# SALT LEACHING EFFICIENCY OF SUBSURFACE DRAINAGE SYSTEMS AT PRESENCE OF DIFFUSING SALINE WATER TABLE BOUNDARY: A CASE STUDY IN KHUZESTAN PLAINS, IRAN

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**ABSTRACT** To design subsurface drain spacings and depths, the main efforts are usually focused on so-called equivalent depth as well as selecting a steady/unsteady drainage model. These models have been used widely for half a century and some software are developed to design the drainage systems. In spite of recent developments in drainage such as dry-drainage, bio-drainage and controlled drainage, the main concern remains on subsurface water quality and its harmful impacts on environment. In regions were the drainage system is most needed for salt leaching at reclamation stage as well as agricultural reclamation rotations, the main concern is salt concentration of drainage outflows. There are some examples in Iran that demonstrate irrigation and drainage networks that are well equipped with open and subsurface drainage systems. Application of suitable irrigation water provides an overall irrigation efficiency of 35-40%. As a result, in surface irrigation practices, the deep percolation is larger than leaching fraction and leaching requirements of the properly arranged cropping patterns in the crop rotation programs. Such conditions are observed in some projects for which the initial/capital salt leaching was well managed, but still after a long time salt concentration in drainage water is much larger than the applied water salinity of the same soil profile. Detail studies indicate that this can be attributed to existence of Salic/Natric horizons below the field laterals and/or sub main drainage canals, presence of highly saline stagnant or perched water tables below the drains which act as a diffuse boundary and low salt leaching efficiency.

**Keywords:** Drainage water quality, Drainage outflow salinity, Drainage performance, Salinity.

**INTRODUCTION** Iran is located between 25-40 degrees North latitude and 44-64 degrees East longitude, covering about 165 million hectares. A great part of the country is covered by mountains surrounding the rocky, sandy, and saline deserts of the central plateau. This naturally forms a closed basin containing various kinds of accumulations. The two major mountain ranges in Iran are Elburz and Zagrus which form a great V-shaped physiographical area. The other three main physiographical areas are: the area within the V-shaped unit beginning as a high plateau, and consisting of the secondary ranges with the slope gradually ending in the deserts; the region of Khuzestan, which is a continuation of the Mesopotamian plains and is a low - lying plains; and finally the Caspian Sea coastal areas which form a separate climate condition since its elevation is below the sea level.

Iran is indeed a country of plateaus which are mainly surrounded by high elevated mountains that hinder the intrusion of moisture - laden atmosphere into the central plateaus. With the exception of the Caspian Sea area, the climatic conditions in other parts of the country change from semi - arid to arid depending on the location and altitude. Moreover, distribution of rainfall is not uniform throughout the year and precipitation mostly occurs during the winter season with an average of about 240-250 mm. The aridity along with high temperature and high evaporation rate (some places > 2000 mm / year) which exceed the precipitation is dominant in most parts of the country and is nearly the same in all plateaus.

Water is not always available in the area where good soil can be found. Also considering the poor quality of irrigation water and improper use of water in agriculture, salinity problem has caused gradual reduction of the soil productivity in many noticeable areas. Many large scale irrigation projects were made possible through the completion of various dams. Since the soils of the area, in which the water is becoming available, were less valuable than the other soils, improper soil drainage condition and irrigation management lead to salinity and sodicity of these lands. Under this condition, their desalinization and reclamation is compulsory and quite expensive. It is obvious that soil and water salinities are the main limiting factors affecting crop production in arid and semi-arid region of the country. This may lead to an extra yield reduction when coupled with water scarcity (Homaee, 2002). The recently collected agricultural statistics shows that the total annual area of cultivated lands is estimated to be 13,418,241 hectares; 6,739,810 hectares irrigated and 6,678,431 hectares of dry farming, respectively (Ministry of Jihade-Agriculture, 2008).

It should be noted that total areas equipped with drainage systems all over the irrigated lands are estimated to be 180,000-200,000 hectares, from which 120,000-150,000 hectares are located in Khuzestan province and still there are priority to study and design 350,000 hectares for the irrigation projects (Akram, et. al.2010).

**Salinity Problems in Iran** About 25 million hectares, which is equal to 15% of the total area of the country, suffer from salinity, sodicity, and water logging, as well as a combination of these problems. In arid and semi-arid parts of the country, the main cause of salt accumulation in the soil is water scarcity. Low amount of yearly precipitation in these regions has not been effective to leach out the soil salts. Consequently, most soils become inherently salty. However, it may result also from the presence of high amount of salts in the parent material from which the soils are formed.

Generally, all water resources in Iran contain salts that increase from the center of origin to the sea**,** or groundwater resources. Another factor that contributes to soil salinization is the depth of saline groundwater; salinity is up to 2.5 meters from the soil surface. In this condition, the upward movement through capillary will facilitate the period of salinization, if the soil texture is fine, which is predominant in the most irrigated projects of Iran (Pazira and Homaee, 2003).

The removal of salts from these areas by rainfall depends on whether the soils are permeable or not. The causes of water logging, in Iran are from different sources of seepage, water losses and irrigation with improper water distribution and management. The two main conditions that cause soil salinity in Iran are as follows:

**- Salinity due to natural conditions**, parent material, salt lakes, salt marshes close to sea or lakes, high saline water table, surface and groundwater resources quality.

**- Man made salinity**, commonly the irrigation efficiency is as low as 40- 35% and also as a habit and practice, the farmers, whenever they have to work on saline soil, will apply more water for irrigation, which will rise the water table, and so on.

**Salt affected Soils** In Iran many different types of salt-affected soils can be observed as a result of the interplay of various factors. Generally, the basis for the cycle of formation of these soils is a secondary accumulation of salts and a redistribution (Kovda, 1973).

The description of various groups of saline soils based on their properties and forming conditions were done by Dewan and Famuri (1964). The grouping was prepared in a rather broad way for the purpose of relating, their use and feasibility of reclamation as follows;

- 7.7 million hectares Aridisols and Entisols, consist of Saline and Saline Alluvial soils which can be considered as reclaimable lands.

- 8.2 million hectares Salt Marsh soils, consist of Aridisols and great soil group of Aquisalids which can be reclaimed through much care and expenses.

- 7.6 million hectares consist of soils which are immature or with very low maturity and are formed on Limestone or originated from Saliferous and Gypsiferous marls. These soils are shallow in depth and mostly Saline and Sodic, which can be considered as Entisols and some parts are Aridisols. The mentioned soils inherently are not suitable for reclamation.

From the above discussions, it can be estimated that the total area of salt-affected soils in Iran is about 23.5 million hectares which is about 14.2% of the total area of the country, or 30% of the total plains and flat – sloping lands. Considering the land being and can be irrigated, the extent of salt soil formation will be much more than 50%.

**Solutions for Soil Salinity Problems** The requirements for the establishment of reclamation projects, according to the local condition of Iran, are as follows;

- Topography of the area should be suitable for the purpose of reclamation practices.

- Salt leaching which is the key of land improvement should not have special difficulty. The reclamation of salt-affected soils should be done by simple leaching practices to bring them to non-saline, non-sodic soils for economical crop production. Otherwise, this group of soils may be considered unsuitable for reclamation.

- Sufficient water should be available for reclamation, irrigation and leaching practices.

- Drainage facilities should be available within the projects or should be established.

- The quality of irrigation water must be fair.

Since most of the above requirements had been fulfilled in Khuzestan plains and also much research and execution works had been done in this area for the purpose of soil desalinization and land reclamation projects, the Khuzestan plains area was chosen for this analysis. We assume that the obtained results can be used for a large part of the country especially in South and South-West part of Iran, if the above mentioned requirements are available.

**Khuzestan plains** Khuzestan province (part of Khuzestan plains) is located in the South-Western part of Iran and covers an area of about 6,465,900 hectares. The province is situated between 47°, 37' and 50°, 30' East longitude, and 29°, 56' and 33° North latitude. It is surrounded at the North and East by the Zagrus and Bakhtiari mountains, at the South by the Persian Gulf, and in the West by Iraq. The plains are almost flat or with gentle slope, but in the Northern parts about 100-170 meters above the sea level.

Historians believe that Khuzestan is one of the oldest areas in the world where irrigation was first used. According to some documents, between 1500-2000 years ago Khuzestan was one of the most prosperous and populous parts of ancient Iran. During that time, very important irrigation schemes were set up. Some of the remains of irrigation canals and dams which are more than 1500 years old can still be seen in the area. At that time barley, cotton, wheat, rice, some kinds of sugar cane, citrus trees and date palms were grown (Smith and Darvish, 1965).

**The Climate** Khuzestan has a long summer with a short moderate winter. The maximum temperature of the region is 52°C the minimum is 1°C, the average yearly temperature is about 24°C-28°C. The annual relative humidity of the region reaches 50%. Its annual rain ranges from 150 to 350 mm. The average annual evaporation exceeds 2000 mm based on class A-pan. From the climatic point of view, the region can be described as arid and semi-arid zones.

**Sources of Irrigation Water** From the mountains in the North and East, the following rivers flow into the province: Dez, Hendijan (Zohreh), Jarrahi (Djarrahi), Karun and Karkheh. The Shavour river drains the Southern part of the area between the Karkheh and Dez rivers. All of these rivers are potential sources of irrigation water, while the sources of irrigation water for already constructed irrigation projects are the Dez, Karun, Karkheh, Shavour, Zohreh and Jarrahi rivers. The total annual surface water flowing in the plains is estimated to be 33.5 billion cubic meters which is about one third of all surface waters in the country.

**Soils of Khuzestan** Khuzestan plains, a continuation of the Mesopotamian plain, is a vast low - lying area in the South-West part of Iran. The plains are almost covered by the deltas of the Dez, Karun and Karkheh rivers. The soils consist of alluvial deposits that have coarse texture toward the mountains and very fine texture toward the plains and at the South-West parts of Ahvaz city the deposits consist of large quantities of silt and clay. In general the two major soil orders in the plains are Aridisols and Entisols, with the texture varied from Clay, Silty-Clay to Clay –Loam, the type of soils mineral clay is Smactite (2: 1).The soils temperature and moisture regimes toward the mountains and plains are Thermic, Ustic and Hyperthermic, Aridic respectively. The soil structures are Blocky and Sub angular Blocky in the top soil layers and Columnar (in saline and saline-sodic soils) or without structure in subsurface horizons. From geological point of view the alluvial deposits of the plains belong to the Quarternary period and almost originated from Gachsaran and Aghajary formations which are naturally Saliferous and Gypsiferous marls, this causes the soils in the plains to be mostly salty with the diagnostic Salic horizons(Aquisalids or Haplosalids).The soils of the region are fertile but contains much soluble salt, low amount of gypsum in the form of small crystal and mycelium and high amounts of calcium carbonate. The former minerals (Cambids,Calcids,Gypsids) even with low amount of solubility act to prevent the soil sodicity during reclamation period especially at the stage of initial or capital salt leaching, which is the key of soil reclamation, if the internal soil drainage is fair or it is improve.

**Agriculture in Khuzestan** As noted already, out of the total area of 6,465,900 hectares in Khuzestan province, the area of the fertile Khuzestan plains comprises about 3.0 million hectares according to the FAO survey in 1953. The potential irrigable lands were recognized to be 750,000 hectares which are mainly found in Northern part of the plains. The available statistics at the Ministry of Jihade- Agriculture pointed out that in Khuzestan province there are nearly 1.5 million hectares arable lands. Since there are hot and dry summers and rather mild winters, Khuzestan is well suited for early fruits, vegetables, and grain productions. The agricultural products of the region are wheat, barley, rice, pulses cucumbers, tomatoes, melons, sugar cane, sugar beet, vegetables, foliage crops, dates and citrus. The total area of cultivated lands is estimated about 1,146,660 hectares; 758,113 hectares are irrigated and 388,547 hectares are under dry farming respectively. It should be pointed out that the province is ranked 2$^{nd}$ in the country from the view point of cultivated lands in agriculture (Ministry of Jihade-Agriculture, 2008).

**Agricultural Problems in Khuzestan** Generally, the main restrictive factors on agricultural development in this region can be summarized as:

- The unique climate with extremely hot summers,
- The limited amount of available water for irrigation,
- Water quality problems,
- Salinity, sodicity and water logging problems of the soils, and
- Pest problems which are specified for the region.

The last problem will not be discussed in this paper. However, the other problems will be dealt with some details as they are more typical for the region.

**Salinity, Sodicity and Waterlogging** The origin of the soils in Khuzestan plains is river alluvial. Considering the climatic conditions of the region, the very high rate of evaporation (on bare soils) and evapotranspiration, salt accumulation in topsoil layers is extremely high. Generally another factor which enhances salt accumulation in Center, South and South-Western areas of the plains is the raising up of the groundwater table during irrigation which facilitates soil salt concentration increases when soil is heavy textured.

Detail studies pointed out that among many factors leading to soil salinization and sodication, the following causes are more noticeable; shallow and saline groundwater, existence of salt concentrated layers in the soil profile, salinity of irrigation water, destruction of natural vegetation and consequently increase in evaporation, effect of wind storms and sand precipitation, rivers overflow sediments, heaviness of soil texture and improper soil drainage conditions, predominance of evaporation over rainfall in non irrigated lands and anthropogenic(Pazira, 1999).

As mentioned before, the soils in Khuzestan plains are mainly in the flood plains and deltas of Karun, Dez and Karkheh rivers, and are of both medium and heavy texture due to the natural course of sedimentation. The Northern part of the plains consists of medium textured sandy loam soils which are well drained. Therefore a salinity problem does not exist in that area. On the other hand, the Western part of plains, Karkheh area, is a low land with the same soil texture, but with a salinity problem. In the Southern part of the plains, the soil is heavy textured clay loam with poor drainage, also salinity, sodicity and water logging is very serious problems.

**Investigation for Drain Spacing** Drain spacing determination can be done using drainage equations which are available for different situations. The equation helps to express quantitative relations among various factors governing the flow of water to the drain such as, hydraulic conductivity (K), the height of the water table above the drain level or hydraulic head (m), drain spacing (L), location of soil impermeable layer in the soil profile (HP), and finally, the rate of draining or rate of drain discharge (q). The drain spacing and hydraulic head will help to determine the hydraulic gradient which is the driving force of the flow towards the drains. In case where the flow is in the non-steady state, the soil drainable porosity (S) must be considered.

However, in most cases, the flow of water into the drains varies considerably with time, because the rates of irrigation and/or rainfall are not uniform. As a result, under the real conditions, the flow into the drains is non- steady. For most field conditions, it is much more simple and practical to apply steady state solutions to the drainage design.

The most well known steady state equation was developed in (1936) by Hooghoudt. This equation is based on the Dupuit-Forchheimer assumption and appropriate modifications were done by Luthin (1965) for flow convergence near the drains as follows:

$$L^2 = (8K_b de.m / q) + (4K_a m^2 / q) \tag{1}$$

Where; L = Drain spacing (m) , $K_b$ =Hydraulic conductivity of the soil below the drain (m/day), $K_a$ = Hydraulic conductivity of the soil above the drain (m/day), $d_e$ = Equivalent depth (m), m = The height of the water table above the drain level or hydraulic head (m), and q = The rate of draining or rate of drain discharge(m /day).

If the soil profile is homogenous /or a single value for $\overline{K}$ is desirable (weighted average) the same equation can be used too. As mentioned before, under the real field conditions, usually, the non-steady state flow is predominant. Several equations have been introduced in this regard. One of the most practical and suitable equation was developed by Glover and Dumm (1960). The modified form of this equation can be defined as follow:

$$L= \pi \, [t \, K \, (de +0.5y_o)/S]^{0.5}[\ln(1.16(y_0 /y_t)]^{-0.5} \qquad (2)$$

In which: t= Irrigation intervals (days), S= Drainable porosity (%), $y_\circ$ = Maximum water table height above the drain (m), $y_t$ = Variable water table height as a function of time (m), K = Average hydraulic conductivity of soil profile (m/day), and Ri = Recharge rate or deep percolation (m). Other symbols are defined previously. It should be stated that if m in equation (1) is substituted by $m = [0.5(y_\circ + y_t)]$, which are exist in equation (2), the calculated L (drain spacing) will be rather the same (Ritzama,1994 ).

As it was already mentioned the total area under the drainage system in Khuzestan province, is about 120,000 hectares, which are mainly belong to Sugar Cane Agro-Industry Companies, as the result the subsurface drainage computation is done for this perennial and industrial crop ,which is the most high water demanding crop too. Using equation (1) as an primary estimation ,then equation(2) for a more accurate calculation and finally applying the dynamic equilibrium concepts, based on irrigation scheduling of the sugar cane resulted to the subsurface tile drain spacing of 60-75 meters apart ,in the condition that the depth of installations were 2.0 meter from soil surface. The drain spacing seems to be in conflict with soils textures mentioned before, but regarding the amount of natural sources of Calcium in the soil profile, enable the same to have a much better soil physical properties than the same soil textures. Another factor which can be contributed in this sense is the rather deepness of the restricted layer in the soil profile, which was varied from 4.0 to more then 6.0 meters. Even with a drainage coefficient of 5.0 mm /day or 25.0 mm per irrigation intervals of 5 days in most critical duration of growing period, which is in the month of July. The mentioned conditions were set up to maintain the water table at the depth of 1.5 meter below the soil surface, which is a very conservative value (Pazira, et, al, 1997).

**Soil Desalinization and Desodification.** Accumulated salts in the soil profile can affect the chemical and physical properties of soil, such as osmotic pressure, permeability, and infiltration so adversely that the plant growth is either partially or completely stunted. The results of high solubility of sodium ($Na^+$) salts and precipitation of calcium carbonate ($CaCO_3$) at high values of pH which will occur in nature, lead to increasing of salt contents (salinization) and soil solution pH (alkalinization/high pH). Consequently, the soil sodication (alkalization/high ESP) will be enhanced (Leffelaar and Sharma, 1977).

Therefore, in irrigated agricultural practices, the harmful levels of soil salinity and sodicity should be reduced to lower and safer values. Experimentally as well as practically, soil salt leaching can be done by continuous and intermittent ponding methods for improvement of salt-affected soils (Pazira et al,1998).

Since 1966 much efforts had been put forth to study the possibilities for reclamation of the saline and saline- sodic soils of the Khuzestan plains. Among others Famuri (1966), Pazira and Kawachi (1981), Pazira et.al (1998), Pazira (1999), Pazira (2006), Mohsenifar et.al (2006) and Rajabzadeh et.al(2009), carried out field experiments in most saline-sodic soil of the area and introduced some empirical models for determination of reclamation water requirement as well as predication of final soil salinity and sodicity. The above mentioned research results indicated that, there is no necessity to use any soil amendment agent such as Gypsum. This was in conflict with Dielman (1963), who stated that if the soil chemical agents are not used the soil salt leaching would fail.

**Desalinization** The principle of soil desalinization consists of leaching out the soluble salts downward, especially from the top soil layers. This can be done by means of leaching water application as well as irrigation. The percolated water (leachate) contains much soluble salts which should be removed by installment of subsurface drainage systems, if the ground water table is high. The presence of high saline water table causes the soil internal drainage condition to be insufficient and poor.

A comprehension and detail study was done on the research works mentioned above to conclude and introduce an empirical equation, which could be used in a wide range of the region conditions, also attempts were focus to use more parameter in its derivation, keeping in mind the principle of so called Dielman (1963) leaching theory, using SPSS and Curve Expert softwares, with some modification to be practically applicable. It was concluded that the most suitable mathematical expression, is in the form of exponential function that can be presented as follows:

$$Y = a \exp(-b.X) \qquad (3)$$

in which Y= [($EC_f$ -$EC_{eq}$) / ($EC_i$-$EC_{eq}$)], and X= [Dlw /Ds]; $EC_i$ and $EC_f$ are the initial and final Electrical conductivity of soil saturation extract ($dSm^{-1}$) and $EC_{eq}$ represents the Electrical conductivity of the same soil extract obtained after an equilibrium level of salinity reached under the given condition ($dSm^{-1}$).

The Dlw/Ds is called "depth of leaching water per unit depth of soil" and Dlw is the depth of leaching water (net depth of applied water) and Ds is the depth of soil, a and b are numerical experiment constants .Inserting (f) as the leaching efficiency coefficient (-) and ($\theta v$), volumetric water content $(Cm^3/Cm^3)$, resulted equation (3) to be in the form of following equations:

$$[(EC_f - EC_{eq})/(EC_i - EC_{eq})] = a .\exp \{- b. [Dlw / Ds]. [f / \theta v ] \} \qquad (4)$$

or:

$$[(EC_f - EC_{eq})/(EC_i - EC_{eq})] = a .\exp \{- b. [f. Dlw] / [\theta v . Ds]\}$$

Solving the above mentioned equations for unknown desirable values yields (Pazira, 2006):

$$f = \left(\frac{Ds.\theta v}{b.Dlw}\right) \ln\left[\frac{a\,(EC_i - EC_{eq})}{(EC_f - EC_{eq})}\right] \qquad (5)$$

$$Dlw = \left(\frac{Ds.\theta v}{b.f}\right) \ln\left[\frac{a\,(EC_i - EC_{eq})}{(EC_f - EC_{eq})}\right] \qquad (6)$$

$$EC_f = (EC_i - EC_{eq}).a.\exp[-b(Dlw.f)/(Ds.\theta v)] + EC_{eq} \quad (7)$$

From the above mentioned equations it can be seen that as the depth of leaching water or the ratio of leaching to the depth of soil increases, the salt leaches, also increases and the rate of salt leaching within the soil profile increases with an increase in depth of leaching water. However, in general, the mean depth values and the obtained results seem nearly to be the same. The salinity will be reduced only to a special rate (ECeq =1.5- 2.0 times ECw of irrigation water, $dSm^{-1}$), either under high or low application of leaching water. Therefore, it can be concluded that the reclamation requirement will be strongly related to the initial soil salt content, soil physical condition rather than to the increase in depth of leaching water. It should be pointed out that, $EC_{eq}$ represents the Electrical conductivity of the same soil extract obtained after an equilibrium level of salinity reached under the given condition. The value of $EC_{eq}$ is considered as $EC_e$ of the upper layer of soil profile, after the leaching has stopped.

Dielman (1963) stated that it depends mainly on evaporation, internal soil drainage conditions, and salinity of the irrigation water (ECw). When the value of $EC_{eq}$ is subtracted from $EC_f$ and $EC_i$, the relationship $[(EC_f\text{-}EC_{eq}) /(EC_i\text{-}EC_{eq})]$ and (Dlw/DS) become independent of the ECw, existing drainage and evaporation conditions, thus the resulting equation(or graphs) solely determined by soil characteristics. To facilitate the calculations procedure, efforts were made to prepare Table 1 for estimating the amount of water required (Dlw or net water requirement) to reduce the soil salinity class to the desirable value in the soil profile, as a directory in this regards for the region. This was in conditions were the quality of applied leaching water was ranging from C2 S1- C3 S2 according to USSL (1954).

As can be observed from the data presented in Table 1, for conditions when the initial soil salinities are at the Classes of $S_4$ and $S_3$ (extremity saline to very saline), their reclamations may need huge amount of leaching water, if it is desirable to bring them to non-saline or slightly saline soils directly, thus in such a cases it would be much economical and practical to choose the stepwise methods for their reclamations. This can be done by intermittent salt leaching method, which was recommended by some other researcher for similar conditions (e.g. Abrol .et al, 1988).

Furthermore, it is worthy to use a unit depth of leaching water per unit depth of soil segment (which is roughly equal to two pore volumes of water, in heavy textured soils) as the reclamation requirement and to continue the salt leaching gradually by irrigation through the principle of leaching requirement if leaching of soluble salts from the soil profile is our target (Pazira, 2006 ).

Table.1. Reclamation water requirement (Dlw) for different soil depths with respect to soil salinity class ($10^3 M^3 ha^{-1}$)

| Soil salinity class after leaching | Soil salinity class prior to leaching (dS/m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $S_1$ | | | $S_2$ | | | $S_3$ | | | $S_4$ | | |
| | Soil depth (cm) | | | Soil depth (cm) | | | Soil depth (cm) | | | Soil depth (cm) | | |
| | 0-50 | 0-100 | 0-150 | 0-50 | 0-100 | 0-150 | 0-50 | 0-100 | 0-150 | 0-50 | 0-100 | 0-150 |
| $S_0$ | 0.60 | 1.20 | 1.80 | 3.40 | 6.80 | 10.20 | 6.80 | 13.6 | 20.40 | 8.20 | 16.40 | 24.60 |
| $S_1$ | - | - | - | 0.20 | 0.40 | 0.60 | 1.80 | 3.60 | 5.40 | 3.30 | 6.60 | 9.90 |
| $S_2$ | - | - | - | - | - | - | 0.12 | 0.24 | 0.36 | 0.50 | 1.00 | 1.50 |
| $S_3$ | - | - | - | - | - | - | - | - | - | 0.10 | 0.20 | 0.40 |

* Soil salinity classes are based on the classification used by Soil and Water Research Institute of Iran.

| Salinity Class | $S_0$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ |
|---|---|---|---|---|---|
| EC (dS/m) | <4 | 4-8 | 8-16 | 16-32 | >32 |

**Desodification** The arable, but saline-sodic soils in the Khuzestan plains, can be considered as "pseudo alkaline" because their sodicity is related to high concentration of soluble salts in soil solution and extract, which appears in the SAR. Famuri (1966) stated that the presence of natural calcium in the soil even with low degree of solubility prevent the same to be non-sodic during the leaching process. But still some field experiments were conducted using gypsum and sulfuric acid to confirm the former noted results. As it was expected there were no significant sign in the same regards, but application of sulfuric acid improved the soil infiltration rate at the first stage of initial/or capital salt leaching which facilitate the time of soil reclamation to be rather reduced. But from the view point of chemical reaction there was no notice able results to be pointed out. As in the case of soil desalinization , comprehension and detail study was done on the research works mentioned above to conclude and introduce an empirical equation for soil desodification as well, which could be used in a wide range of the region conditions, also attempts were focused to use more parameters in its derivation, using SPSS and Curve Expert softwares, with some modification to be practically applicable. It was concluded that the most suitable mathematical expression, is in the form of exponential function too, that can be presented as follows;

$$Y = a.\ \exp(-\ b.\ X) \qquad (8)$$

where $Y = [(ESP_f - ESP_{eq}) / (ESP_i - ESP_{eq})]$, and $X = [Dlw / Ds]$

in which $ESP_i$ and $ESP_f$ are the initial and final soil Exchangeable Sodium Percentage (calculated from SAR-ESP ,or CEC-Ex $Na^+$ relationships) and $ESP_{eq}$ represents the ESP of the same soil obtained after an equilibrium level of ESP or SAR reached under the given condition.

The Dlw/Ds is called "depth of leaching water per unit depth of soil" and Dlw is the depth of leaching water (net depth of applied water) and Ds is the depth of soil, a and b are numerical experiment constants. Inserting (f) as the leaching efficiency coefficient (-) and ($\theta v$), volumetric water content $(Cm^3/Cm^3)$, caused equation (8) to be in the form of following equations:

$$[(ESP_f-ESP_{eq})/(ESP_i-ESP_{eq})]=a.\exp\{-b.[Dl / Ds].[f / \theta v]\} \tag{9}$$

or:

$$[(ESP_f-ESP_{eq})/(ESP_i-ESP_{eq})]= a.\exp\{-b.[f.Dlw]/[\theta v.Ds]\}$$

Solving the above mentioned equations for unknown desirable values yields (Pazira, 2006):

$$f = \left(\frac{Ds.\theta v}{b.Dlw}\right)\ln\left[\frac{a\,(ESP_i - ESP_{eq})}{(ESP_f - ESP_{eq})}\right] \tag{10}$$

$$Dlw = \left(\frac{Ds.\theta v}{b.f}\right)\ln\left[\frac{a\,(ESP_i - ESP_{eq})}{(ESP_f - ESP_{eq})}\right] \tag{11}$$

$$ESP_f = (ESP_i - ESP_{eq}).a.\exp[-b(Dlw.f)/(Ds.\theta v)] + ESP_{eq} \tag{12}$$

From the above mentioned equations it can be seen that as the depth of leaching water or the ratio of leaching to the depth of soil increases, the salt leaches, also increases and the rate of salt leaching within the soil profile increases with an increase in depth of leaching water. The soil Exchangeable Sodium Percentage (ESP) will be reduced only to a special rate (ESPeq =1.7- 2.4 times SAR of irrigation water), either under high or low application of leaching water. Therefore, it can be concluded that the reclamation requirement will be strongly related to the initial soil sodicity, soil physical condition rather than to the increase in depth of leaching water. It should be pointed out that, $ESP_{eq}$ represents the ESP of the same soil obtained after an equilibrium level of sodicity reached under the given condition. The value of $ESP_{eq}$ is considered as ESP of the upper layer of soil profile, after the leaching has stopped.

From above mentioned, it is evident that Desalinization automatically takes care of soil Desodification. Therefore, in reclamation of salt affected soils of the region, the amount of waters mentioned in Table 1, will be sufficient for both desalinization and desodification targets, and again it can be concluded that it is not necessary to use any amendment such as gypsum for reclamation of these soil.

## CAUSES LEADING TO LOW SOIL SALT LEACHING EFFICIENCY

**Methods of physical land preparation and initial/or capital leaching** In the modern irrigation and drainage projects, land leveling is done prior to initial soil salt leaching, in conditions were heavy machinery is used for this purpose, as its result the surface land of the fields are completely compacted. To reduce the former effects in respect to water penetration into the soil surface, at least soil sub soiling will be done two times perpendicular to each other, this will increase the top soil porosity to a depth of 0.5 meter or even a little more. Appling the leaching water in such a condition enhances the solutes movements downwards, but only to a depth which is made permeable by the methods mentioned above. The leachate water face the retardation in vertical penetration in sub soil layers, as these horizons are in natural forms and will act and behave according to their own properties. In such cases a “quasi external salt concentrated horizon“ will be formed, as the result its desalinization and will be rather independent from depth of applied leaching water, but time dependent. This can be considered as a serious problem in respect to soil resalinization if special care is not done. Soil desalinization in such condition is a long process, even if the field is equipped with subsurface drainage and the quality of irrigation water is fair as it is in the case study area.

**Improper depth of Subsurface (tile drain) installations** As it was mentioned in pervious sections, the depth of subsurface drains (field laterals) are fixed to be about 2.0 meters below the fields soil surface, this was done according to the idea that if the drains are installed deeper, their spacing will increase if the other conditions are the same. Recently it is recommended to decrease the depth of field lateral drains, for which some agronomical and technical benefits such as; more rapidly chemical equilibrium in soil water will be achieved, plants can consume some of their needed water from ground water, adaptations of annual and perennial field crops to salinity and water stresses etc. Local investigations showed that an installation depth of 1.5 meters seems to be applicable. In this case the former mentioned problem will be rather recovered and soil profile desalinization will also be enhanced and less amounts of water will be used efficiently. In the same time if the cropping pattern is done properly and proper water management activates are considered, the quality of drainage outflows, may relay the much better and rather more sooner behavior, as it is. To correct the already installed subsurface drains it seems possible to provide them with some kind of controlled drainage devices to act, as these are installed in a depth of 1.5 metes. A few field trials in this regards by using simply an elbow and a riser which were installed at the lateral outlets, conformed this suggestion in the farm levels.

**Low released minerals of parent material** As it was mentioned in previous section under the heading of **“**Soils of Khuzestan**”** the plains a continuation of the Mesopotamian plain, and is a vast low - lying area, almost covered by the deltas of the Dez, Karun and Karkheh rivers. The soils consist of alluvial deposits that have very fine texture toward the plains and at the South-West parts; deposits consist of large quantities of silt and clay. In general the two major soil orders in the plains are Aridisols and Entisols, with the texture varied from Clay, Silty-Clay to Clay –Loam, the type of soils mineral clay is Smactite (2: 1). From geological point of view the alluvial deposits of the plains are belong to the Quarternary period and almost originated from Gachsaran and Aghajary formations which are naturally Saliferous and Gypsiferous marls, this causes the soils in the plains to be mostly salty with the diagnostic Salic horizons (Aquisalids or

Haplosalids).The soils of the region contains much soluble salt, low amount of gypsum in the form of small crystal and mycelium and high amounts of calcium carbonate. The mentioned minerals: Cambids ,Calcids and Gypsids are low released parent material, some with low amount of solubility; therefore, it seems that their complete reclamation is not rapidly achievable, but time consuming, as the result even if the salt leaching is done extensively, still the low released mineral act to the same extent, keeping the soils slightly saline for some years, unless special technical and agronomical methods are used properly. Even so the quality of irrigation water will play a noticeable role in this respect. This is also a natural factor, affecting the quality of drain outflows, not to reach an equilibrium conditions even for many years.

**Location of Salic/or Natric horizons, just above or below the subsurface field drains**

Existence of the mentioned horizons in the soil profiles of saline and saline-sodic soils is almost expectable, but its location in the soil layer is related to the nature and factors affecting the soil formation. In arid and semi arid regions, such as the case study area, location of the mentioned horizons is strongly related to the natural factors causing the soils to be saline or saline-sodic. As it was mentioned the origin of the soil are mainly river alluvial, the deposition of material and compounds are done alternatively by floods and river overflows; therefore, even if the problematic soil horizons inherently were formed through the primary or secondary salinization, the mentioned layers are buried under the soil surface, somewhere in the soil profiles. According to definitions offered in Soil Taxonomy by USDA, these horizons contain noticeable amounts of salts and in the conditions in which sub surface layers are heavy textured, without structure and with low to very low permeability, the harmful physical and chemicals behavior, will finalize soil salt distribution and affect the solute concentration in drainage outflows. To minimize these unexpected effects, care should be done in lateral drains installation. Drains should be located in an appropriate depth and layer to overcome this natural phenomena, which is the matter of engineering at the stages of execution and inspection. Thus, it will be necessary to join a soil survey expert at the site during the subsurface drain installations. If the same horizons are located under the lateral field drains, the conditions may conclude at a relatively better situation, except during the critical irrigation periods (month or season), which water application is noticeable and accordingly with the short intervals. In this case an increase in drainage outflowwill result in some dilution in this response.

**Stagnant or perched extremely saline ground water table** As it was mentioned before one of the most effective factors leading to soil salinity and sodicity in the region is the existence of shallow to very shallow and extremity saline ground water of both kinds: stagnant /or perched tables. These are almost unconfined and their movements rely rather on same hydraulics gradients as the lands are lied in the plains. Naturally the water movements in such very gentle slopes is solved. this with heavy textured soils, facilitate both noticeable capillary rise and water table build up as well. In such conditions, there will be a permanent source to act as a diffuse boundary to feed the upper parts in the soil profile, whenever the soil media is saturated or unsaturated. The dominant of such a phenomena is not restricted to the locations where the sub surface field drains are installed, but will reach the zone of saturated levels between tile drains and soil surface, during the cropping and fallows periods, respectively. The mentioned factor also will affect the quality of drainage out flows, as a source of concentrated or very brackish water, which partially and gradually act to increase the salinity/or alkalinity of drainage outflow. The dilution of extremity saline ground water is very difficult practically, even if the amount of really deep percolations in practice is quite noticeable; therefore, it is the problem of the time and human management. There are some examples in the study area to show that after some decade, the acceptable equilibrium is still not achieved. As a conclusion, it is recommended to relate the quality of subsurface drainage outflows into two fractions: upper part quality which is influenced by irrigation and agricultural activities, and lower part which is almost under the effects of the quality of ground water. It is a more wise action to calculate the soil salt distribution in the soil profile from bottom upwards, then the most effective strategy for salt leaching by cropping rotation can be chosen to over come the over estimation of the amount of water needed for more effective soil and water salinity control.

**CONCLUSIONS** Leaching practices and programming can be conducted in some different ways. The main difference in the leaching methods depends on whether the application of leaching water will be done on bare soil or it will be programmed by cropping systems. Consequently, the selection of appropriate method for salt leaching is not completely dependent on soil properties, but also on social and economical aspects. However, based on the mentioned considerations, a specified reclamation procedure seems to be advisable. Moreover, the use of leaching data will enable us to arrange the various steps of accurate planning in relation to reclamation water requirement as well as the time needed for completion of reclamation procedures.

To facilitate the calculations procedure, efforts were made to prepare Table 1, based on desalinization leaching data. In this table, estimating the amount of water required (Dlw or net requirement) to reduce the soil salinity class to the desirable value in the soil profile is presented as a directory.

Also good soil drainage, effective irrigation and proper cropping systems are important to improve and maintain the productivity of the improved irrigable lands. Continuous monitoring is needed for irrigation of reclaimed lands, if any problem happens, the solution should be studied.

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