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Leaching Requirements to Prevent Soil Salinization

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Abstract: The purpose of this study was to develop a model to quantify the rate of upward water movement from a shallow water table for different soils with and without plants as a function of water table depth and time, to predict Electrical Conductivity (EC) of the soil in a one-dimensional homogenous soil profile and to develop a water management procedure to control soil profile salinity in the presence of a shallow water table. The model simulates water and solute movement from a shallow water table for a bare soil surface. Salt distribution in the soil profile, caused by a saline shallow water table, was simulated by assuming a steady state upward water movement in the absence of a crop. As water moves upward through a soil profile from a shallow water table, the water evaporates at the surface, leaving the salt behind. Some of the salt moves down to a depth about 30 cm by molecular diffusion. This raises the salt concentration within the top 30 cm of the soil. The model also simulates crop water extraction patterns and consequently the salt distribution patterns in an irrigated soil profile for a specified root distribution. After a fallow season and the resulting salt concentration near the soil surface, the salt redistributes downward because of irrigation water application. Different leaching fractions were used in the simulations. A computer program, for the model SALTCTRL (Salt Control), was written in QBASIC language. The program was tested for two soils for different leaching fractions. The soil parameters needed for the computations were selected from the literature. Application of model results is discussed and recommendations for further research were made.

Key words: SALTCTRL, simulation, watertable, salinization, irrigation

INTRODUCTION

Ever since irrigated agriculture has been practiced, people have been faced with numerous problems resulting from the controlled use of water. The most dominant of the problems are waterlogging and salinity, which continuously pose a threat to any irrigated area. The productive status of the land becomes more critical whenever it is confronted simultaneously with waterlogging and salinity problems and water deficits, which are also related to the soil characteristics and topography of the area.

Water table position is very important to salt distribution in the soil profile. According to Beke *et al.* (1993) there is a relationship between groundwater depth (m) and electrical conductivity (dS m^{-1}) of the soil surface. As groundwater depth increases, electrical conductivity of the surface soil is usually less. A high water table can supply water to the root zone for crop growth; however, direct water evaporation from the soil surface in an arid area can result in serious soil salinity problems.

Salt moves either upward or downward in the soil, depending on the direction of water movement in the soil profile. Upward water flow from the water table, which is called capillary rise, results when water evaporates from the soil surface or is extracted from the soil profile by plant roots. Salt accumulates in the root zone due to plant extraction of water (Hopmans and Immerzel, 1988) unless the salts are removed by leaching.

After an irrigation, some of irrigation water moves below the root zone through deep percolation. The irrigation water stored in the root zone moves out of the soil through the plants or moves upward by capillarity and evaporates at the soil surface. Water consumed by plants or evaporated at the soil surface leaves salt behind in the soil. Salt may therefore accumulate in the soil and cause a low quality root environment. The salt content and salt distribution in the soil profile depends on the amount of applied water, the amount of drained water, the amount used by the plants and the amount moving upward into the root zone from the water table. Salinization of the soil and the increase in soluble salts in

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the root zone, is influenced by climate, soil type, crop, irrigation water quality and management practices and the depth to and salinity of the water table (Parathapar *et al.*, 1992). Salinity levels of agricultural lands are conventionally controlled by maintaining some downward movement of water and salts out of the root zone to the soil beneath. Excess water, over and above the needs of plants, must be provided to the soil to produce this net downward flow. The design of an installed drainage system has to be such as to maintain the position of the groundwater table at a depth that will provide the necessary potential capacity for drainage of excess irrigation and leaching water. The salinity level of the soil depends upon the net deep percolation, the salt concentration of the irrigation water and the relative amount of upward movement of capillary water from the subsoil between irrigations.

Unsaturated water flow: Darcy's law was originally developed for saturated flow only. Buckingham (1907) noticed that the equation could be used for unsaturated media. The main assumption is that the unsaturated hydraulic conductivity is a function of the soil-water content (Luthin, 1978; Hillel, 1982; Kabat and Beekma, 1994). An equation describing one-dimensional steady flow of water in both saturated and unsaturated soil may be written as:

$$q = -k\nabla H \qquad (1)$$

Where q is the discharge per unit area or flux density (L/T), K is the hydraulic conductivity (L/T), H is the total head loss in (L), ($H = h + z$), h is the soil water matric head and z is the gravitation head (positive downward). ∇ is the gradient operator ($\nabla = /\partial x + \partial/\partial y + \partial/\partial z$), where x, y and z are the gradient components of the three directions (Buckingham, 1907; Gardner, 1958; Hillel, 1982; Kabat and Beekma, 1994).

Evaporation from a bare surface soil over a shallow water table: Evaporation occurs directly from a bare soil surface that is affected by radiation and wind (Hillel, 1982). In agricultural lands, under annual crops, the soil surface may remain largely bare throughout the periods of tillage, planting, germination and early seeding growth (Hillel, 1982). Evaporation from a bare soil surface causes soil moisture depletion and results in solute accumulation in the surface soil. Salinity can be a serious problem in arid and semiarid regions with shallow, groundwater tables (Hillel, 1982).

The evaporation rate from bare soil depends on the atmospheric evaporativity and the body of the soil system (Hassan and Ghaibeh, 1977; Hillel, 1982; Yakirevich *et al.*, 1997). The former refers to external conditions and depends on the solar radiation and the removal of water vapor by movement of air. The latter is an interior characteristic of the soil that supplies water for evaporation. In practice, controlling atmospheric evaporativity is almost impossible. The only way to control evaporation is through soil water management. One effective method of controlling surface evaporation is to control water table depth through drainage and irrigation practice (Willardson *et al.*, 1981).

In irrigated areas, during the intervals between irrigation or during fallow periods where there is no downward flow of soil water, significant amounts of water can move upward by capillary forces (Buckingham, 1907). The capillary upward flux varies with soil type, depth of water table and the soil water gradient. Capillary flow brings water to the surface soil and evaporation causes the surface soil to be at lower water potential than that at static equilibrium. The lower water potential of the surface soil causes water flow from the water table toward the soil surface. If the atmospheric evapority is much greater than the ability of soil to transport water to the soil surface, the steady-state evaporation reaches the maximum rate, which is a function of water table depth (Gardner, 1958).

The permanence of irrigated agriculture requires that root zone soil salinity be controlled. Therefore, drains are sometimes installed on irrigated land to minimize the rate of salt accumulation (Saleh and Troeh, 1982). The salt concentration in a soil with a shallow water table, as water evaporates from the surface of the soil and the inflow of saline water at the bottom of a soil column control the addition of salt to the soil column. The loss of water by evaporation causes much of this salt to accumulate at or near the surface. A salt buildup below the surface results in a downward redistribution of salt by diffusion. The diffusion of salt downward was measured by the difference in the net rates of salt movement upward from a shallow water table. The greatest salt accumulation was found to be in the top 30 cm or less of a clay soil (Saleh and Troeh, 1982).

Salinity control and irrigation management: Salts can accumulate at the surface of a shallow soil and in the deeper layers of a deep soil (Doering *et al.*, 1963). Growing plants tend to increase salt accumulation in the root zone while decreasing it at the soil surface. The soils profile salt accumulation with a 75 cm water table depth point to a hazard that might occur in a crop-fallow system (Saleh and Troeh, 1982).

Reeve *et al.* (1955) found that flushing water over a highly saline soil surface as a reclamation procedure was ineffective; however, the application of one foot (30 cm) of water for each foot (30 cm) depth of soil removed approximately 80% of the excess salt from a soil profile.

In arid areas, salinity control is one of the mayor objectives of drainage. Salinity control, using leaching as a management tool, has been of interest for many years for obtaining optimum crop yields. A number of attempts have been made to describe the salt movement during the leaching process and to describe the effect of salinity on crop growth (Nimah and Hanks, 1973; Raats, 1974; Bresler and Hoffman, 1986; Hamdy *et al*., 1993; Wu *et al*., 1977).

The average root zone salinity is affected by the degree to which the soil water is depleted by evapotranspiration between irrigations. The amount of leaching water required for removing excess soil salinity can be reduced by leaching with intermittent applications of water (Miller *et al*., 1965). Salt balance requires that a mass of salt equal to the total amount of salt applied in the irrigation water be carried out of the soil profile in the drainage water (Willardson *et al*., 1981) to prevent salt accumulation.

$$\text{salt input} = \text{salt output} \qquad (2)$$

The proposed research was to quantify the rate of upward movement from a shallow water table having both surface evapotranspiration and water uptake by plant roots, to estimate the resulting salt concentrations at different depths in the soil profile and to develop an approach to set a water management procedure to control salinity in the presence of a shallow water table. The objective was to present salinisation and keep the salt concentration low in the root zone. Results will enable better on-farm management of irrigation water, the water table, soil profile salt concentration and leaching requirements to optimize the growth of crops.

MATERIALS AND METHODS

Model development procedures: A computer-based model was developed (SALTCTRL) to evaluate the water and salt content of an irrigated soil profile as affected by soil properties, water table depth and plant water extraction and leaching fraction using data from previous work done by engineers and soil physicists.

The model was designed to predict fallow season water and salt transport from the water table to the soil surface by evaporation and the leaching that would occur from irrigation water applications. Water and salt movement was assumed to occur under steady-state conditions. The model was developed to quantify salt accumulation near the soil surface for different water table depths and soil types and was based on the works of Gardner (1958), Raats (1974) and Wagenet (1984). All the soil physical data such as water content, matric potential, hydraulic conductivity and salt amount in the soil at the end of the fallow season were used for a second season irrigation simulation. The model is used to describe salt accumulation near the surface and the salt movement downward under the intermittent irrigation and an irrigation management scheme for salinity control and to predict how much leaching is required to control salinity caused by surface evaporation and water uptake from a shallow water table by plant roots. Irrigation management and leaching requirements are defined based on Raats (1974). A formulation of the root extraction term was taken from Raats (1974), Feddes *et al.* (1976) and Wagenet (1984). The model is intended to be used to recommend water management procedures to control soil surface and root-zone salinity.

The calculation procedure for salt movement procedure was Miscible Displacement. “when the water containing a different salt content from the soil solution is passed through a nody of soil, the concentration of salts in the outflow or drainage material will gradually change in manner that depends upon the kinds of processes that occur in the soil. The process of replacing the soil solution with another having a different salt concentration has been referred to as Miscible Displacement because the solution are completely misciple with each other. The term miscible displacement is used to be describe the process of flow through porous media when encroaching fluid is completely misciple with the encumbant fluid. The presence of the blind pores through which there is little or no flow causes a portion of the water to be retained. If saline soil is the displaced by fresh water, some of saline water, therefore is bypassed and mixing occurs. As the flow continues, the mixing with the initially bypassed solution continues and leaching is accomplished”.

The year was divided into two different periods. The first period is a fallow period with evaporation from bare soil and a resulting salt accumulation in soil. The second period describes water and salt movement during irrigation, with and without plant uptake and with a leaching fraction.

The calculation procedure starts with a fallow season with an initially uniform profile salt content. At the end of the fallow season, pre-irrigations were applied. After the pre-irrigations, the growing season starts, the end of the growing season completes the first year. Second and future years repeat the process. The initial conditions for each year were taken from the end of the previous year.

Table 1: Soil-physical properties of the soils (Gardner, 1958; Torres and Hanks, 1989; Simunek *et al.*, 1996)

	Soil	
	Nibley silty clay loam	Kidman fine sandy loam
θs (cm^3/cm^3)	0.520	0.340
θr (cm^3/cm^3)	0.089	0.065
Ks (cm/day)	163.200	362.400
α (cm^{-1})	0.010	0.075
β (cm^{-1})	0.060	0.080
n	2.000	1.890

Soil characterization: Soil characteristics for a Nibley silty clay loam and a Kidman fine sandy loam were taken from Gardner (1958), Torres and Hanks (1989) and Simunek *et al.* (1996) (Table 1). van Genuchten (1980) used a new and relatively simple equation for the soil-water-content-pressure head curve, $\theta(h)$. Basic soil-physical properties such as θs (saturated water content (cm^3/cm^3)), Ks (saturated hydraulic conductivity (cm/day)), calculated values of θr (residual water content (cm^3/cm^3)), α (is an empirical parameter (cm^{-1}) and n (power of the effective saturation) were used. β is an empirical parameter (Gardner, 1958). Using the values define above, a soil water retention curve was produced.

Computer model and program description: The computer program SALTCTRL was written in QBASIC programming language for the modeled procedures outlined in the previous section. The program requires input of soil properties such as saturated hydraulic conductivity, residual water content and alpha and n values (Table 1). The program also needs the length of crop growth period, water table depth, salt concentration of water table, root depth and distribution for the plant, the surface boundary evaporation flux, leaching fraction, salt concentration of irrigation water, number of simulation years, number of pre-irrigations, water amount for pre-irrigation, pre-irrigation interval, irrigation interval and daily evapotranspiration rate. The program first makes calculations for the fallow season when only surface evaporation occurs. The program can be run for different numbers of years.

RESULTS AND DISCUSSION

In this study, a computer model (SALTCTRL) was developed to predict soil moisture profiles, pressure head profiles, upward flux and salt distribution in the soil from the shallow water table as a function of water table depth and time. The model was also used to predict EC of the soil solution in different layers in the root zone and to predict drainage water EC, given the amount of irrigation and the EC of irrigation water for different soils during irrigation periods. The model deals only with the physical processes involved with solute movement and does not account for any chemical reactions taking place in the soil that might be the result of precipitation or dissolution. Also the model, as developed, assumes a well-established plant and homogenous soil with a drainage system, so that the excess water can pass through soil layers and can be discharged from the bottom of the soil root zone profile.

The SALTCTRL model developed can be used to estimate salt accumulation near the soil surface for different water table depths and soil types during the fallow season and can estimate how much of the accumulated salt is leached in one or more cropping seasons under specific irrigation conditions. The model can also estimate the amount of water that will be drained, the volumetric moisture content of the soil profile at any time and the salinity level of each layer in the soil profile for a specified root distribution at any time during the year. SALTCTRL can be used to predict the salt buildup in the profile during fallow periods and the salinity of the drainage water after any number of irrigations. SALTCTRL also allows prediction of the leaching fraction that is necessary to attain an acceptable salinity level in the root zone, which is a function of the salt tolerance of the specified crop. The model can also estimate the time required to reclaim a saline profile. The number of irrigations with water of a particular salinity for a given profile at which a steady-state salt balance will be attained can also be predicted.

The SALTCTRL model was developed to work under shallow water table conditions. There are a number of existing models that calculate salt movement and leaching fractions for preventing soil salinization. However, most models were developed for a single cropping season and do not simulate a shallow water table and a non-cropping season. Wherever irrigated agriculture has been practiced, shallow and highly saline water tables have occurred. Lands that are high in clay and that have very flat slopes are often affected by problems of waterlogging and salinity, complicated by low hydraulic conductivity and high capillarity rise. Downward water movement as a result of precipitation and irrigation will prevent soil salinization, but in arid and semi-arid areas, especially during the fallow season, salt can move upward with water from the shallow water table due to surface evaporation. The SALTCTRL model was developed to evaluate these particular conditions.

Evaporation rate at the soil surface is one of the important factors contributing to the build up of salts near the surface of bare soil. As the water moves upward through a soil profile from a shallow water table containing dissolved salts, the water evaporates at or near the soil surface and the salts remain in the soil near the soil surface. As salinization of the surface soil increases, concentration gradients develop which cause some of the salt to move downward by molecular diffusion against the liquid flow. Salt accumulation therefore increases in the top soil layer (Saleh and Troeh, 1982) and not just on the surface.

Assumptions for SALTCTRL: For development of SALTCTRL, a number of simplifying assumptions were made. The model is designed so that the individual assumptions can be replaced with more complicated functions, look-up tables, or actual data. ET was constant for the cropped period. Surface evaporation was constant for the fallow season and is water table depth dependent. No rainfall occurred during the fallow or cropping season. The irrigation interval was uniform. The constant irrigation application amount was dependent on ET and the leaching fraction. The leaching fraction and the water table depth were constant. The water table EC and depth were not affected by deep seepage. Instantaneous water movement occurred. A new equilibrium was assumed at the beginning of each day. Water extraction of 40, 30, 20 and 10% was from four layers in the root zone. Salt movement in the root zone was by miscible displacement.

The SALTCRTL model was run for two different soils, namely Nibley Silty Clay Loam soil and Kidman Fine Sandy Loam soil. Using both soils, simulations were run under eight different conditions. Run results are discussed. Four simulation results were compared with results from another simulation model called SOWATSAL, written by Childs and Hanks (1975).

Model comparison: The model (SALTCTRL) developed in this study was compared with results from a model called SOWATSAL written by Childs and Hanks (1975) that was developed to simulate salt movement in an irrigated soil profile. The same data, such as irrigation water amounts, leaching fraction, irrigation interval, water content and initial salt distribution in the soil profile, were used as initial conditions for both models and for one cropping season. The SALTCTRL model was written to include special cases such as a shallow water table. SOWATSAL was written for a fixed water table depth. The SALTCTRL model allows for non-cropping (fallow) season water evaporation from the soil surface with the water being supplied by a shallow water table. The upward flow from the water table is constant so there is no water content change in the soil layers during the fallow season. SOWATSAL does not simulate continuous upward flow. SOWATSAL was run for a non-cropping season where water leaves the soil surface by evaporation. In SOWATSAL, the water content decreases in the upper soil profile because there is no replacement from the shallow water table. The SOWATSAL model cannot handle upward seepage.

The SALTCTRL model used daily values for calculation and SOWATSAL uses very small time increments of 0.0024 h. Another concern was the differences in the way the models treat the assumed root system. The SALTCTRL model used water uptake from an assumed root distribution of 40, 30, 20 and 10% from the top to the bottom of root zone depth and also assumed that the root system was fully established from the first day with constant full water use all through the cropping season. In the SOWATSAL model, the root distribution inputs are given with the same general percentages but are divided into 5 cm layers. SOWATSAL has a simulated root growing function because the model calculates root growth over time. To make both models give comparable values, some fictitious input values had to be entered in the SOWATSAL model, such as 0.1 days to full root development. Aboveground growth started after 0.01 days and after 0.48 days, aboveground growth was forced to the maximum to give a steady-state ET.

Sample input file for SALTCTRL: The van Genuchten (1980) model was used to predict initial water contents above the water table. The initial soil water EC was uniformity equal to water table EC in the soil. The SALTCTRL model subsequently calculates the required irrigation water amount depending on evapotranspiration and the irrigation interval values used during the simulation.

A SALTCTRL input data file consists of three lines of data. The first line is text and shows the soil, the leaching fraction and the water table depth (LAB$). The second line has 11 data, which are number of years in the simulation (YEA), water table depth (WTD), root depth (L), saturated hydraulic conductivity (KS), alpha value (ALPH), van-Genuchten n value (VGN), residual water content (TR), saturated water content (TS) (last five data were taken from Simunek *et al*. (1996), water table EC (ECWT), irrigation water EC (ECIW) and total days in the cropped season (PLANT). The third line has six data, which are irrigation interval in days during cropped season (IRINT), water amount for pre-irrigations (PREIRRIG), number of pre-irrigations (PRE), pre-irrigation interval (PREINT), leaching fraction (LEAC) and Gardner's β value (BETA). Depths are in cm, time is in days and salt concentration of the soil water is in dS m^{-1}.

Sample
NI1005.DAT

Nibley silty clay loam soil with 5% Leaching water table 100 cm
2, 100, 80, 163.2, 0.001, 1.23, 0.089, 0.52, 2, 0.3, 95
5, 5, 6, 1, 5, 0.06

The NI1005.DAT data files were for Nibley Silty Clay Loam soil. During the simulated cropping season the water table was 100 cm below the soil surface and 20 cm below the bottom of the 80 cm layer where root extraction of water takes place. Root zone layer thicknesses were 20 cm. The program can simulate different numbers of irrigations depending on the length of the plant growing season and the irrigation interval. For this simulation, the irrigation interval was assumed to be 5 days and 19 irrigations were calculated by the model for the growing season. The number of irrigations depends on season length and irrigation interval. The SALTCTRL model also simulates different numbers of years. An example case was run for two years with one pre-irrigation using a 5 cm depth of irrigation water. Leaching fractions used were 0.05 and 0.20. The length of the growing season was assumed to be 95 days, the root zone depth was assumed to be a constant 80 cm, EC of irrigation water was assumed 0.30 dS m^{-1}, water table EC was 2.0 dS m^{-1}, the total ET was assumed to be a uniform 0.7 cm/day and the water extraction for each soil layer was calculated in the model.

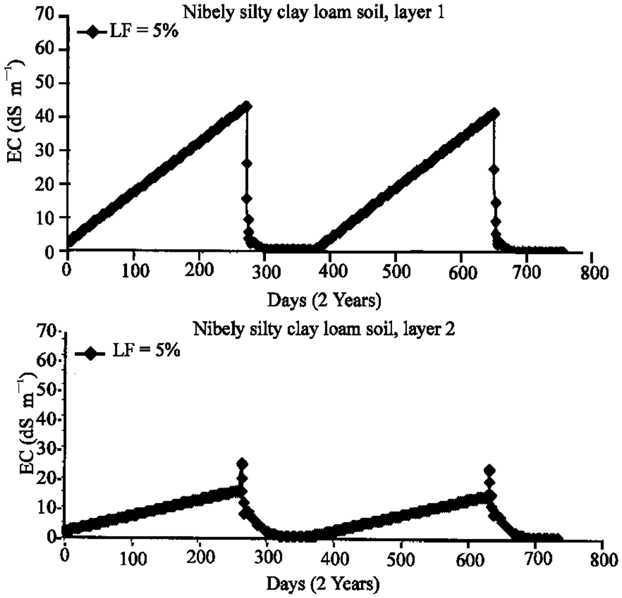

Fig. 1: The EC of the first and second layer for a two-year simulation with 5% leaching fraction for nibley silty clay loam soil

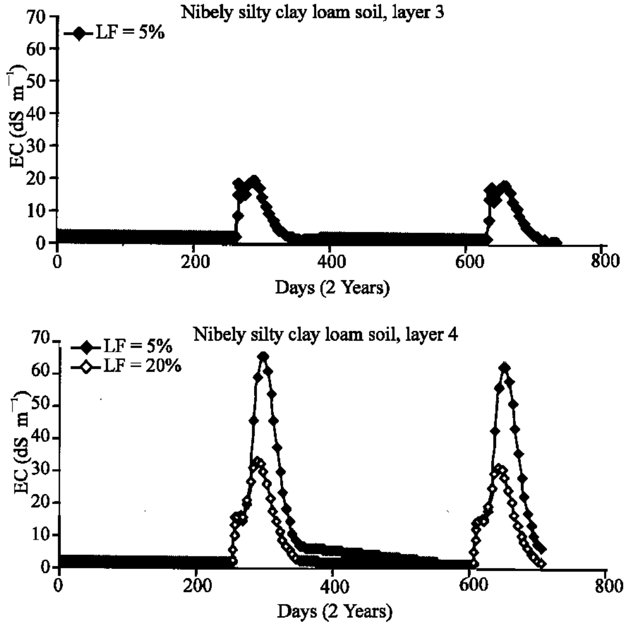

Fig. 2: The EC of the third for a two-year simulation with 5% and EC of the fourth layer with 5% and 20% leaching fraction for nibley silty clay loam soil

Figures 1 to 2 show the EC of the first, second, third and fourth layers for a period of 2 years for the 0.05 and also Fig. 2 show the EC the fourth layer the 0.20 leaching fractions. Figure 1 shows that there were 264 days in the fallow season. The EC level in the first layer increased to 43.31 dS m^{-1}. After six pre-irrigations the EC level drops to 0.95 dS m^{-1} in the first layer. After starting irrigations with a crop, the soil solution EC continued to decrease for both leaching fractions. Evaporation rate from the soil surface during the fallow season and pre-irrigation water amounts were the same for both runs. At the end of the pre-irrigations, salt was already leached from the first layer and EC became constant. Fig. 1 shows the EC levels of the second layer with leaching fraction of 0.05. In the fallow season, the EC of the soil increased to almost 15.75 dS m^{-1}. Salt accumulation in the fallow season was lower than in the first layer as shown in Fig. 1. After water evaporates from the soil surface and leaves salt on or near the surface of the soil, the salt concentration difference causes salt diffusion downward in the soil. The salt accumulated mostly in the first 40 cm depth from the soil surface. After pre-irrigations, EC of the second layers initially increased but after the second pre-irrigation the EC of the soil in the second layer started to decrease. At the same time some of the salt was leached from the second layer. In the cropping period, irrigation with 0.05 leaching fraction caused the EC of the soil in the second layer to increase after the first irrigation because of the water with high salt concentration that comes from the

Table 2: Soil water EC at end of irrigation season for nibley silty clay loam soil, with different water table depths and with same leaching fractions

Simulation run	SALTCTRL		SOWATSAL	
Water table = 100 cm	Salt removed from root zone,		Salt removed from root zone,	
LF = 10%	EC reached steady state. Profile EC's		EC reached steady state. Profile	
Pre-Irrig. = 30 cm	end of the first year were;		EC's end of the first year were;	
	Layer 1	0.35 dS m^{-1}	Layer 1	0.41 dS m^{-1}
	Layer 2	0.54 dS m^{-1}	Layer 2	0.80 dS m^{-1}
	Layer 3	1.00 dS m^{-1}	Layer 3	1.50 dS m^{-1}
	Layer 4	3.08 dS m^{-1}	Layer 4	3.20 dS m^{-1}
Water table = 200 cm	Salt removed from root zone,		Salt removed from root zone,	
LF = 10%	EC reached steady state. Profile		EC reached steady state. Profile	
Pre-Irrig. = 30 cm	EC's end of the first year were;		EC's end of the first year were;	
	Layer 1	0.36 dS m^{-1}	Layer 1	0.40 dS m^{-1}
	Layer 2	0.54 dS m^{-1}	Layer 2	0.82 dS m^{-1}
	Layer 3	0.91 dS m^{-1}	Layer 3	1.38 dS m^{-1}
	Layer 4	1.78 dS m^{-1}	Layer 4	1.31 dS m^{-1}

Table 3: Soil water EC at end of irrigation season for kidman fine sandy loam soil, with different water table depths and with same leaching fractions

Simulation run	SALTCTRL		SOWATSAL	
Water table = 100 cm	Salt removed from root zone,		Salt removed from root zone,	
LF = 10%	EC reached steady state.		EC reached steady state.	
Pre-Irrig. = 30 cm	Profile EC's end of the first year were;		Profile EC's end of the first year were;	
	Layer 1	0.39 dS m^{-1}	Layer 1	0.32 dS m^{-1}
	Layer 2	0.58 dS m^{-1}	Layer 2	0.45 dS m^{-1}
	Layer 3	0.95 dS m^{-1}	Layer 3	0.62 dS m^{-1}
	Layer 4	1.77 dS m^{-1}	Layer 4	1.74 dS m^{-1}
Water table = 200 cm	Salt removed from root zone,		Salt removed from root zone,	
LF = 10%	EC reached steady state.		EC reached steady state.	
Pre-Irrig. = 30 cm	Profile EC's end of the first year were;		Profile EC's end of the first year were;	
	Layer 1	0.54 dS m^{-1}	Layer 1	0.35 dS m^{-1}
	Layer 2	0.78 dS m^{-1}	Layer 2	0.54 dS m^{-1}
	Layer 3	1.23 dS m^{-1}	Layer 3	0.91 dS m^{-1}
	Layer 4	2.10 dS m^{-1}	Layer 4	2.39 dS m^{-1}

Table 4: Soil water EC at end of irrigation season for two soils, with different water table depths and with different leaching fractions by running SALTCTRL

Simulation run	Nibley silty clay loam soil		Kidman fine sandy loam soil	
Water table = 100 cm	Salt removed from root zone,		Salt removed from root zone,	
LF = 5%	EC still decrease lower layer.		EC still decrease lower layer.	
Pre-Irrig. = 30 cm	EC was high plant growing period.		EC was not high for crop growing.	
	Profile EC's end of the second year were;		Profile EC's end of the second year were;	
	Layer 1	0.40 dS m^{-1}	Layer 1	0.92 dS m^{-1}
	Layer 2	0.61 dS m^{-1}	Layer 2	1.25 dS m^{-1}
	Layer 3	1.21 dS m^{-1}	Layer 3	2.10 dS m^{-1}
	Layer 4	6.62 dS m^{-1}	Layer 4	5.33 dS m^{-1}
Water table = 100 cm	Salt removed from root zone,		Salt removed from root zone,	
F = 20%	EC steady state.		EC reached steady state.	
Pre-Irrig. = 30 cm	Profile EC's end of the second year;		Profile EC's end of the second year were;	
	Layer 1	0.40 dS m^{-1}	Layer 1	0.91 dS m^{-1}
	Layer 2	0.57 dS m^{-1}	Layer 2	1.15 dS m^{-1}
	Layer 3	0.94 dS m^{-1}	Layer 3	1.60 dS m^{-1}
	Layer 4	2.75 dS m^{-1}	Layer 4	2.55 dS m^{-1}

first layer and mixes with the second layer water. But after the second irrigation, the EC level in the second layer started to decrease. After the seventh irrigation, EC levels in both layers became constant. The second year starts with an initial EC that was lower than at the end of the first year. At the end of the first year all EC values were lower than the first year initial values (<2 dS m^{-1}).

Figure 2 shows the EC levels of the third layer with leaching fraction of 0.05. In this layer, EC of the soil water did not increase in the fallow season because the third layer is closer to the water table. It represents the 40 to 60 cm soil layer depth from the soil surface. EC of the soil water was a constant 2.0 dS m^{-1} because in the fallow season water comes upward from the water table with an EC of 2.0 dS m^{-1} and moves up to the surface layer. There was some salt increase after the six pre-irrigations. As discussed earlier, high amounts of salt percolate downward from the upper layers.

After the fourth pre-irrigation, EC started to decrease. Salt leached with 5 and 20% soil water EC values were slightly different. The EC of the soil water was higher with a 0.05 leaching fraction. After the 12th irrigation, EC levels became constant for both runs. Figure 2 shows that with a 0.20 leaching fraction salinity becomes constant at the end of the growing season with a lower value than for a 0.05 leaching fraction. With a 0.05 leaching fraction the

EC value was slightly higher through the crop irrigation period. The second year starts at the slightly lower EC level that increases through the fallow season until it reaches a constant 2.0 dS m^{-1}. Figure 2 shows that there was no additional salt accumulation in the fallow season in the fourth layer. After the end of the fallow season, the pre-irrigations brought salt from the upper layers. A 0.20 leaching fraction for irrigation causes more water to percolate from the upper layer with more salt leached. In the cropping season, salt started to accumulate in the fourth layer because of water extraction.

The EC of the soil water in the second layer for the two leaching fractions decreased equally to 0.60 dS m^{-1}. After the ninth irrigation, EC values become constant with the same value. Results show that pre-irrigations were able to remove the salt concentration from upper layers due to surface water evaporation. The soil solution EC in the third layer increases because of water extraction by the crop. The EC concentration in the fourth layer began to increase immediately after the first irrigation for both leachings. Irrigation with 0.20 leaching fraction soil gave EC values lower than irrigation with a 0.05 leaching fraction. Irrigation with a 0.05 leaching fraction increased EC to a high value in the fourth layer.

In order to compare root zone salinity changes computed by SALTCTRL with SOWATSAL model results, a special comparison was made. Table 2 shows for Nibley Silty Clay Loam soil and Table 3 shows for Kidman Fine Sandy Loam soil, a summary of model results for different water table depths, same pre-irrigations, same leaching fractions and simulation runs using SALTCTRL and SOWATSAL models.

The results presented in Table 2 and 3 indicated that when the water table depth increases, the equilibrium salt content of the bottom soil layer increases. This result is contrary to generally held theory. The same result occurs for both the SALTCTRL and SOWATSAL models. In Table 2-4 show The expected result was that the salt content of the bottom soil layer would be lower for a deeper water table. A separate analysis was therefore made, using SALTCTRL model, for a progressively deeper water table and different leaching fractions for both the Kidman Fine Sandy Loam and Nibley Silty Clay Loam soils.

CONCLUSIONS

The primary objective of this study was to develop a computer model that describes soil salinization from a shallow water table and predicts leaching requirements as a function of water table depth. Salinity levels of agricultural lands are conventionally controlled by maintaining some downward movement of water and salts out of the root zone to underlying soil. Irrigation plays an important role in preventing soil salinization by using appropriate leaching.

The SALTCTRL model can be used to determine the amount at leaching required to control salinity in a given soil profile as a function of cropping and fallow periods and water table depth. The SALTCTRL model was compared to an exiting model called SOWATSAL. Distributions of salt concentration in profile were similar after multiple irrigations for bot models. SALTCTRL is applicable for a wider range of physical conditions than SOWATSAL.

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