shown in Table 4.1. Finally, the high costs of establishing and operating a sprinkler irrigation system limit its adoption by smallholder subsistence farmers.

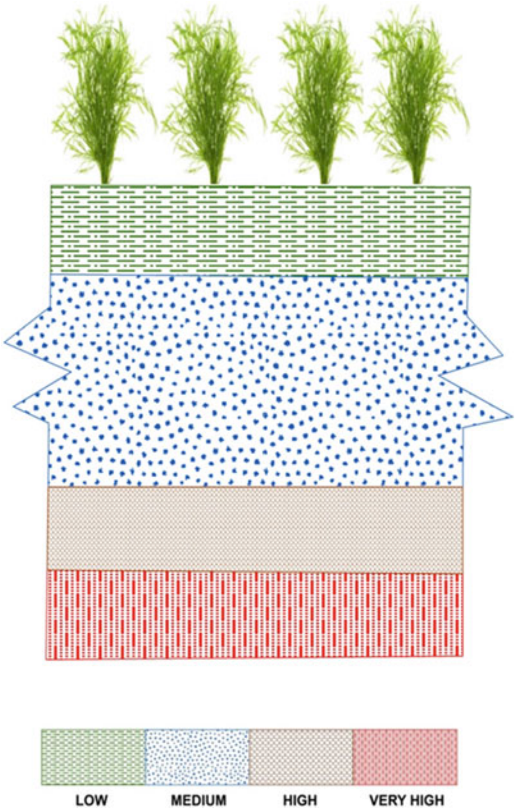


Fig. 4.1 Salinity zone profiles occurring under a wide range of irrigation methods: sprinkler, flood, basin (bubbler) and border irrigation systems (Shahid 2013)

Under sprinkler irrigation, the salinity buildup occurs in the subsurface soil (Fig. 4.1). Thus, the SI system is highly effective in leaching salts from the surface and providing a soil environment which is conducive for seed germination and early stage of plant growth.

3 Drip Irrigation

Drip irrigation system can supply the required quantity of water to the crop on a daily or periodic basis. Drip irrigation delivers water near each plant through pipes (usually plastic) and a series of closely spaced emitters (drippers). This leads to high water use efficiency. The flow rate of each dripper can be controlled from 1 to 4 + liters per hour. The use of drippers for application of poor quality water may give better crop yields due to an ability to maintain high soil moisture levels and replenish the water lost by ET on a daily basis. Drip irrigation is often preferred to sprinkler irrigation for species with a high sensitivity to leaf necrosis. However, because the diameters of the dripper openings are quite small, the evaporation of saline water at

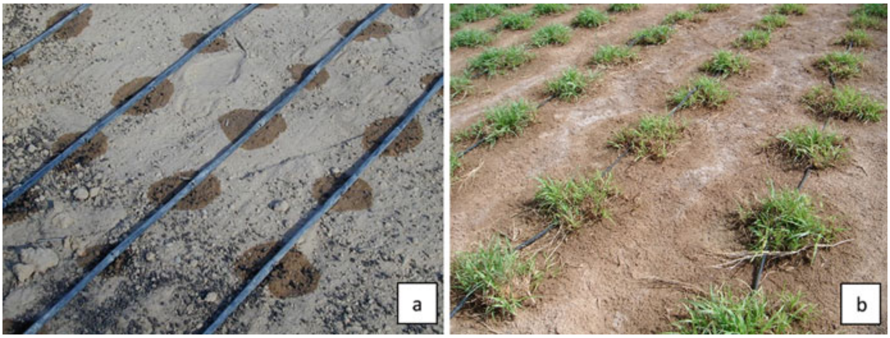


Plate 4.4 Wetting zone and salinity buildup in drip irrigation system: (**a**) Wetted soil, (**b**) Salt accumulation in the center of drip lines where wetting zones meet

the end of the dripper opening can lead to clogging, which reduces (or completely stops) the discharge of irrigation water from individual drippers. Thus, drippers must be inspected periodically to prevent this problem.

In drip irrigation, salt accumulation occurs via two processes. First, the soil becomes saturated with saline water and solutes are spread throughout the soil, saturating neighboring voids (Plate 4.4). In the second process, which occurs between consecutive irrigation cycles, both evaporation of water from the soil and the uptake of water and nutrients by plants are occurring. Solutes, thus, become redistributed in the soil with a final buildup of salts resulting from the interaction of these two processes throughout the crop season. During drip irrigation, salts will concentrate below the soil surface along the perimeters of the expanding wetting soil zone. Prolonged soil drying, or interspersing long intervals between irrigation cycles, can lead to increasingly saline soil-water movement back towards the plant, thereby increasing the likelihood of plant damage. This can be managed by ensuring that irrigation volumes are sufficient to allow the movement of new irrigation water to always be away from the drippers.

Salts concentrate through water evaporation from the soil and also by plant uptake. As discussed above, salt accumulation occurs on the boundaries of the wetted soil volume (Plate 4.4a), with the lowest salt concentration occurring in the immediate vicinity of the water source (Fig. 4.2). Salt concentrations will be the highest at the soil surface, and in the very center of any two drippers, i.e. at the boundary of the volume of wetted soil (Plate 4.4b).

Special care must be exercised to avoid the negative effects of salts to plants, especially during light rains that can push the salts from the center of drip lines towards plants and into the root-zone. Therefore, irrigation should be continued on schedule unless the rain is heavy (50 mm or more), which is very rare in arid and semi-arid regions especially in hot desert environments such as GCC countries. However, when such heavy rains do occur, they are usually sufficient to leach salts to deeper layers, leaving the root-zone salt free.

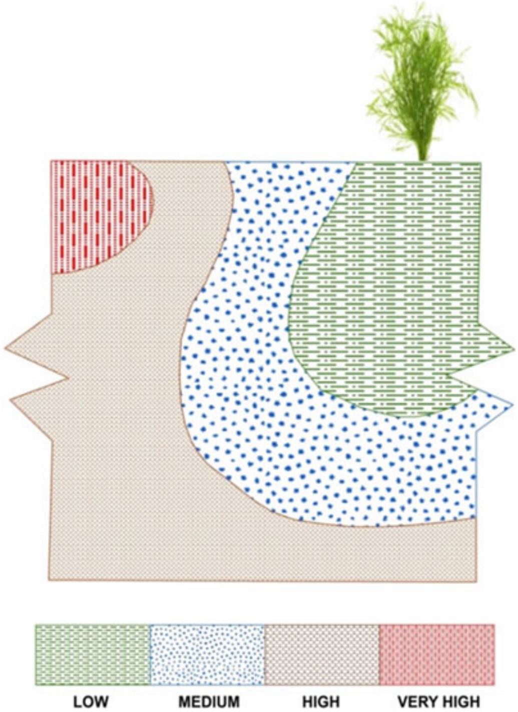


Fig. 4.2 A typical pattern of salt accumulation occurring from surface drip irrigation

In summary, irrigating daily is usually sufficient to continuously move the moisture down, into deeper soil zones, thereby keeping the salt levels under control.

3.1 Salinity Management When Using Drip Irrigation

In an attempt to reduce salinity effect in the root-zone, an experiment was conducted at ICBA experimental station to check the performance of drip irrigation (without a crop) at different dripper (drip emitter) spacings (25, 50 and 75 cm) using a saline water of 30 deci Siemens per meter (dS m^{-1}).

Soil samples collected from the centers of the emitters, were analyzed for electrical conductivity of soil extract from saturated paste (ECe). The ECe was recorded as 26 dS m^{-1} (25 cm spacing), 90 dS m^{-1} (50 cm spacing) and 102 dS m^{-1} (75 cm spacing). The effects of emitters' spacing on soil salinity contours (top view) can be seen at a glance (Fig. 4.3). The larger the white areas became, the higher the soil salinity.

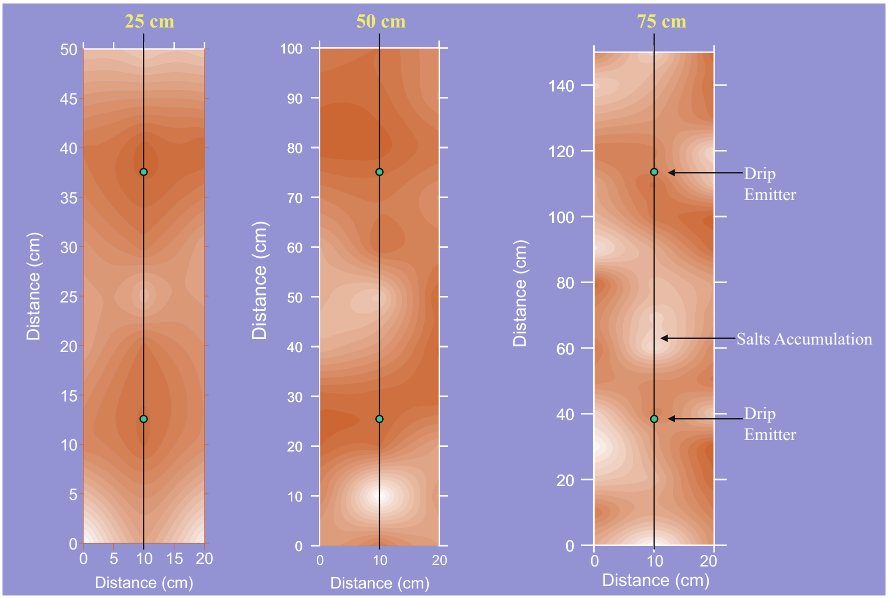


Fig. 4.3 Soil salinity under drip irrigation with emitter spacing at 25, 50 and 75 cm. Intensity of whiteness indicates higher salinity (Shahid and Hasbini 2007)

3.2 *Subsurface Drip Irrigation*

Subsurface drip irrigation (SDI) system, when compared with other irrigation systems, reduces water losses due to evaporation and deep percolation, while completely eliminating surface runoff (Phene 1990). The subsurface drip irrigation also increases marketable crop yield and quality (Ayers et al. 1999), while resulting in high nutrient use efficiency as well (Thompson et al. 2002).

The major limitation of SDI is the fact that salts continuously buildup at the soil surface through an upward capillary movement (Fig. 4.4) from the buried irrigation lines during growing season (Oron et al. 1999). This occurs because there is no above-soil water source, i.e. there is no way for irrigation water to leach the salts. The concept of leaching requirement (LR) does not function under subsurface drip irrigation specially to leach the salts from surface above the buried drip lines. However, salt accumulation in this zone above the buried irrigation line can be managed by supplementing subsurface drip irrigation with sprinkler irrigation (Thompson 2010). This approach may be costly, but is a necessary compromise. Salt accumulation occurs more rapidly when saline/brackish water is used, and also when the soils are fine textured. Only a heavy rainfall and/or occasional switch over from subsurface drip irrigation to sprinkler irrigation can leach salts from this zone. The alternative will be an accumulation of salts to toxic levels.

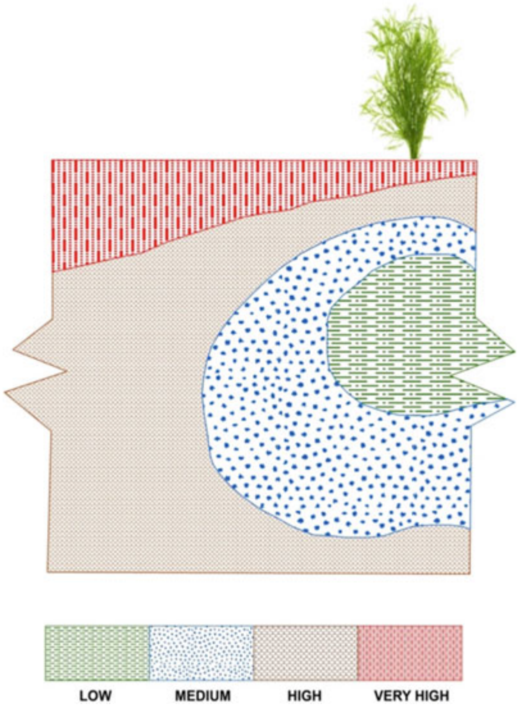


Fig. 4.4 Relative salt accumulation in the soil from subsurface drip irrigation showing high surface salinity in the zone above the irrigation line (Shahid 2013)

4 Furrow Irrigation

Furrow irrigation is most commonly practiced where soils are fine textured. In water scarce regions, and where the soils are sandy (such as GCC countries), furrow irrigation is not recommended. For farmers who do select furrow irrigation, there are various bed shape options to reduce salinity effects on plants (Bernstein et al. 1955; Bernstein and Fireman 1957; Bernstein and Francois 1973; Chhabra 1996) as described in the following sections.

In furrow irrigation, soil salinity varies widely from the base of the furrows to the tops of the ridges. Plate 4.5 shows salt accumulation in ridges of soil between the furrows. This pattern guides the best seed (or seedling) placement to minimize salinity effects, thereby achieving a higher crop yield. Re-plowing the furrow field for each new crop will redistribute the accumulated salinity, thereby allowing a continued cultivation in the area.

If a flatbed is chosen and both (two) furrows are irrigated, the zone of maximum salt accumulation will be in the center of the bed (Plate 4.5, Figs. 4.5, 4.6). In this case, it is safe to place the seeds or transplant seedlings away from the salt accumulation zone (Plate 4.5b). If, however, the farmer has chosen to place the seeds or transplant seedlings in a zone of maximum salt accumulation, it is highly

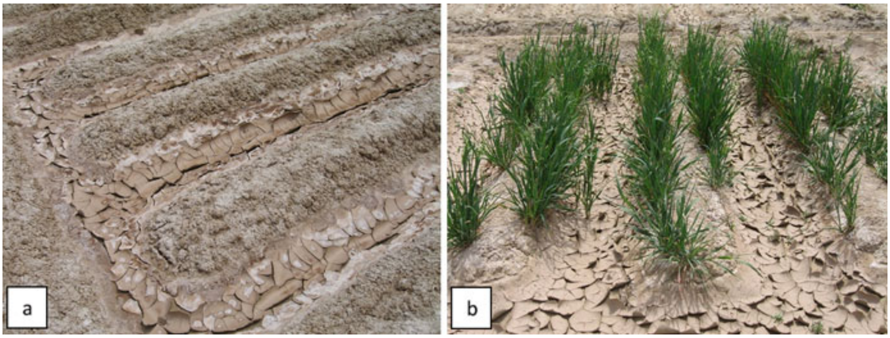
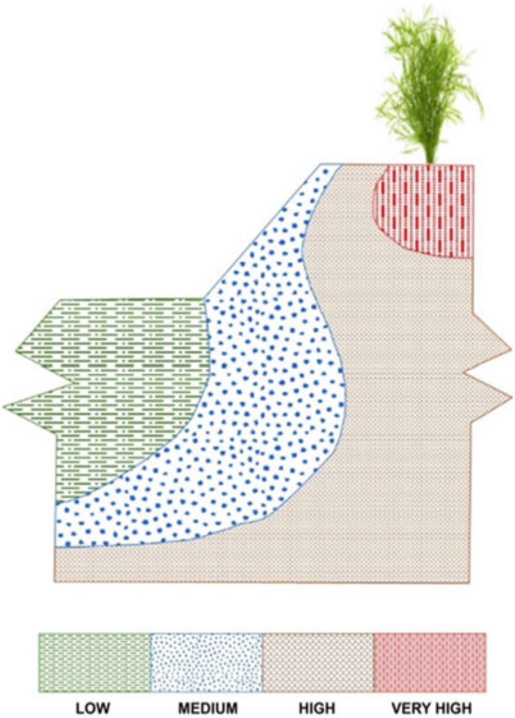


Plate 4.5 Pattern of salt accumulation (**a**), and safe zone for seed placement or transplanting (**b**) in a furrow irrigation system

Fig. 4.5 Salt accumulation when both furrows are irrigated; any plants growing in the very high salt accumulation zone will be affected



likely that either the seeds will not germinate or the seedlings will die over time (Fig. 4.7).

If alternate furrows are irrigated, the maximum zone of salt accumulation will be on the sides of the un-irrigated furrow (Fig. 4.8). In this situation, it is safe to place the seed or transplant seedlings away from the salt accumulation zone.

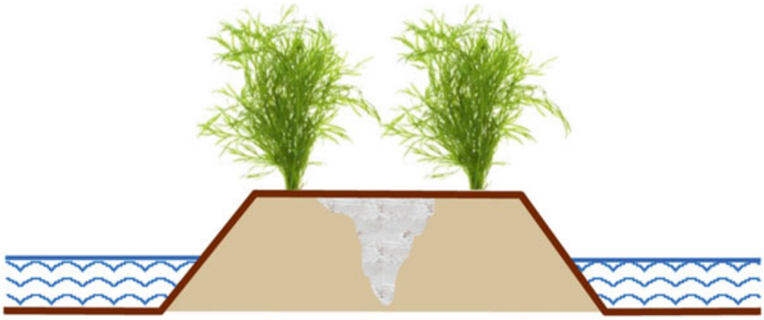


Fig. 4.6 Furrow irrigation system (flatbed); both furrows are irrigated

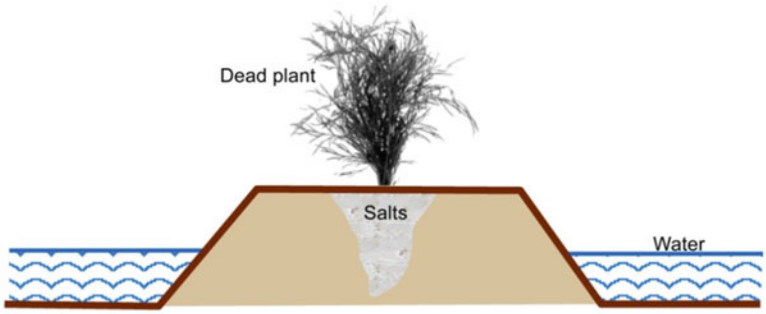


Fig. 4.7 Planting in the salt accumulation zone will result in a dead plant

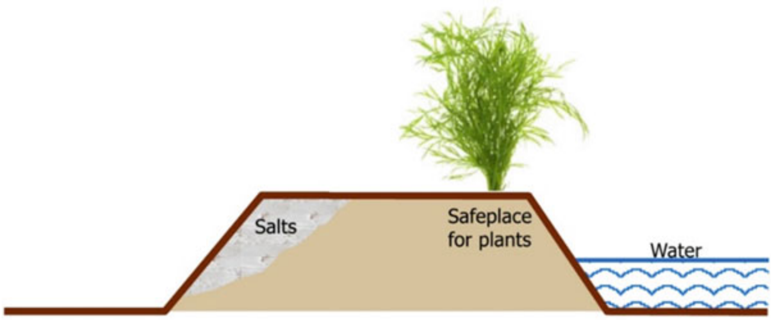


Fig. 4.8 Salt accumulation and the safe zone for seeding when only the alternate furrow is irrigated

If a sloping bed is chosen, and depending upon the bed shape, the maximum salt accumulation will be either on the sides (Fig. 4.9) or in the center of the bed (Fig. 4.10). Avoid this zone of high salt accumulation, and place the seed or transplant the seedlings in the safe zone.

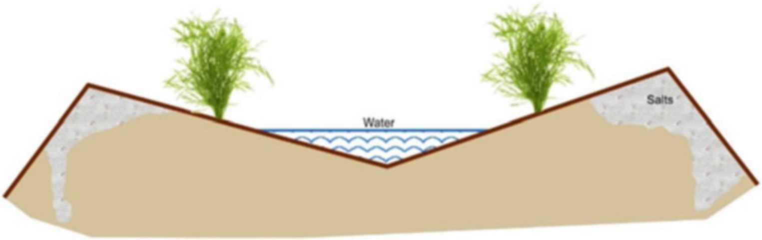


Fig. 4.9 Salt accumulation on sloping beds and the safe zone for seeding

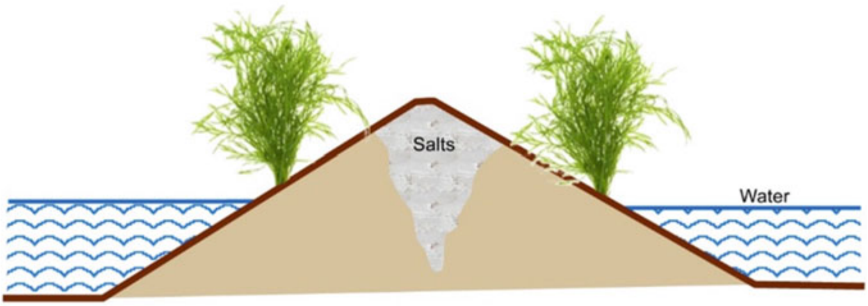


Fig. 4.10 Salt accumulation on sloping beds. Note the safe zone for seeding when both furrows are irrigated

5 Surge Irrigation

Surge irrigation is a method of reducing the amount of runoff and allowing for a more uniform infiltration of irrigation water (Yonts and Eisenhauer 2008). It has long been recognized that water moves to the end of an irrigated field more quickly when applied intermittently than when applied continuously. In the latter case, and especially for coarse textured soils, it is practically impossible for continuously applied irrigation water to reach to the other end of the field; most of the water infiltrates into the soil at the water entrance end of the field.

How Surge Irrigation Works? When water first contacts the soil in the furrow, the infiltration rate is high; as the water flow continues, the infiltration rate is reduced to a near-constant rate. If water is shut off and allowed to infiltrate, a surface seal develops and when water is reintroduced, the infiltration rate into the previously wetted soil is reduced due to this partial sealing action. The end result is more water movement down the furrow and less infiltration into the soil. However, where soils are predominantly sandy, the surge irrigation method may not be a good option. In the GCC countries, surge irrigation has not gained recognition due to irrigation water scarcity, sandy soils and very hot climatic conditions.

6 Salinity and Sodicity Management in the Root-Zone

There is no single or universal technique to manage root-zone salinity. However, scientific diagnostics approach (Plate 4.6) based on a combination of engineering, chemical, physical, hydrological, biological and agronomic techniques can often yield a good solution. Once the problem area is properly diagnosed, a suitable selection of 'best management practices' can be implemented. A summary of such an approach is given below.

6.1 Physical Methods

Laser Guided Land Leveling – an improvement in leveling (preferably laser guided leveling) allows for a more uniform distribution of water.

Subsoiling – is 'deep ripping' to improve soil properties at deeper layers where a dense soil layer (or hard pan) exists, thereby limiting the penetration of roots and water infiltration.

Salts Scraping – salts at the soil surface can be scraped and removed to avoid further effects on plants after rain.

Plate 4.6 Soil sampling for root-zone soil salinity diagnostics

Sanding – sand can be added to a very fine textured (clayey) soil to improve soil texture, however, this practice can be very expensive and is impractical on a large scale basis.

6.2 Chemical Methods

Use of Amendments – It should be noted that salinity cannot be managed by chemical methods, but sodicity can be, and its management may have indirect effects on soil salinity. The most commonly used amendment to rectify soil sodicity is '*gypsum* ($CaSO_4.2H_2O$)', and the amount of gypsum to be applied will be based on the 'gypsum requirement' determined by standard laboratory methods. If, however, the soil contains sufficient quantities of $CaCO_3$ equivalents, then other amendments such as Sulfur (S), sulfuric acid (H_2SO_4) or pyrite (FeS_2), etc. can be used, again based on the 'gypsum requirement'. These amendments mobilize calcium from calcium carbonates equivalents and, thus, behave like gypsum to reclaim soil sodicity.

6.3 Hydrological Methods

Drainage System – a drainage system (surface and subsurface) can lower the soil water-table to a safer level in order to avoid detrimental effects of excess water in the normal plant root-zone. At the farm level, drainage is a 'moisture control system' that is required to maintain moisture and regulate salt balance in the root-zone.

Irrigation System – an irrigation system, when adopted, should permit frequent, uniform and efficient water application with as minimum a percolation loss as possible, but without curtailing essential leaching requirement. In addition, a good irrigation system should also avoid using saline water at the seed germination stage (a very sensitive stage). Where appropriate, and good quality water is also available, farmers should practice the use of re-cycled water for irrigation.

Leaching Requirement – where necessary, farmer should use water additional to the volume required for crop ET (evapotranspiration). This will allow salts to be leached down, below the root-zone.

The uses of saline/brackish water usually raise root-zone soil salinity. This salt accumulation can be controlled by applying water additional to the ET water requirement of the crop. This extra water will usually push the salts below the root-zone. The amounts of water required for leaching (leaching requirement – LR) can be calculated by standard procedures (Ayers and Westcot 1985).

$$LR = \frac{EC_w}{(5EC_e - EC_w)}$$

Where,

LR = leaching requirement ratio
ECw = EC of the irrigation water (dS m^{-1})
ECe = estimated EC of the average saturation extract of the soil root-zone profile for an appropriate yield (10%) reduction (dS m^{-1}) as presented by Ayers and Westcott (1985)

Example
Calculate leaching requirement for a sprinkler irrigation (SI) system for an alfalfa crop when irrigation water salinity is 5 dS m^{-1}.

The ECe that would give a 10% crop yield reduction is 3.4 dS m^{-1}, assuming threshold salinity level of alfalfa is 2 dS/m (ECe).

Using the above equation,

$$LR = \frac{5}{[(5 \text{ x } 3.4) - 5]} = 0.41$$

6.4 Agronomic Methods

Proper Seeding – use planting procedures that minimize the effects of salts on the seeds at germination and early plant growth stages (see earlier section on irrigation systems and salinity zones).

6.5 Biological Methods

Where it is not possible to practice conventional agriculture due to unavailability of good quality water, harsh environmental conditions and exceptionally saline lands, as a compromise the use of salt tolerant crops (***Biosaline Agriculture***) can be adopted. Table 4.2 provides guidelines for selection of crops tolerant to salinity.

7 Relative Crop Salinity Tolerance Rating

Relative crop salinity tolerance rating based on Fig. 4.11 is divided into five categories. Each group represents the crops with similar tolerance. Based on the data in Table 4.2, minimum and maximum ECe boundaries can be assigned to each

Table 4.2 Relative crop salinity tolerance rating

Relative crop salinity tolerance rating	Soil salinity (ECe, dS m^{-1}) at which yield loss begins
Sensitive (S)	< 1.3
Moderately sensitive (MS)	1.3–3.0
Moderately tolerant (MT)	3.0–6.0
Tolerant (T)	6.0–10.0
Unsuitable for most crops (unless reduced yield is acceptable)	> 10.0

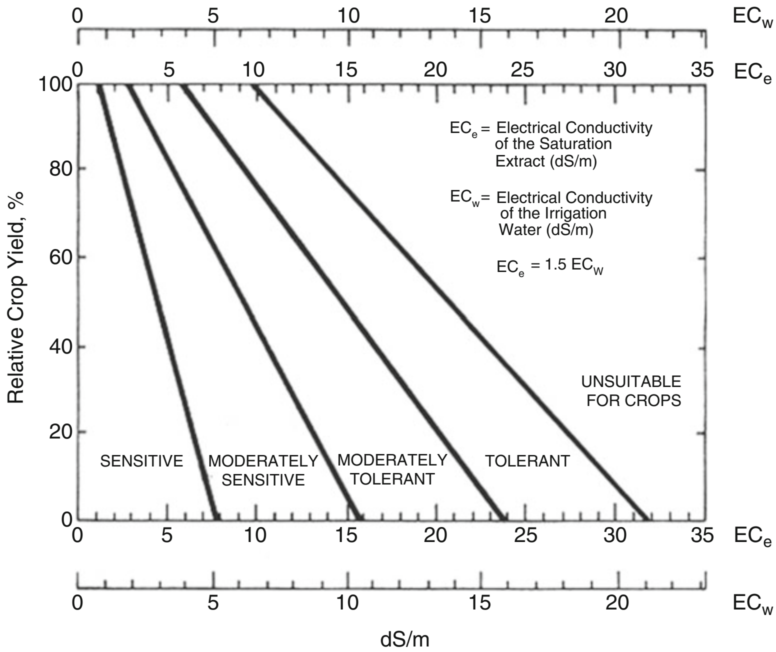


Fig. 4.11 Divisions for relative salt tolerance ratings of agricultural crops (Maas 1987). (Source: Ayers and Westcot 1985)

category. It should be noted that this broader division is for general guidelines and not meant to be a strict rule (Maas 1987).

8 Soil Salinity and Relative Yield Reduction of Crops

Crops can tolerate salinity up to certain levels without a measurable loss in yield (this is called the threshold level). As a general rule, the more salt tolerant is the crop, the higher is the threshold level. At salinity levels greater than the threshold, crop yield is reduced in a linear fashion as salinity increases. Using the salinity values from a salinity/yield model developed by Maas and Hoffman (1977), predictions of expected yield loss can be made (Table 4.3), as expressed in the following relationship.

$$Y_r = 100 - s\,(EC_e - t)$$

Where,

Y_r = percentage yield of the crop grown in saline conditions, relative to that yield obtained under non-saline conditions
t = threshold salinity level where the yield decrease begins
s = percent yield loss per increase of 1 ECe (dS m^{-1}) in excess of t

Salinity mapping at the farm level and the use of Table 4.3 may be used as a guide to predict yield losses.

General groupings for salt tolerance are shown in the schematic diagram in Fig. 4.11. The relative tolerance ratings, even if based on a limited amount of data, can be useful for comparisons among crops.

Table 4.3 Salt tolerance of important crops (Ayers and Westcot 1985)

Crop common name	Botanical name	Threshold (t) ECe, dSm^{-1}	Slope (s) % per dSm^{-1}	Rating[a]	Minimum[b] ECe, dSm^{-1}	Maximum[c] ECe, dSm^{-1}
Field crops						
Barley (forage)	*Hordeum vulgare*	8.0	5.0	T	8.0	28.0
Sugar beet	*Beta vulgaris*	7.0	5.9	T	7.0	24.0
Sorghum	*Sorghum bicolor*	6.8	16.0	MT	6.8	13
Triticale	*X Triticosecale*	6.1	2.5	T	6.1	46.0
Wheat	*Triticum aestivum*	6.0	7.1	MT	6.0	20.0
Wheat, durum	*Triticum turgidum*	5.9	3.8	T	5.7	20.0
Alfalfa	*Medicago sativa*	2.0	7.3	MS	2.0	16.0
Corn (maize)	*Zea mays*	1.7	12.0	MS	1.7	10.0
Cow peas	*Vigna unguiculata*	4.9	12.0	MT	4.9	13.0

(continued)

Table 4.3 (continued)

Crop common name	Botanical name	Threshold (t) ECe, dSm^{-1}	Slope (s) % per dSm^{-1}	Rating[a]	Minimum[b] ECe, dSm^{-1}	Maximum[c] ECe, dSm^{-1}
Vegetables						
Broccoli	*Brassica oleracea botrytis*	2.8	9.2	MS	2.8	14.0
Tomato	*Lycopersicon esculentum*	2.5	9.9	MS	2.5	13.0
Cucumber	*Cucumis sativus*	2.5	13.0	MS	2.5	10.0
Spinach	*Spinacia oleracea*	2.0	7.6	MS	2.0	15.0
Celery	*Apium graveolens*	1.8	6.2	MS	1.8	18.0
Cabbage	*Brassica oleracea capitata*	1.8	9.7	MS	1.8	12.0
Potato	*Solanum tuberosum*	1.7	12.0	MS	1.7	10.0
Pepper	*Capsicum annuum*	1.5	14.0	MS	1.5	8.5
Lettuce	*Lactuca sativa*	1.3	13.0	MS	1.3	9.0
Radish	*Raphanus sativus*	1.2	13	MS	1.2	8.9
Onion	*Allium cepa*	1.2	16.0	S	1.2	7.4
Carrot	*Daucus carota*	1.0	14.0	S	1.0	8.1
Beans	*Phaseolus vulgaris*	1.0	19.0	S	1.0	6.3
Turnip	*Brassica rapa*	0.9	9.0	MS	0.9	12.0
Fruits						
Date palm	*Phoenix dactylifera*	4.0	3.6	T	4.0	32.0
Orange	*Citrus sinensis*	1.7	16.0	S	1.7	8.0
Peach	*Prunus persica*	1.7	21.0	S	1.7	6.5
Apricot	*Prunus armeniaca*	1.6	24.0	S	1.6	5.8
Grape	*Vitus sp.*	1.5	9.6	MS	1.5	12.0

(continued)

Table 4.3 (continued)

Crop common name	Botanical name	Threshold (t) ECe, dSm^{-1}	Slope (s) % per dSm^{-1}	Rating[a]	Minimum[b] ECe, dSm^{-1}	Maximum[c] ECe, dSm^{-1}
Almond	*Prunus dulcis*	1.5	19.0	S	1.5	6.8
Plum, prune	*Prunus domestica*	1.5	18.0	S	1.5	7.1
Blackberry	*Rubus sp.*	1.5	22.0	S	1.5	6.0
Strawberry	*Fragaria sp.*	1.0	33.0	S	1.0	4.0

Adapted from Ayers and Westcot (1985); Maas (1990); Maas and Hoffman (1977)
S sensitive, *MS* moderately sensitive, *T* tolerant, *MT* moderately tolerant
[a]Relative crop salinity tolerance rating (see Table 4.2)
[b]Minimum ECe does not reduce yield (threshold)
[c]Maximum ECe reduces yield to zero

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