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Saline irrigation water matrix (siwm) to optimize crop productivity:- (a review)

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Abstract. Due to water scarcity in the arid and semi-arid regions, it is necessary to find other renewable water alternatives to reduce its impact on the food security and drought environmental effects. Using the saline water is suitable especially in the regions containing huge quantities of this water; Iraqi Main Out Flow (MOF) discharges about 10 BCM of moderate saline water with water salinity ranging between (2.5 dS.m-1 to 10 dS.m-1) to the Arab gulf. Three salinity effects are osmotic, infiltration, and toxicity of special ions like chloride, sodium, and boron. Combining these effects with five field conditions, climate, crop tolerance, soil texture, field management, and irrigation system, constructs a matrix of three columns versus five rows representing the field conditions. This matrix is summarized any salinity effects on soil and crops. The current study aims to design and evaluate the Saline Irrigation Water Matrix (SIWM) referring to published studies that studying optimizing the use of saline water in irrigation. Many researchers recommend expanding in using these water resources to overcome food security and improve the environment by expanding green zones. The main conclusion can be summarized as a wide range of moderate saline water for irrigation proposes.

Keywords; salinity, Mean Out Flow, crop tolerance, moderate Saline water.

1. Introduction

Salts have general effects on plants that directly affect crop growth and yield. Series of studies in the field of using saline water in irrigation was started several years ago, but further studies are still needed. The most general effects of salts on plants are to decrease plant stand and growth range. Salts also affect certain soil physic and chemical properties, which affect the soil's suitability as a medium for plant growth. The Plants different in their tolerances to salts and lots of are adequately tolerant.[1]

Irrigation has previously played the most role in growing food production over the past years. Irrigated land within the world was 8 million hectares in 1800, 48 million hectares in 1900, 94 million hectares in 1950, 198 million hectares in 1970, and about 220 million hectares in 1990.[2]

There are two common measures of the quality of water that define the salinity of irrigation water. Irrigation water salinity has often been recorded as total salt concentration or total dissolved solids (TDS). TDS units are usually expressed in milligrams of salt per litre (mg/L) of water. [3]

This term is still used in industrial, analytical laboratories and reflects the total amount of milligrams of salt left after one litre of water has evaporated to dry. The higher the number of solids dissolved, the higher the salinity of the water. Irrigation water salinity is often characterized as total dissolved solids (TDS) or total salt concentrations. The other measurement recorded in the study on water quality is electrical conductivity. Electrical conductivity (EC) is considered more critical and useful than TDS because it can be easily carried out by irrigators or farm managers in the field. [4]



In the current study, The salinity effects are expressed as a matrix of three columns (Osmotic (O), Infiltration (I) and Toxicity (T) and five-row (Climate (C), Plant (P), Soil texture (S), Field management (F) and Irrigation method (IM).

2. Water Quality Guideline

Guidelines for the evaluation of water quality for irrigation are given in Table 1. The guidelines are practical and are used successfully generally in irrigated agriculture. The rules are a primary step in remarking the standard limitations of a water system. [1]

The recommendations for water quality in Table 1 reflect the broad range of conditions encountered in irrigated crops. Several simple assumptions have been used to describe their usability fields. Guidelines can be modified if the water is used in very different circumstances. Broad deviations from assumptions can result in incorrect decisions on the usability of a particular water supply, especially in the case of borderline. Guidelines can be adjusted to suit local conditions more closely, provided that adequate experience, field trials, studies or findings are available. [5]

3. Classification of saline water

The suitability of saltwater for irrigation depends on the conditions of usage, including crop, climate, soil, irrigation, and management practices. It helps lay down a classification arrangement to define the water salinity stages for which these guidelines are intended. Such classifications are given in Table 2 in terms of the total salt concentrations, which is the key quality factor that generally limits saline waters for crop production. Only very tolerant crops can be generated positively with water that tops 10 dS/m in electrical conductivity. [6]

Table 1: Water quality guidelines for crop production. [5]

Irrigation Problem		The unit	The limits		
			None	Slight to Moderate	Severe
The Salinity					
	Electrical conductivity	dS/m	< 0.7	0.7 – 3.0	> 3.0
	Total Dissolved salt	mg/l	< 450	450 – 2000	> 2000
Infiltration		dS/m			
Sodium Adsorption Ratio	0-3		> 0.7	0.7 – 0.2	< 0.2
	3-6		> 1.2	1.2 – 0.3	< 0.3
	6-12		> 1.9	1.9 – 0.5	< 0.5
	12-20		> 2.9	2.9 – 1.3	< 1.3
	20-40		> 5	5.0 – 2.9	< 2.9
Toxicity					
	Sodium				
	surface irrigation	SAR	< 3	3 – 9	> 9
	sprinkler irrigation	me/l	< 3	< 3	
	Chloride				
	surface irrigation	me/l	< 4	4 – 10	> 10
	sprinkler irrigation	me/l	< 3	< 3	
	Boron	mg/l	< 0.7	0.7 – 3.0	> 3
	Trace Elements				
Miscellaneous Ions Effects					
	Nitrogen (NO ₃ – N)	mg/l	< 5	5 – 30	> 30

	Bicarbonate (HCO ₃)	me/l	< 1.5	1.5 – 8.5	> 8.5
	pH		Allowable Range 6.5 – 8.4		

Table 2: classification of saline water. [6]

Water class	Electrical conductivity dS/m	Salt concentration mg/l	Water Suitability
Non-saline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7 – 2	500-1500	Irrigation water
Moderately saline	2 – 10	1500-7000	Primary drainage water and groundwater
Highly saline	10-25	7000-15000	Secondary drainage water and groundwater
Very highly saline	25 – 45	15000-35000	Very saline groundwater
Brine	>45	>35000	Sea water

4. The salinity effects on plants

The salinity effects on plants can be summarized as a matrix of three columns of salinity problems versus five rows of field conditions, as explained in the table (3) below:

Table 3: Matrix of salinity problem versus field condition

NO.		1	2	3
	Salinity problem	Osmotic	Infiltration	Toxicity
	Field condition	(O)	(I)	(T)
1	Climate (C)	(CO)	(CI)	(CT)
2	Plant (P)	(PO)	(PI)	(PT)
3	Soil texture (S)	(SO)	(SI)	(ST)
4	Field management (F)	(FO)	(FI)	(FT)
5	Irrigation method (IM)	(IMO)	(IMI)	(IMT)

5. Salinity problems

Three main problems affecting soil and plant due to increasing salinity concentration are osmotic effects, infiltration effects and toxicity problems.

5.1. Osmotic (O)

Osmotic pressure is the key cause of plants to consume water. Soil water has the pressure within the absorbent capillaries at the roots more significant than the osmotic pressure. The pressure within the absorbent capillaries contributes to the movement of water from the soil to the roots. When a plant cell is put in a highly concentrated solution, the plant starts to shrink due to the outflow of water and diffuses into a highly concentrated solution to form a state of equilibrium of pressure.[7]

Osmotic effects can be said to predominate when plant growth is linked to root media osmotic potentials that contain different salts or salt combinations. [8]

5.2. Infiltration

Infiltration is the entry of water into the soil. Figure (1) shows the salinity (EC_w) and the sodium adsorption ratio (SAR) effect on the speed of infiltration of water. Very low salinity water almost invariably leads to water infiltration problems. If the irrigation water does not enter the soil rapidly enough during a traditional irrigation cycle. [9].

There will be an infiltration prevalent if sodium exceeds calcium by more than around 3:1. Sodium can contribute to soil dispersion and structural breakdown. Such a relatively high sodium content also results in extreme water penetration problems due to soil dispersion and surface pore sealing. [5] In general, the rate of infiltration varies directly with salinity and indirectly with sodium adsorption ratio. [10]

5.3. Toxicity (T)

The toxicity problem is distinct from the salinity problem because it exists inside the plant itself. Toxicity problem arose when the plant was taking up the ions from the soil or irrigation water. The toxicity degree depends on the plant sensitivity and absorption; many plants may be damaged at low toxic ion concentration. Chloride, sodium, and boron are the ions of key significance. [4]

Toxicity can also occur due to the direct sucking of dangerous ions from the leaves moistened by the sprayers above. The main ions absorbed by the leaves are sodium and chloride. [11]

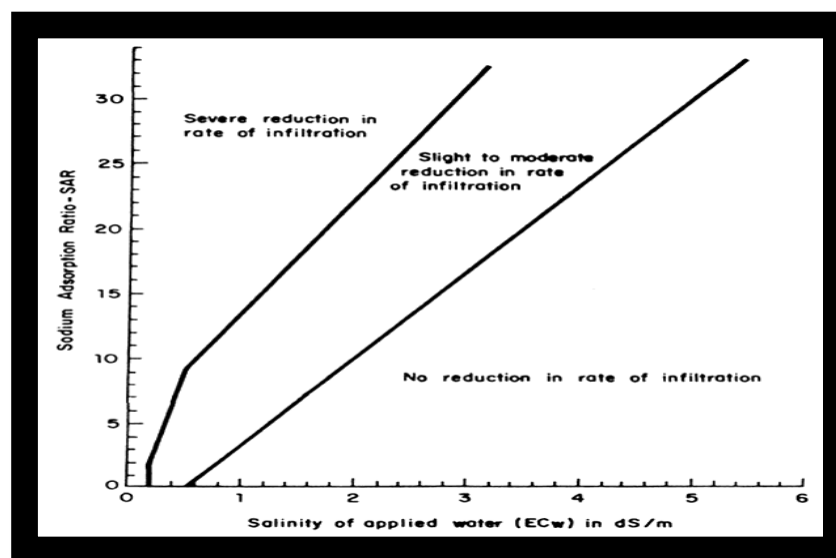


Figure 1: Infiltration rate ratio as affected by SAR and salinity (FAO,1985)

6. Field conditions

Five field conditions must be considered when studying the salinity effects on crop production. There are climate, plant, soil texture, field management, and irrigation method.

6.1. Climate effect (C)

Climate change effects on salinity are significant to gauge the extent of the matter to acknowledge trends and formulate irrigation and crop management strategies. [12]

Climate changes have an impact on the salinization process. Rainfall may have significant effects on soil salinity inside the root zone. Excessive rainfall raises the water level capillary rise because the upward movement of salts from the water level to the soil surface leads to the accumulation of salinity or near the soil surface. Some plants can tolerate salt better when the weather is humid and cold than when the weather is dry and hot; this is often because the soil in cold and humid weather retains moisture better, which reduces the concentration of salt inside the soil near the roots. The reverse occurs during

the time of dry and hot weather; the soil rapidly becomes drier, which raises the concentration of salt within the soil nearest the roots zone, occasionally to a level that hurts plants. [13]

6.1.1. Climate – osmotic (CO): Water moving to roots slows down as a soil water concentration increases. This process decreases the quantity of available water obtainable to plants for growth and productivity. When precipitation occurs, the soil's moisture content will significantly alter soil wetness and the available water to the crop production. [8]. Matric potential was increased as water content decreased. Using saline water in irrigation was followed by increasing soil salinity and osmotic potential, so the plant suffered from both matric and osmotic potential in the dry season. The lesser the soil moisture content, the upper concentration of salts, so the rainy season is better for the plant due to minimizing both matric and osmotic potential. [14]

6.1.2. Climate – Infiltration (CI): In most areas where water shortages exist, it is important to increase rainfall penetration into the soil to ensure food and water protection. Land management should promote infiltration rather than escape. There are several exceptional cases where rainwater harvesting is required for crop production, and large-scale infiltration can lead to the risk of landslides or other types of mass movement [15]. The amount of rain that infiltrates can be controlled by the rainstorm's strength concerning soil infiltration rate. The rain penetration rate into the soil is influenced by the quantity, stability, and size of the soil surface pores [10].

6.1.3. Climate – Toxicity (CT): Toxicity also occurs when particular ions are absorbed with irrigation water and collect in crop leaves, leading to plant damage. In irrigation water, the specified toxic ions are boron, sodium, and chloride. The crops varied in their sensitivity to the toxic ions [16]. During cycles of high temperature and low humidity, harmful chloride and sodium ions will be sucked straight to the crop by moistening its leaves, which accelerates the sucking of the leaves using the accumulation of toxic ions [11].

6.2. A plant (P)

Plants are distinctive in the way they tolerate salts. The crop's capability to adapt to salinity is very beneficial, where certain crops can achieve reasonable produces at a much greater soil salinity than others. In areas where soil salinity cannot be managed, another crop can be chosen that is further tolerant of predicted soil salinity and can yield economic yields. There is a specific range of tolerances for salt in crops. This wide range of intolerance makes the use of reasonably salty water, most of which was formerly considered not fit to be used [1].

6.2.1. Plant – Osmotic (PO): Surplus salinity within the plant's root zone has a general harmful impact on plant growth, which is shown to be almost equal decreases in transpiration and growth degrees. The osmotic effect is because plants remove water from the soil by using an absorption force bigger than that that keeps the soil in the soil [17]. The extra salt in the water, the bigger the osmotic potential and the further energy the plant requires to remove water. Consequently, plants draw less water in soils with a high salt concentration than in soils with a little salt concentration. High salinity can therefore decrease plant obtainability of moisture and result in plant dryness.

6.2.2. Plant – Infiltration (PI): The type of plant significantly influences the infiltration rate, since the plant or trees' roots permeate the soil and create voids in it. On the other side, it also decreases the speed of water and increases infiltration [10]. Soil moisture is influenced by plant evaporation and water use. The infiltration rate decreases with an increase in soil moisture content. Dry soil makes it easier for water to penetrate since it includes pores and cracks.

6.2.3. Plant – Toxicity (PT): High stages of salts can too contribute to ion toxicity. Generally anxieties excess sodium and more prominently chloride ions that have a negative effect on plant enzymes. This great concentration of NaCl also decreases the sucking of important metal nutrients, K and Ca, which

more decreases cell growth, mainly in roots. Na's high concentration can also adversely affect physical soil conditions due to the possibly harmful accumulation of Na ions in plant texture. For example, rise the dispersal of soil particles and encourage crust formation, which reduces water infiltration. High salt levels also decrease the suck of some micronutrients, especially Fe [18].

6.3. Soil Texture (*S*)

Texture reference the proportional content of particles of diverse sizes, like sand, clay, and silt within the soil. Texture impacts the speed at which water can enter and move through the soil and, therefore, the ease with which soil is often worked.

Soil texture plays a crucial part in irrigated agriculture, and soil texture also affects salinity and sodicity. Soil texture helps determine what proportion of water will be ready to undergo the soil and how much water the soil can store. Sandy soils can flush more water through the root zone than clay soils. Sandy soils will tolerate higher salinity irrigation water because more resolve salts can be removed from the root zone by leaching [5].

6.3.1. Soil texture – Osmotic (SO). The osmotic potential (the real soil water concentration of salt depends on the soil's water content). The osmotic potential of the soil reductions due to an increase in salts' concentration in the solution when the water content reductions. The osmotic potential can be further suitable for determining the impact of salt on plant growth than for electrical conductivity. (Ben-Gal et al.,2009). It is essential to compare the influence of salinity on soils of diverse textures. Finer-textured soil has more water-retaining ability than rough soils. The osmotic potential of the soil solution is minor in the coarse-textured soil [17].

6.3.2. Soil texture – Infiltration (SI): Soil texture is the main inherent element influencing infiltration. In sandy soil water moves quickly through large pores more than through small pores in clay soil. If the clay is compacted and has little to no structure or accumulation, some clay soils become dry cause cracks to shrink [19].

6.3.3. Soil texture – Toxicity (ST). The high percentage of sodium ion to calcium and magnesium concentrations in soil solution is one of the farthest important elements on soil cluster dissolution in smaller sub-clumps. In addition to the dispersion of clay minerals and their accumulation in the soil's pores on its surface, it contributes to the hardening of the crust (surface crusting) and a decrease in porosity and permeability. Influences are most severe in clay soils where sodium can contribute to a structural breakdown [20].

6.4. Field management (*F*)

The effect of dissolved salts depends on the concentration of salt in the soil solution. Due to sampling problems, soil solution concentration in the normal field moisture content is challenging to quantify. The simplified method consists of mixing a soil sample with appropriate water to create a saturated paste and then extracting a solution to measure conductivity [21]. Reasonable agricultural irrigation and management practices (for example, leaching, salinity selection, and particular ion-tolerant plants) can minimize the harmful impact of salinity on crop production. In order to improve irrigation and agronomic management methods, salinity, and sodium are tested in the irrigation water to sustain crop yields, sustain or develop soil physical properties, and decrease hostile environmental influences.

6.4.1. Field management – Osmotic (FO). Salinity impacts crop growth through the absorption of plant water osmotic effect because the osmotic potential of the soil solution reduces the plant has less ability to access soil water thanks to the reduction of the general soil water potential. The potential osmotic lessening because the concentration of salt within the soil solution increases because the soil dries. The osmotic effect is modified by synthesizing organic solutes or taking over salts and classifying them in the plant part [22].

6.4.2. Field management – Infiltration (FI). Infiltration is impacted by land management practices causing surface crusting, compaction, and soil organic matter. Erosive powers of raindrops are soil particles dislodged. These particles seal in and block surface pores and participate in creating surface crusts that limit the flow of water to the soil [23].

Farming practices that lead to bad infiltration include: [24]

- Combining, combustion or harvesting of the crop remains to leave soil nude and susceptible to erosion.
- Tillage methods and soil trouble practices interrupt surface connected pores and avoid the accumulation of soil organic matter.
- Equipment and cattle traffic is used, particularly on wet soils which reason compaction and reduce porosity.

6.4.3. Field management – Toxicity (FT). The most successful way to avoid toxicity problems is to select irrigation water that has little potential to produce toxicity if such water is not used. There are also management options that can be used to minimize toxicity and increase efficiency. Potentially toxic sodium, chloride, and boron ions can be decreased by leaching. Relatively petty changes in farm practices can mitigate the effects [25].

6.5. Irrigation Method (IM)

Irrigation is the method of adding water to the soil to fulfil the needs of developing plants for water. Over time, different irrigation methods have been advanced to meet the irrigation needs of certain crops. The three major methods of irrigation are surface, sprinkler, and drip [1].

- **Surface irrigation** means the application of water by gravity of the flow of water to the field's surface. Either the entire field is flooded, or the water is fed into small channels.
- **Sprinkler irrigation** is alike to natural precipitation where the water is pumped into the pipe system through the revolving sprinkler heads and then sprayed onto the crops.
- **Drip irrigation** is the latest field irrigation technique. Drip irrigation is sometimes called trickle irrigation. Water is transferred under pressure through the pipe system to the fields, where it drips gradually through the emitters into the soil.

Whatever method of irrigation is chosen, its purpose is to achieve better crop yields and higher yields.

6.5.1. Irrigation method – Osmotic (IMO): The irrigation method may play an important part in controlling salts in the root zone. The relationship between the growth of crops and the position of salts relative to the placement of roots or seeds is a significant factor of soil importance to achieve a more favourable salt distribution. Irrigation methods may also be changed; most plants need a continuous supply of readily available moisture to grow naturally and achieve high yields. The soil moisture content is the highest after an irrigation event. The soil solution's osmotic pressure is low if the soil gradually dries out due to lack of evapotranspiration. Plants will be exposed to very high soil moisture stress resulting in losses if saline soils are rarely irrigated [26]. Figure (2) shows the result of the osmotic and the matric potential. Increasing the salinity increases the osmotic potential, but the increase in the moisture content reductions the matric potential. Therefore, if the irrigation water is saline, drip irrigation is used to make the matric, and osmotic totality within the plant capacity is acceptable.



Figure 2: the result of the osmotic and the matric potential

6.5.2. Irrigation method – Infiltration (IMI): Infiltration characteristics are important parts of the irrigated field, which differ through irrigation from one irrigation to another and from one field to another. At the beginning of the season, the soil surface is relatively rough due to tillage operations, but the vegetative cover is thin as the irrigation season advancements. The surface may become fine due to erosion and deposition of the soiled material, but the vegetative cover will become denser. As a result, this variance has a complex effect on the penetration of surface irrigation. This variance also affects the ranking of infiltration factors, the design, and evaluation of irrigation systems [23].

6.5.3. Irrigation method – Toxicity (IMT): Toxicity problem occurs when the sprinkler ingests excessive levels of boron, sodium, and chloride from the irrigation water through wet leaves. High-frequency sprinkler irrigation creates a problem; some activities may require minor adjustments while others may require more detailed modifications, including the irrigation system [6].

7. Modelling using saline water in irrigation

Irrigated agriculture would make a major contribution to meeting the world's food needs, but at the same time, would have to struggle for ever more scarce water sources. However, by reassessing the suitability of water for irrigation, the available supplies can be greatly increased. Quite conservative criteria have been implemented in the past. If these requirements are relaxed, water commonly classified as being too salty for irrigation can often be used effectively without dangerous long-term consequences for crops or soils, even under traditional farming practices. The use of modern crop and water management techniques would encourage salt water for irrigation and could potentially contribute to a major expansion of irrigated agriculture [27].

Modelling water and soil motion help to explain salinity build-up and leaching processes. Also, it helps to extract additional information that can be used for the design of field trials[28]

Many computer models have been built to simulate crop growth in the presence of water or salt stress, some of which are very detailed and technically sound, while others are relatively simple. Theoretically, sound models need detailed experimental help and need an exhaustive amount of input data that may not be available at times. However, such models deliver the most persuasive results and expand the insight into the problem [29].

The results of studies conducted by the researcher (Rhoads 1968-1992) on his program (Wat-Suit), the summary of the two words (water suitability). It is a computer program that predicts soil-water salinity, sodicity, and toxic-solute concentration. It can be used to evaluate the effect of sodicity level on soil permeability and the effect of a given salinity level on crop yield.

Water suitability for irrigation is completed by comparing predict soil water compositions, salinities, and sodicities obtained from Wat-Suit with salinity, permeability, and toxicity requirements. Indirectly, the influence of irrigation frequency is taken into account by altering the salinity index [30].

8. Leaching Requirements (LR)

The additional amount of irrigation water the plant needs from waterworks to wash away the accumulated salts towards the root zone's bottom. The irrigation water salinity and the crop tolerance to soil salinity need to be known for evaluating the leaching requirement.

The essential leaching requirement (LR) can be expected from the leaching requirement equation [31] :

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

LR: leaching requirement and fraction.

EC_w: salinity of irrigation water in dSm-1.

EC_e: average crop tolerated salinity.

The leaching requirement (LR) is a specific quantitative value defined as the minimum LF needed for a particular irrigation water quality, especially in the growing period. A reliable and accurate LR

value is essential for the efficient use of irrigation water. Underestimation of the LR will result in salt accumulation in the root zone and a decrease in yield. At the same time, overestimating the LR will lead to excessive water use and removal of nutrients, negative environmental effects on groundwater or irrigation water, and a decline in crop water yields [32].

A measurement of the leaching requirements is needed to examine whether the average amount of filtration water meets the minimum leaching requirement to prevent soil salinization [33].

By increasing the effective precipitation ratio, the effect of leaching requirements on production is decreased. But the increase in production due to increased leaching requirements is much more significant than the increase in production associated with increased precipitation [34].

Often, the terms leaching fraction (LF) and leaching requirement (LR) are used interchangeably. They both discuss the irrigation that would pass through the root zone to control salts. Researchers almost expressed LR as a fraction or a percentage of irrigation depth, while the expressed LF only as fraction [1].

If the soil salinity decreased, the leaching requirements increased, which means the crop production improved. When using saline water for irrigation purposes must be followed by increasing leaching fraction (LF) to maintain acceptable salt water balance within the depth of the root zone. [35]

9. Conclusion

The effects of salinity were expressed in three columns: osmotic, infiltration, and toxicity - and field conditions in five rows: Climate, Plant, Soil texture, Field management, and Irrigation method.

It also shows that climate change has major effects. The higher the soil moisture content, the plant ability to slurp water from the soil more increases (osmotic effect), the amount of rainfall affects the rate of infiltration into the soil. During periods of high temperature, the leaf preoccupation speeds the level of accumulation of toxic ion.

Crops differ in the carry salinity; each plant has its power of absorption. The type of crop also dramatically influences the infiltration rate. Soil texture has an integral part in all sides of irrigated agriculture. The water retention ability of a more refined textured soil is more significant than a coarse-textured soil; the soil solution's osmotic potential is minor in the coarse-textured soil. Soil texture is the main aspect affecting infiltration.

Proper agronomic management practices can reduce the adverse effect of salinity on crop production and reduce a toxicity problem.

The irrigation method is of utmost importance to attain a better crop and a higher yield. The irrigation method plays an important role in controlling salts, infiltration, and toxicity.

Many models are developed to minimize the salinity effects and maximize using moderate saline water in irrigation.

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