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Research Report

Mechanically Reclaiming Abandoned Saline Soils: A Numerical Evaluation

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International Water Management Institute

Research Reports

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Contents

Summary

In arid and semiarid regions, large tracks of land developed for irrigation are being abandoned each year due to secondary salinization from saline water tables. During non-monsoon months, the mulchability of the surface layers and the hydraulic properties of the subsurface layers influence the rate of salinization of these lands. During monsoon months, the infiltration rate of the surface layers and the depth to the water table control leaching of the surface layers. Mechanical cultivation of the surface layer will increase the mulchability, break the continuity of micro pores between the surface and subsurface layers, and increase the infiltration rate of the surface layer. These changes to the soil physical properties will minimize the rate of salinization and assist reclamation of these saline soils.

In this respect, the effect of surface cultivation, monsoon rains, depth to water table, and groundwater salinity on secondary salinization are evaluated using a numerical model, SWAP93 (Van Dam et al. 1997). The simulations were performed for three water table regimes (i.e., 0.5 m, 1 m, and 1.5 m). The surface cultivation was done before the monsoon. The results show that with a water table at 1 m or below, abandoned saline soils can be reclaimed by pre-monsoon surface cultivation within a few years. The rate of reclamation is largely independent of the groundwater quality. Continuous pre-monsoon cultivation will prevent re-salinization of these soils. The rate of reclamation is inadequate if the water table is at 0.5 m. The results of this study can be applicable to parts of the Punjab and Sindh provinces of Pakistan, where large areas are being abandoned due to secondary salinization.

Mechanically Reclaiming Abandoned Saline Soils: A Numerical Evaluation

S. A. Prathapar and Asad S. Qureshi

Introduction

In irrigated areas around the world, shallow water tables are becoming an inevitable feature contributing to secondary salinization. Secondary salinization is the result of accelerated redistribution of salts in the soil profile either due to shallow water tables or due to the use of insufficient water to leach the salts. The rate of salinization is high when the water table is shallow and saline. In the Indus Basin of Pakistan, about 4.76 million hectares have a water table within 1.5 m below the soil surface after the monsoon season. Prior to the monsoon, this area is reduced to 1.5 million hectares. Some 1.7 million hectares in the Punjab and 4.5 million hectares in Sindh are underlain by saline groundwater. Due to the presence of these saline water tables, about 40,000 hectares are abandoned within the Indus Basin annually due to secondary salinization. As a result, approximately 6 million hectares are salt-affected, of which about half is in irrigated areas of Pakistan (WAPDA 1989). Another 2 million hectares are estimated to be abandoned due to severe salinity (Bhutta and Wolters 1997). Another estimate is that the land area abandoned due to salinization is approximately equal to the land area developed for irrigation annually around the world. Such lands represent significant investments made during this century.

The physical process that contributes to water table-induced secondary salinization is referred to as ‘water table evaporation’ or ‘capillary upflow.’ In abandoned bare soils, the rate of capillary upflow is determined by the hydraulic gradient between soil surface and the water tables plus the unsaturated hydraulic conductivity of the soil profile. The matric potential at the water table will be zero. In abandoned soils, the soil water content of the surface soil will decrease to its residual water content due to evaporation. Therefore, the lowest matric potential of the surface soil will correspond to the residual soil water content. The gravitational potential between the soil surface and the water table will be equal to the depth to the water table. Consequently, the maximum hydraulic gradient, between the water table and the soil surface will be equal to the residual water content of the soil surface minus the depth to the water table. The soil water content will decrease from saturated volumetric water content at the water table, to a drier value at the soil surface. The unsaturated hydraulic conductivity will decrease accordingly, and will reflect the changes in soil structure as well as the water content. The soil layer with the lowest unsaturated hydraulic conductivity will bind the flow of water from the water table to the soil surface.

Bare soils are subjected to a constant meteorologically induced potential evaporation, which is considered to be maximal. Under constant evaporative demand, the bare soil evaporation process can be divided into three stages: the *constant rate stage,* controlled by potential evaporation demand; the *falling rate stage,* controlled by the transmission of water within the soil profile; and the *vapor diffusion stage,* controlled by the vapor diffusivity of the dried soil surface (Hillel 1975).

In shallow water table areas where lands are abandoned and bare, opportunities for constant rate stage evaporation are restricted to short periods, following heavy rainfalls. The soil surface must be close to saturated conditions for the constant rate stage evaporation to occur. Saturated conditions will lead to downward water movement within the soil profile, as well as leaching of salts. This process will counter salinization.

During the falling rate stage, the water for bare soil evaporation moves from the water table with dissolved salts. Once the water is lost to the atmosphere, salts are deposited within the root zone, resulting in salinization. The rate of salinization, therefore, depends on the rate at which water moves from the water table, and the extent to which the bare soil acts as a mulch to reduce the potential evaporation. When the actual rate of evaporation is restricted by mulching, the rate of water movement within the soil profile will be restricted to the rate of mulch-limited evaporation. Otherwise, the rate of evaporation will be limited by the rate of water movement as restricted by the hydraulic characteristics of the subsoil.

The rate of evaporation during the vapor diffusion stage is controlled by the physical properties of the unsaturated surface layers and the direction of heat flow within the soil profile. In general, heat flow within the soil profile is downwards during daytime. Further, the concentration of vapor in soil pores decreases with an increase in depth, which facilitates downward vapor diffusion. Therefore, under such circumstances, the vapor will not be released to the atmosphere. However, when the direction of heat flow within the soil profile is upwards, and the vapor concentration of atmospheric layers immediately above the soil layers is low, water from the soil profile is lost to the atmosphere. Such losses during the vapor diffusion stage will increase the capillary upflow from the water table. However, the relative increase in capillary upflow due to evaporation during the vapor diffusion stage will be negligible, and will have a minimal effect on the rate of salinization.

From the above discussion, the following inferences can be made. Secondary salinization from a shallow water table in arid and semiarid areas can be minimized by

(a) increasing the 'mulchability' of the soil surface, and

(b) modifying the hydraulic properties of the surface soil.

Conditions for (a) and (b) can be obtained in the field by mechanically cultivating the soil surface. Mechanical cultivation of abandoned soils can be achieved by plowing. Most farmers in developing countries, such as Pakistan, either own or rent four-wheel tractors to plow the soil. Farmers without access to four-wheel tractors use buffalo-mounted wooden plows to cultivate the soil to a depth of 30 cm. When the soil is plowed and turned over, it will break the continuity of capillary pores from the water table to the soil surface. As the loosened soils settle, some degree of continuity of micro pores will take place. However, this will be less than that of the uncultivated soil. In other words, the complete discontinuity of micro pores will not occur because the soil is made of individual semi-spherical particles, whose settlement cannot be completely prevented due to gravity and mobilization with water. Therefore, the physical processes of the soil water flow will continue to apply to a plowed soil profile. The soil water content of this layer will reduce to its residual water content level at which the rate of capillary upflow will be minimal, preventing salt movement to the surface layers from the subsurface (water table) layers.

The total porosity of a cultivated soil is greater than that of an uncultivated soil. This will increase the infiltration rate and the saturated hydraulic conductivity (Hillel 1980; Hall et al. 1993; Benjamin 1993). However, the unsaturated hydraulic conductivity of a cultivated soil is lower than that of an uncultivated soil, even at relatively low suctions (Creswell, Smiles, and Williams 1993; Somaratne and Smettem 1993; Murphy et al. 1993). Thus, the rate of capillary upflow in the unsaturated phase in a cultivated soil will be less than that in an uncultivated soil.

In summary, in semiarid areas where monsoon rains are restricted to a few months of the year, an annual pre-monsoon mechanical cultivation can be practiced to reclaim abandoned saline soils. Surface cultivation will increase the infiltration rate and decrease the unsaturated hydraulic conductivity of the soil. Furthermore, by minimizing the continuity of micro pores within the soil profile, the cultivated soil will act as mulch and reduce the rate of water table evaporation. In combination, these changes to the soil physical environment will increase the rate of leaching and reduce the capillary upflow from water tables. However, since the soil physical properties will be reversed with time due to rainfall and trafficking, periodic cultivation will be necessary.

The objective of this report was to test the hypothesis that timely surface cultivation and monsoon, or winter rains in semiarid and arid areas, will assist reclamation of abandoned saline soils. To test the hypothesis, a one-dimensional, vertical, water, and solute transport model, SWAP93 (Van Dam et al. 1997) calibrated by Smets (1996) was used. This report presents a brief description of SWAP93, the methodology adopted to calibrate the model, and the simulation results to evaluate the effectiveness of surface cultivation to reclaim abandoned saline lands in shallow water table areas in view of monsoon rains and groundwater salinity.

Theory of SWAP93 Model

The SWAP93 model describes a one-dimensional, vertical, unsaturated flow in a heterogeneous soil-root system. The model has the capability to simulate water and solute transport in the unsaturated zone. A brief description of the model is given below.

Soil Water Flow

In SWAP93, transient soil water flow is based on Darcy's law and the principles of mass conservation and spatial and temporal continuity. The governing equation is referred to as Richards' equation and one of its forms is:

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right] - S(h) \qquad (1)$$

where, h is the pressure head (cm), $K(h)$ is the hydraulic conductivity at pressure h (cm.d^{-1}), $C(h)$ is the differential soil moisture capacity (cm^{-1}), $S(h)$ is the sink term for water uptake by roots (cm.d^{-1}), z is the gravitational potential positive in the upward direction (cm), and t is time (d). The equation is solved by a finite difference scheme as proposed by Haverkamp et al. (1977).

Water Uptake by Roots

The flow within the root zone is strongly nonlinear and is greatly influenced by the water uptake by the roots. Since precise data are rarely available, either on the distribution of the roots as a function of depth or on water uptake, the latter is represented as an extraction or sink term, $S(h)$, distributed over the root zone. Feddes, Kowalik, and Zaradny (1978) described the sink term semiempirically as:

$$S(h) = \alpha(h)\, S_{max} \qquad (2)$$

where, $\alpha(h)$ is a dimensionless function of pressure head and S_{max} is the maximum possible root extraction rate (d^{-1}). The value of α varies between 0 and 1. When it is 1, water extraction by roots is considered as maximum. In this study, S_{max} is defined as proposed by Prasad (1988). It describes S_{max} in the following way:

$$S_{max} = \frac{2\, T_{pot}}{z_r}\left(1 - \frac{z}{z_r}\right) \qquad (3)$$

where, T_{pot} is the potential transpiration rate ($cm.d^{-1}$) and z_r is the depth of the root zone (cm).

Soil Hydraulic Properties

The soil profile can be split up into a maximum of five layers with different physical properties. Each layer may contain one or more compartments (finite difference layers). For each soil layer, the soil moisture retention curve $h(\theta)$ and the relationship between hydraulic conductivity and pressure head need to be defined. The soil physical relationships can be defined in the tabulated form or in the form of Mualem-Van Genuchten (VGM) parameters (Mualem 1976; Van Genuchten 1980). The volumetric water content θ is expressed as a function of the pressure head h with the empirical equation:

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{(1+(\alpha|h|)^n)^m} \qquad (4)$$

where, θ_r is residual volumetric water content ($cm^3.cm^{-3}$), θ_s is volumetric water content at saturation ($cm^{-3}.cm^{-3}$) and α and n are empirical shape parameters. The parameter m is defined as:

$$m = 1 - \frac{1}{n} \qquad (5)$$

The unsaturated hydraulic conductivity as a function of pressure head is defined as:

$$K(h) = K_S \frac{((1+|\alpha h|^n)^m - |\alpha h|^{n-1})^2}{(1+|\alpha h|^n)^{m(\lambda+2)}} \qquad (6)$$

where, K_S is the saturated hydraulic conductivity ($cm.d^{-1}$) and λ is a pore connectivity factor that expresses the correlation between pores and flow path tortuosity.

Top Boundary Conditions

Evapotranspiration, precipitation, and irrigation describe the top boundary conditions of the soil profile. SWAP93 offers four alternatives for the calculation of daily evapotranspiration: Monteith (1965), Rijtema (1965), Priestly and Taylor (1972), Penman (1948), and Class A Pan. The computed data for ET_{pot} are used to calculate the potential soil evaporation and potential transpiration according to Belmans, Wesseling, and Feddes (1983) as a function of leaf area index.

The actual soil evaporation depends on the prevailing conditions in the soil profile. SWAP93 offers two models for reduction in the potential soil evaporation as reported by Black, Gardner, and Thertell (1969) and Boesten and Stroosnijder (1986). In this report, the Boesten model has been used. According to this model, actual soil evaporation (E_{act}) depends on the sum of potential evaporation (E_{pot}) since the time of last irrigation or rainfall event.

Bottom Boundary Conditions

The bottom boundary condition of the system can be defined by three different types of conditions: (a) Dirichlet condition, where the pressure head is specified; (b) Neumann condition, where the flux is specified; and (c) Cauchy condition, where the flux is a function of the groundwater level.

Solute Transport

In SWAP93, solutes are considered as being conservative, which means that exchange processes and chemical reactions do not take place. In case of a transient, one-dimensional, vertical flow in the soil root system, the transport of conservative solutes can be described by the convection-dispersion equation:

$$J = qc_l - \theta(D_{dis}+D_{dif})\frac{\partial c_l}{\partial z} \qquad (7)$$

where, θ is the volumetric water content ($cm^3.cm^{-3}$), D_{dis} is the dispersion coefficient ($cm^2.d^{-1}$), D_{dif} is the effective diffusion coefficient ($cm^2.d^{-1}$), c_l is the concentration in the liquid phase ($g.cm^{-3}$), J is the total solute flux ($g.cm^{-2}.d^{-1}$), and q is the water flux ($cm.d^{-1}$). Further details of SWAP93 can be seen in Van Dam et al. (1997).

Model Calibration

Study Site

Smets (1996) calibrated the model using the data from the Chishtian Subdivision, Fordwah Eastern Sadiqia Project, Punjab, Pakistan. The climate of the area is arid and is characterized by long hot summers and cool winters. The mean annual precipitation is about 260 mm. Two-thirds of the precipitation occurs during the monsoon season, between early July and mid-September, in high intensity bursts. One-third occurs from January to March as low intensity frontal rains. The average annual evaporation is about 2,400 mm. Data from a field located in the tail end of the Fordwah Branch canal was used for the model calibration. The sample field is located in the cotton-wheat agro-ecological zone of the Punjab Province. Soil textural analysis shows that the field belongs to the Jhang soil series, which consists of a loamy sand top soil underlain by a sandy subsoil.

Input Data

The calibration period comprised 12 months (from July 1994 to June 1995) covering two growing seasons. The field was extensively monitored during this period. The crop rotation during this period was cotton-wheat. Pressure heads, soil moisture contents, electrical conductivity of the saturation paste (EC_e), irrigation depths, and meteorological data were measured.

The top boundary of the soil profile was described by the evapotranspiration, irrigation, and rainfall. Reference ET was calculated by using CROPWAT (Smith 1992), which was converted into ET_{pot} by multiplying with the corresponding crop factors. The reference evapotranspiration was based on the modified Penman method. The depths of all irrigations applied to the monitored field were recorded and used as an input.

The daily groundwater table depth was measured with the help of piezometers and was used as a bottom boundary condition. The maximum rooting depth for wheat and cotton was taken as 110 cm and 140 cm, respectively. Measured pressure head values at different depths were used as the initial conditions for water balance calculations, whereas, measured EC_e values at different depths were used for salt balance calculations.

The soil profile was divided into two layers, and each layer was divided into a number of compartments along the vertical axis. The thickness of each compartment was variable. Where large hydraulic head differences were expected, like at the soil surface, small compartments (4 cm each) were defined. The soil hydraulic properties were described by 6 VGM parameters (θ_r, θ_s, K_s, α, n, and λ). These parameters were taken from the soil series described by Wösten (1987) and were adjusted to match the measured and simulated results. The VGM parameters used for top and bottom layers are given in table 1. The soil water retention and hydraulic conductivity curves for both layers are shown in figures 1 and 2.

TABLE 1.
VGM-parameters for two layers of the monitored field.

Layer	Depth	θ_r	θ_s	K_s	α	n	λ
No.	(cm)	($cm^3.cm^{-3}$)	($cm^3.cm^{-3}$)	($cm.d^{-1}$)	(cm^{-1})		
1	0–140	0	0.33	45	0.028	2.1	0
2	140–315	0	0.35	150	0.026	2.6	1

The EC_e of the soil profile was measured by taking soil samples at depths of 15, 30, 45, 60, 90, 120, 150, and 200 cm. These samples were analyzed in the laboratory and the EC (electrical conductivity) of the saturation extract was determined. The soil analysis shows that the initial salinity of the soil profile ranged between 1.15dS/m and 1.40 dS/m from a depth of 15 cm to 200 cm.

The physical parameters that describe the salt transport in SWAP93 are the dispersivity coefficient, D_{dis} and the diffusion coefficient, D_{dis} (Eq. 7). The model is most sensitive for D_{dis}. Under laminar flow conditions, as in most unsaturated soils, the dispersion coefficient is proportional to the pore water velocity (Bolt 1979).

$$D_{dis} = L_{dis}\ \nu$$

where, L_{dis} is the dispersion length (cm). The size of dispersion length depends on the scale at which the water flux and solute convection averaged. The values of this parameter typically range from 0.5 cm to 2 cm for packed laboratory columns and 5 cm to 20 cm for field-scale experiments (Nielsen, Genuchten, and Bigger 1986).

FIGURE 1.
Soil water retention curves for the top and bottom layers.

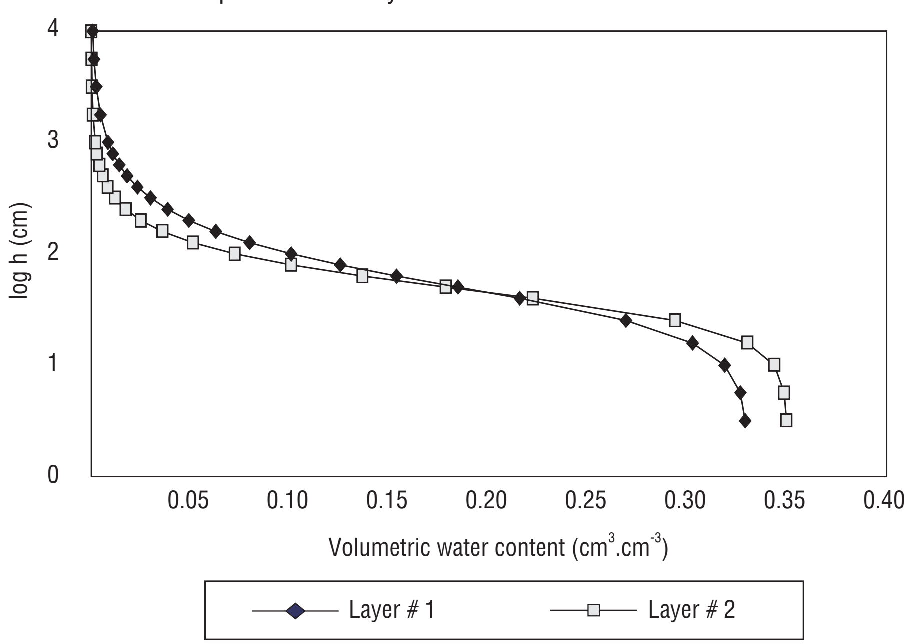
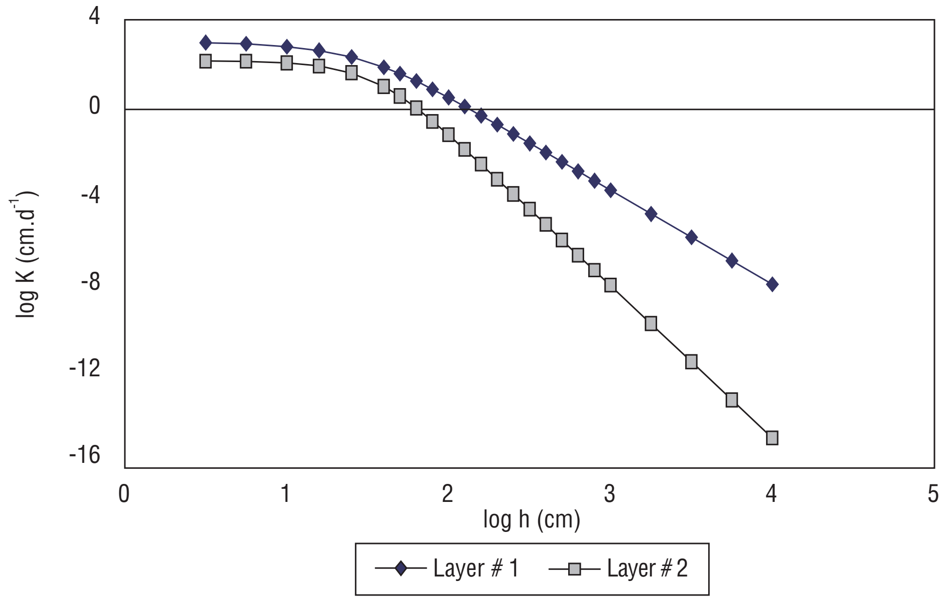


FIGURE 2.
Hydraulic conductivity curves for the top and bottom layers.



Results of Model Calibration

The measured pressure heads and EC_e values were compared with the model-simulated results for the model calibration (Smets 1996). Pressure heads were measured in the field by means of tensiometers, installed at depths of 15, 30, 45, 60, 90, 120, 150, and 200 cm, and were read weekly. Tensiometers were installed in the beginning of rabi 1994–1995. Therefore, only data for 6 months (180 days) were available for comparison. The soil samples for the determination of EC_e were collected by boring 10 holes (using an auger) for each depth at different locations in the field. The EC_e values were determined twice (on the 141st and 365th days) during the calibration period.

Figure 3 shows the comparison of measured and simulated pressure heads at 45 cm and 90 cm depths. The results indicate that the measured and simulated values are in good agreement at both depths. For the calibration of solute transport, measured EC_e data were compared with the model-simulated results. Figure 4 shows the comparison on the 365th day. The measured EC_e values are presented by rectangles instead of points. The length of each rectangle shows the standard deviation of 10 EC_e measurements at each depth. Figure 4 shows that the model slightly underestimated the measured EC_e values, although they are still within the measured ranges. It is evident from the graph that there are large deviations in the measured EC_e values at the same depth within a field. This is possibly due to the variability of soil hydraulic parameters within the field and uneven distribution of irrigation water over the field. The farmers usually use the basin/flooding method of irrigation. This practice produces parts of low and high infiltration that, in turn, result in low and high patches of salinity. Further details of field measurements and salt and water balance analyses can be found in Smets (1996) and Smets et al. (1997).

FIGURE 3.
Comparison of measured and simulated pressure heads at 45 cm and 90 cm depths.

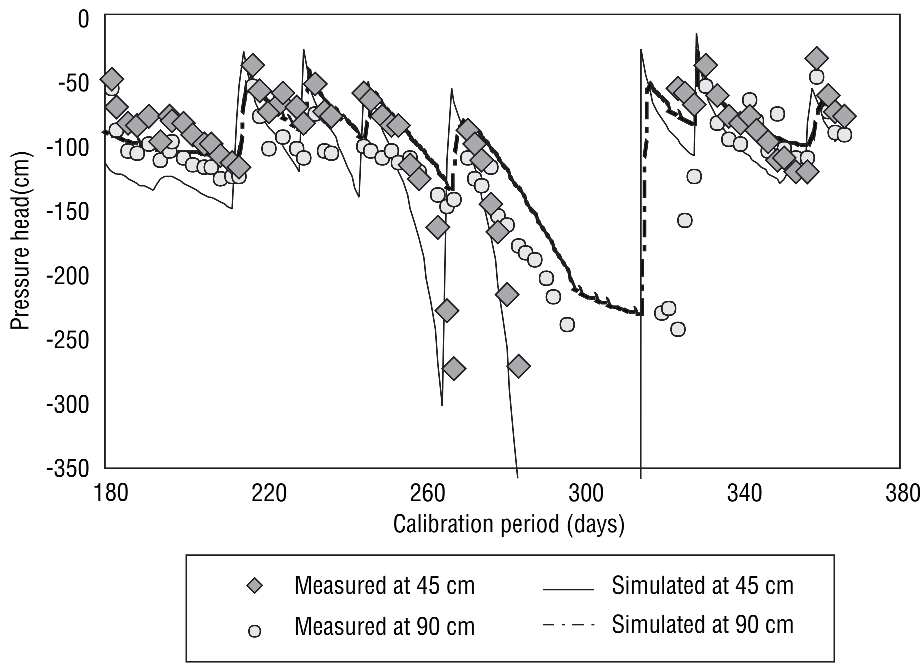
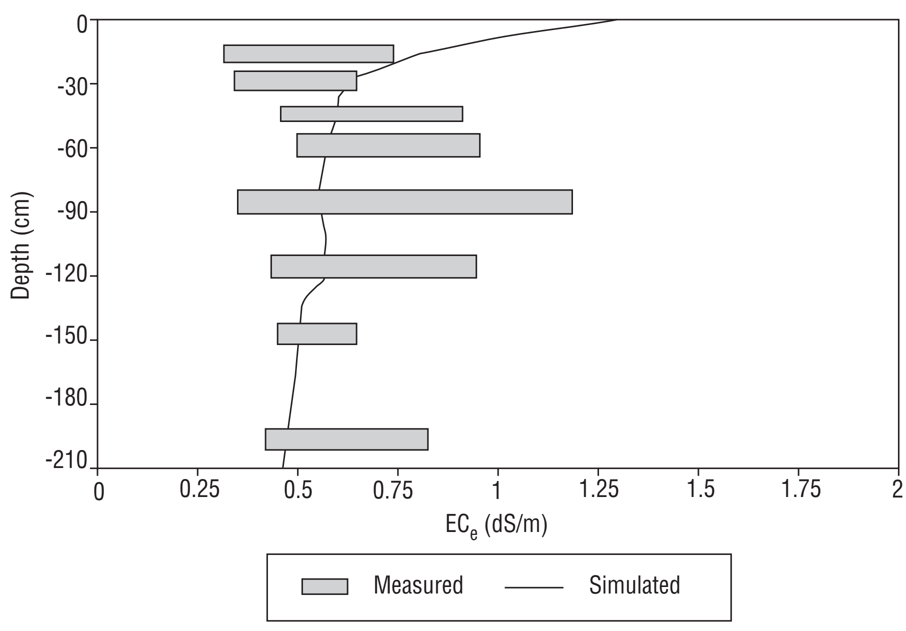


FIGURE 4.
Comparison of measured and simulated EC_e on the 365th day.



Evaluating the Effectiveness of Soil Surface Cultivation

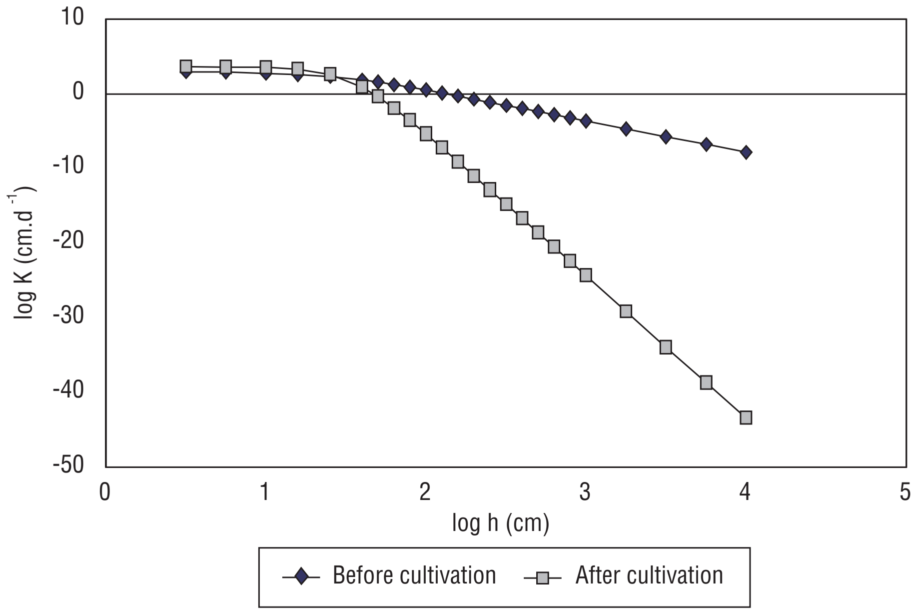
As alluded to in the introduction, mechanically cultivating the soil will increase the mulchability and modify the physical characteristics of the cultivated surface. Surface cultivation will increase the macro porosity and saturated hydraulic conductivity and break the continuity between micro pores within the soil profile. An increase in macro pore hydraulic conductivity will improve the potential for downward leaching and the discontinuity of micro pores will reduce the rate of capillary upflow from the water table that, in turn, will retard salinization.

The effectiveness of soil surface cultivation is evaluated by using the calibrated SWAP93 model. As noted earlier, the calibration was carried out by Smets (1996) from the data obtained from a field under wheat and cotton cultivation. Its water balance patterns along the soil profile were characterised by equations (2) and (3). The values of limiting pressure heads to describe $\alpha(h)$ were adopted from Taylor and Ashcroft (1972). It is assumed that roots grow at a constant rate from the time of sowing until they reach their maximum depth. According to Borg and Grimes (1986), maximum rooting depth for most of the crops is achieved at the physiological maturity of the crop. Once it is achieved, the rooting depth remains constant up to harvesting. Maturity was assumed in the middle of the mid-season stage. The maximum rooting depths (Z_r) for wheat and cotton were assumed to be 1.60 m and 1.10 m, respectively. In other words, it is a fixed value and not a calibrated one. To evaluate the effectiveness of surface cultivation of bare soil on salinization, these parameters were set to zero. Therefore, they had negligible effect on calibrated soil hydraulic parameters.

Simulations are performed for three water table depths, i.e., 0.5 m, 1 m, and 1.5 m. The groundwater salinity is taken as 10 dS/m to represent the most severe conditions. In real conditions, the water table will fluctuate with time, unless the field has subsurface drainage. However, by simulating salt and water balances at a static level, an additional insight into the minimum depth required to reclaim abandoned soils can be gained. Under field conditions, subsurface drainage will be required to control water table at, or below, a specified level.

The depth of the cultivated layer is taken as 0.3 m to represent field conditions. The surface cultivation is modeled by modifying hydraulic properties of the top 0.3 m soil layer of the profile. The comparison of $K(h)$-h function before and after cultivating the surface layer is shown in figure 5. The $K(h)$-h function for cultivated soil is only an assumption. Measured values for this function for cultivated soil are not available. Physical determination of the function is tedious, and often shows a considerable variation with space and time. Since our purpose is to test a concept, rather than being prescriptive, assumed values of K_S, α, n, and λ are considered appropriate. The K_S value of the loosened soil is set at 200 cm. d^{-1}, so that it will permit infiltration of all rainfall and minimize runoff. The values of α, n, and λ are set in such a manner that the unsaturated hydraulic conductivity of the loosened soil at a particular suction is less than that of the uncultivated soil. The values of VGM parameters α, n, and λ for this layer were taken as 0.028, 2.9, and 7, respectively.

FIGURE 5.
Comparison of hydraulic conductivity curves before and after surface cultivation.



Establishment of Initial Conditions

To determine the distribution of matric potential for the initial conditions, for different water table depths, the model was run for one year using newly set water table depths and climatic conditions. The resultant matric potentials at different depths at the end of the year were taken as the initial conditions for the simulations made to evaluate the effectiveness of surface cultivation to reclaim abandoned saline soils.

Salinity data were not available to describe the initial conditions for the bare soil simulation. However, the EC_e values at different depths for the first day of calculations for cropped conditions were available. To determine the initial conditions for the bare soil, the model was run for one year using the available EC_e values and considering that the soil is bare. The profile salinity of the last day simulated by the model was then used as an initial condition for the bare soil conditions.

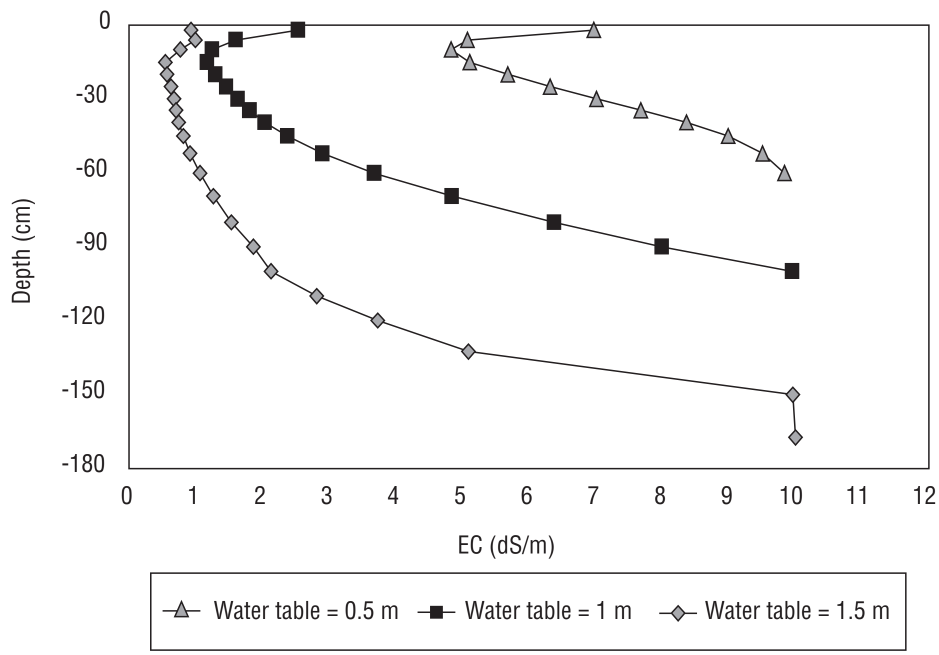
Results and Discussion

The interaction between depth to water table, groundwater salinity, a single monsoon, and pre-monsoonal surface cultivation was studied, using a one-year simulation.

Depth to Water Table

The influence of different water table depths on the soil salinity before the monsoon in uncultivated soils is shown in figure 6. Figure 7 demonstrates the effect of surface cultivation and monsoon rains on soil salinity at different water table depths. It can be seen that without surface cultivation and with the water table at 0.5 m, the impact of monsoon rains on soil salinity is not very substantial. When the water table is at 1 m or below, the salinity of the upper 0.6 m of the soil profile reduces to 2 dS/m, whereas, the lower part of the profile remains highly saline even after the monsoon. By cultivating the top 0.3 m of the soil before the monsoon season, a considerable decrease in the soil salinity for all water table depths can be obtained. These simulations show that under deeper water table conditions (> 1 m), a considerable amount of salts can be leached down by cultivating the soil surface before the monsoon. However, the effect of surface cultivation at shallow water table depths (< 0.5 m) is not very significant.

FIGURE 6.
Pre-monsoon salinity profile of uncultivated soils at different water table depths (groundwater EC = 10 dS/m).



Groundwater Salinity

The effect of different groundwater qualities on the root zone salinity is shown in figure 8. Figure 9 shows the effect of surface cultivation on soil salinity under different water table salinities. The surface cultivation leaches the salts not only from the top 0.3 m of the profile but also at the lower depths. Figure 9 shows that with surface cultivation, salinity in the top 0.5–0.6 m of the soil profile reduces to 2 dS/m after the monsoon season, irrespective of the groundwater salinity. From these simulations, it is evident that controlling the depth to the water table is more important in salinity control than controlling the quality of the groundwater.

FIGURE 7.
Effect of surface cultivation on salinity profile after monsoon (groundwater EC = 10 dS/m).

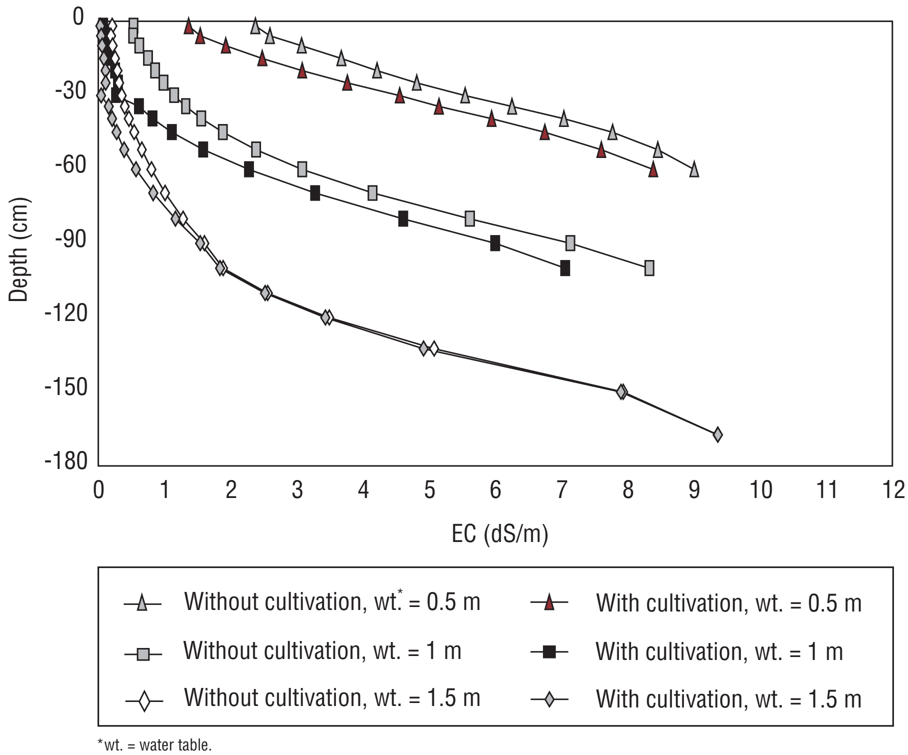


FIGURE 8.
Pre-monsoon salinity profile of uncultivated soils at different groundwater salinities (water table at 1m).

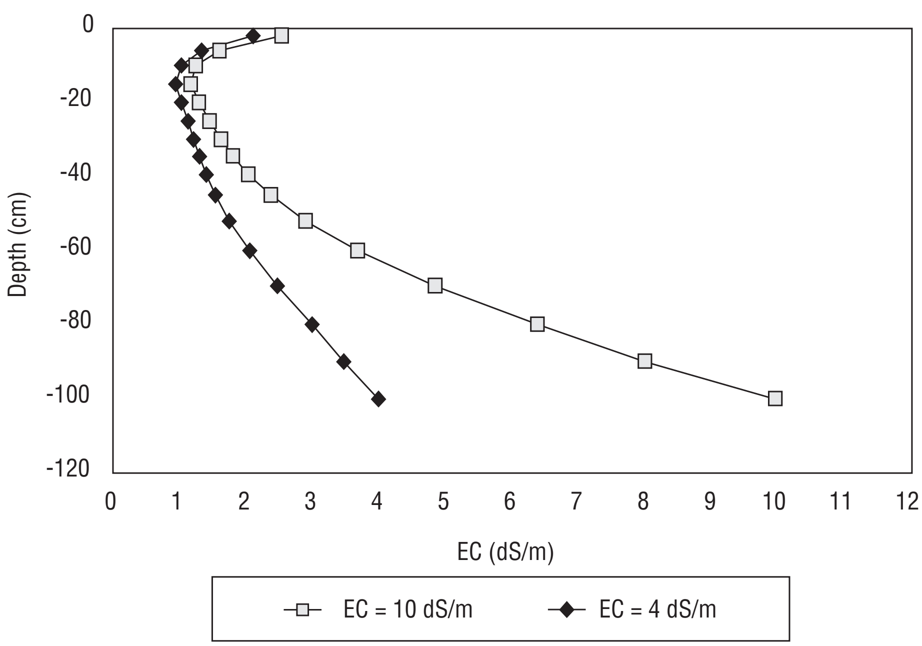
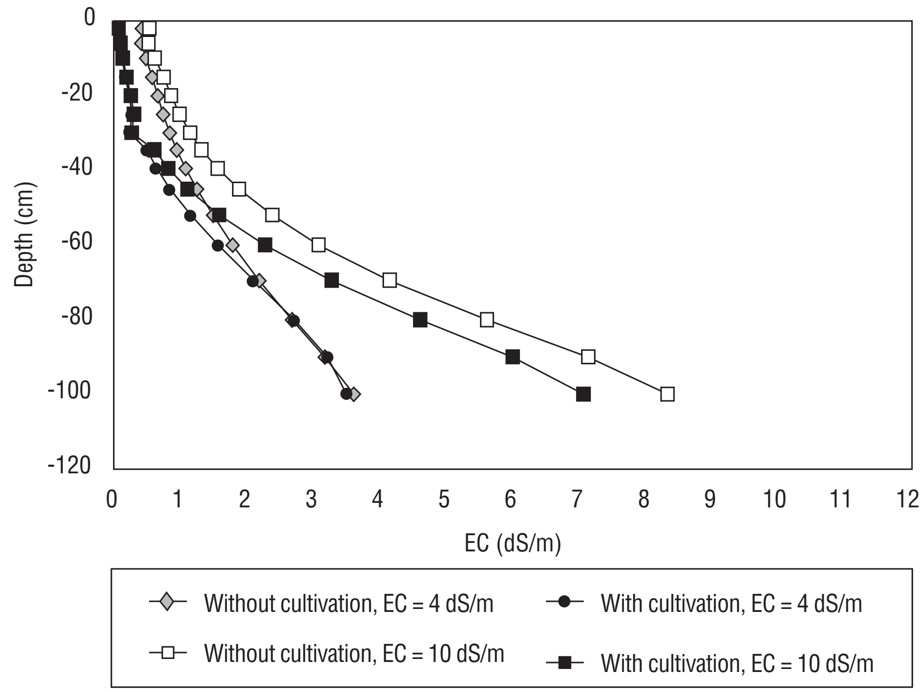


FIGURE 9.
Effect of different EC and surface cultivation on salinity profile after monsoon (water table at 1 m).



Long-Term Simulations

Previous results are based on one-year simulations. The process of leaching the salts from the root zone can be reversed in the dry months following the monsoon. To investigate long-term effects of surface cultivation on reclamation of abandoned saline soils, simulations were performed for a period of 10 years, using rainfall and evaporation data between 1980 and 1990. The initial soil salinity was assumed to be 3 dS/m throughout the soil profile for these simulations.

Figure 10 shows the pre-monsoon buildup of soil salinity without surface cultivation when the water table is at 0.5 m depth. Without cultivation, soil salinity continues to increase and in 5 years, the surface salinity will reach 10 dS/m, almost equal to the salinity of the groundwater. Simulation also shows that with prolonged periods, the surface salinity may well exceed the groundwater salinity. Figure 11 shows the long-term effect of pre-monsoon surface cultivation at shallow water table depths. It shows that without cultivation, leaching of salts with the monsoon will only be temporary, and permanent improvement in the salinity status of the soil cannot be expected.

If the soil surface is cultivated before the monsoon every year, salinity of the soil profile will not reach to the extent that it would without cultivation. However, the reduction in soil salinity is still not sufficient to consider these soils as reclaimed. Figure 11 also shows that with the water table at 0.5 m depth, the influence of monsoon rainfall is seen only in the top 0.2 m of the soil profile. There is no difference in soil salinity below 0.2 m between the cultivated and noncultivated soils. Any improvement obtained in these layers is reversed during dry years (figure 12). The graph shows that under shallow water table conditions, surface salinity will increase sharply during relatively dry years. This means that the effect of surface cultivation is not significant on the soils with shallow water tables.

FIGURE 10.
Long-term pre-monsoon salinity profile of uncultivated soils (water table = 0.5 m, groundwater EC = 10 dS/m).

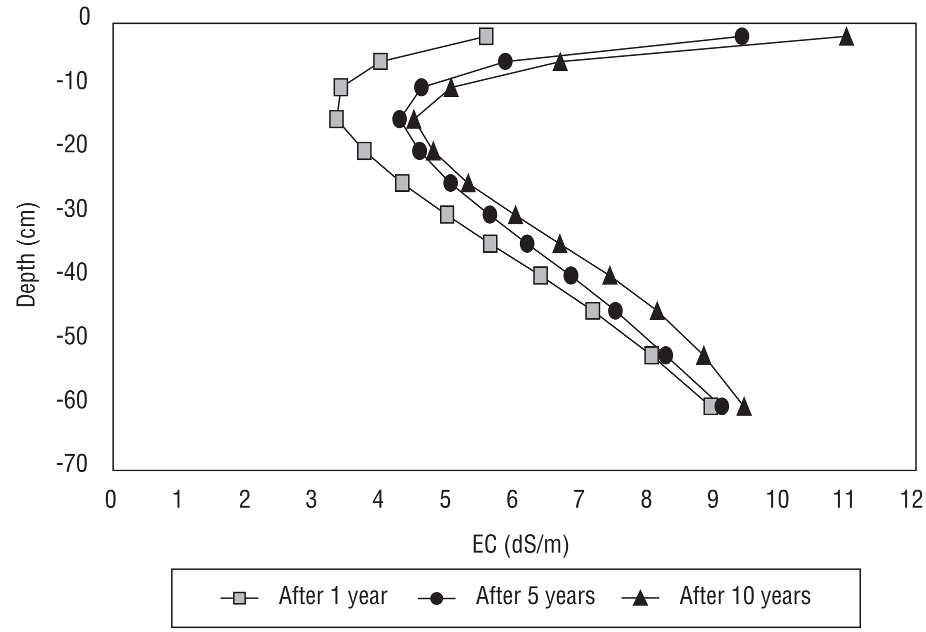


FIGURE 11.
Long-term effect of surface cultivation on salinity profile after monsoon
(water table = 0.5 m, groundwater EC = 10 dS/m).

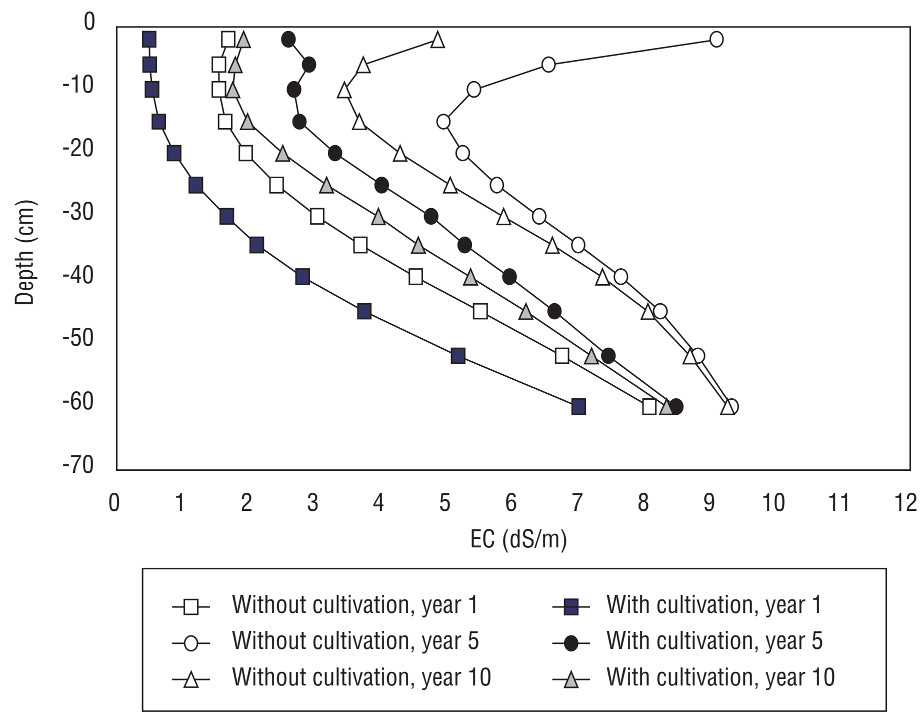


FIGURE 12.
Effect of rainfall on the salinity of cultivated surface layers.

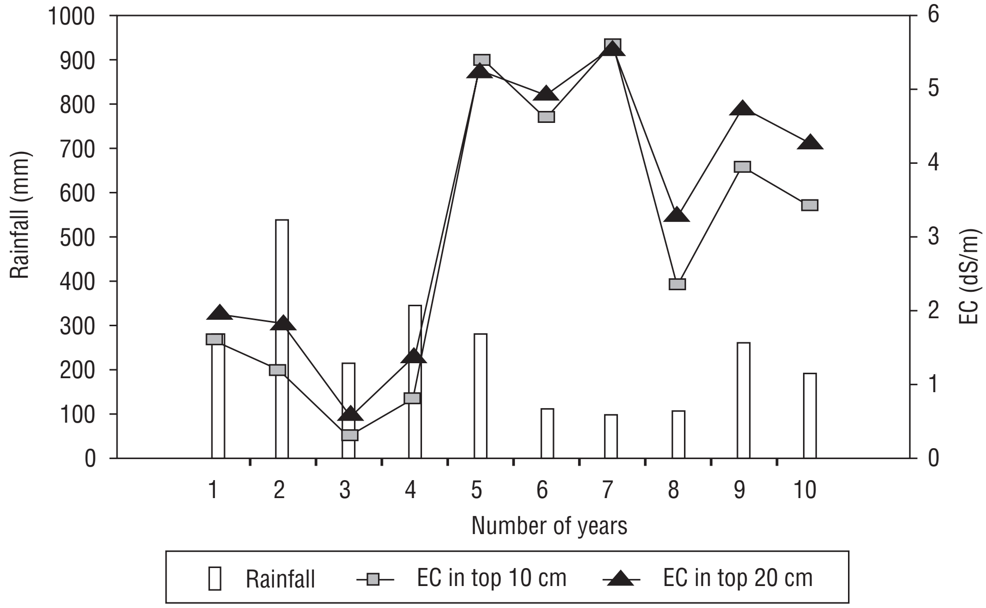


Figure 13 presents the long-term soil salinity profile of uncultivated soils before the monsoon season, when the water table is at 1 m. The graph shows that without treatment, soil salinity will continue to increase. Figure 14 compares the salinity profiles with and without pre-monsoon surface cultivation. The graph shows that without cultivation, salinity of surface layers fluctuates with time, depending on rainfall during the previous and the current years. However, in the long run, no permanent improvement in the soil salinity can be expected. The changes in soil salinity at deeper layers are not significant. Such fluctuations in the soil salinity will not be enough to reclaim the soil and to grow crops satisfactorily. However, by adopting surface cultivation, reclamation of these soils can be achieved. Figure 14 shows that in soil profiles with water tables below 1 m, by cultivating the surface soil every year before the monsoon season, abandoned saline soils can be fully reclaimed in a period of 2–3 years. The most encouraging factor is that once reclamation is achieved and the practice of surface cultivation continues, these soils would not turn into saline soils, even after 10 years. The soils reclaimed by this method can be used for rain-fed agriculture even if good quality irrigation water is not available.

Water Balances

The underlying reason for the reclamation of abandoned saline soils by surface cultivation is that the rate of capillary upflow from the water table will be reduced, which will decrease the actual soil evaporation and retard soil salinization. To account for the effect of surface cultivation on cumulative actual soil evaporation and flux through the bottom of the soil profile, it is useful to study the water and salt balances. Table 2 represents the effect of surface cultivation on cumulative soil evaporation and the bottom flux under different water table depths. These data are based on one-year simulations.

FIGURE 13.
Long-term pre-monsoon salinity profile of uncultivated soils (water table = 1m, groundwater EC = 10 dS/m).

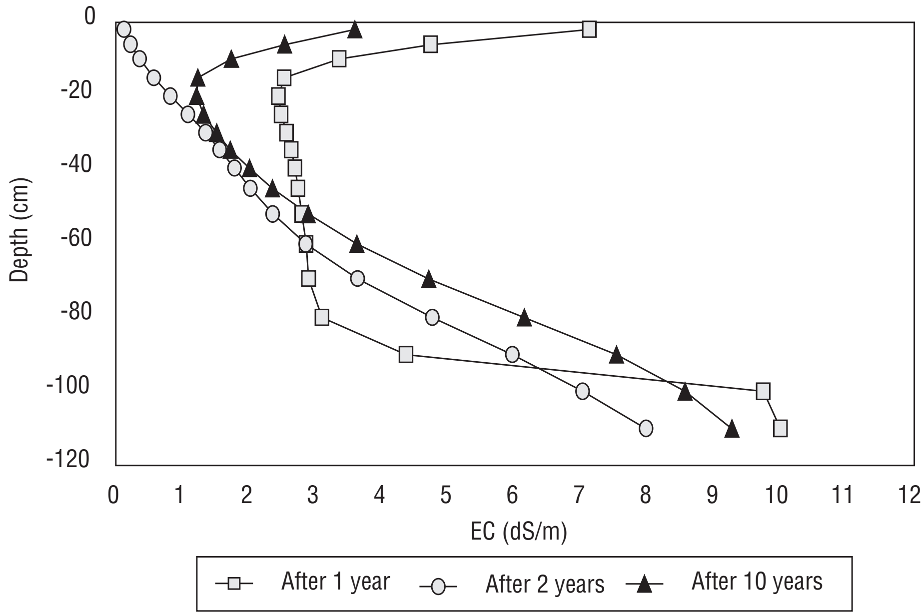


FIGURE 14.
Long-term effect of surface cultivation on salinity profile after monsoon (water table = 1 m, groundwater = 10 dS/m).

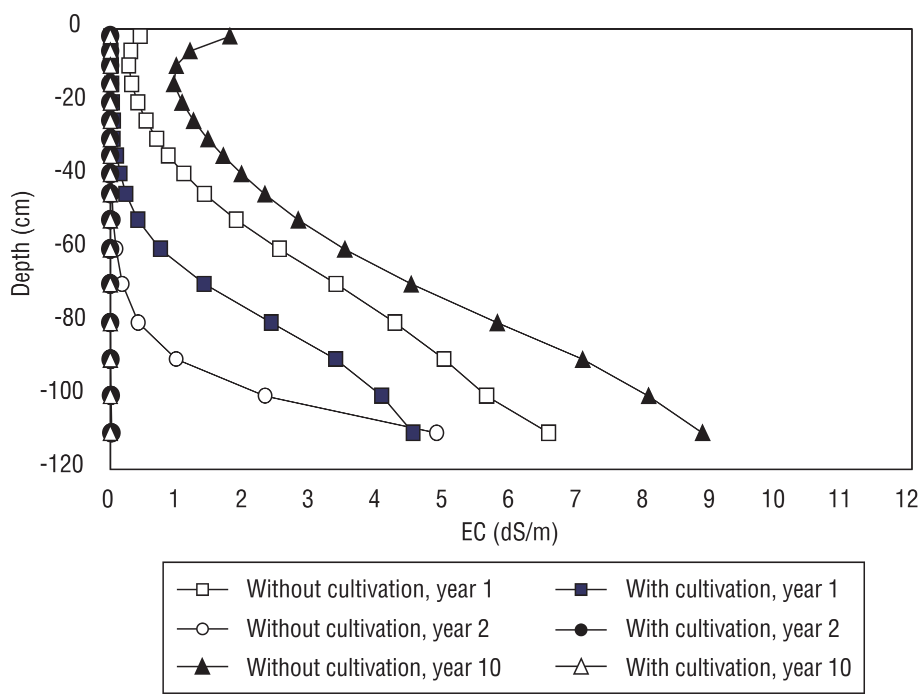


TABLE 2.
Actual soil evaporation and bottom flux as influenced by surface cultivation.

Water table depth (m)	Actual soil evaporation (mm)		Bottom flux (mm)	
	Without cultivation	With cultivation	Without cultivation	With cultivation
0.5	380	380	-45	-92
1	380	230	-37	-217
1.5	378	228	-38	-218
Annual rainfall = 480 mm				

From table 2, it can be seen that with the water table at 0.5 m depth, no reduction in actual soil evaporation had occurred even after surface cultivation. The possible reason might be that after cultivating the top 0.3 m of the top layer, and with the water table at 0.5 m, the length of the unsaturated zone is too small to accommodate percolating water. As a result, the soil profile remains wet, and contributes to the actual soil evaporation. However, with the water table at 1 m or below, about 40 percent reduction in soil evaporation can be obtained by surface cultivation.

The bottom flux describes the amount of water that needs to be drained to maintain the water table at a specific depth. Due to increased saturated hydraulic conductivity of the cultivated surface layer, the rate of downward flux increases tremendously (-217 mm) when compared to uncultivated soil (-37 mm). This large downward flux actually acts as a driving force to leach the salts downwards. Table 2 also shows that lowering the water table below 1 m has very little effect on soil evaporation and downward flux. This means that a water table below 1 m practically has no benefit for the reclamation of such soils.

Salt Balances

Long-term effects of surface cultivation on soil salinization are presented in table 3 from which it is evident that with the water table at 0.5 m depth, a negligible amount of salts is leached down even after surface cultivation. Instead, more salts are added to the profile when fields are left untreated for a longer period. The reasons already described for water balance also hold good for this trend, whereas, with the water table at 1 m depth or below, considerable leaching of salts for the first 2 years occurred even without cultivation. The heavy leaching during the first 2 years was mainly due to the generous rains (i.e., 480 mm and 700 mm per year), which were sufficient to leach down heavy amounts of salts. We can call these wet years. However, this trend did not continue over longer periods and the process of desalinization is reversed because 3–10 years were medium to dry years, with rainfall ranging from 200 to 400 mm per year. During these years, the actual soil evaporation was equal, or more, than the rainfall (± 300 mm per year). Under these conditions, atmospheric demand was met by the groundwater contribution, which added more salts to the soil profile. This clearly shows that without any treatment, the process of desalinization will be reversed during relatively dry years and abandoned soils will become increasingly saline. If soil surface is cultivated every year before the monsoon, this does not happen, and after 2 years, almost all salts are washed out of the root zone. Simulations also show that the period of complete reclamation could be 4–5 years for relatively dry years (annual rainfall < 300 mm).

TABLE 3.
Soil salinization as influenced by surface cultivation (mg.cm^{-2}).

Year	Water table = 0.5 m				Water table = 1 m			
	Without cultivation		With cultivation		Without cultivation		With cultivation	
	S_{bottom}	S_{total}	S_{bottom}	S_{total}	S_{bottom}	S_{total}	S_{bottom}	S_{total}
1	+20.4	122.7	-0.044	96.8	-12.14	147.5	-118.1	25.7
2	-0.042	122.7	+0.616	97.3	-76.70	70.5	-25.4	0.058
5	+3.32	134.4	+7.45	104.8	+35.21	148.2	–	–
10	+14.6	156.3	+9.26	121.7	+13.10	173.2	–	–

Notes: S_{bottom}= Salts added or leached out of the root zone.
S_{total}= Total salts present in the soil profile.

Conclusions

The following conclusions can be drawn from the results of the model simulations.

1. The salinity of bare surface soils with a shallow water table is higher than that with deeper water tables. Monsoon rains have a minimal impact on soil salinity when water tables are shallow. Under shallow water table conditions, the surface soil salinity will continue to increase and exceed the salinity of groundwater with time.
2. Depth to water table influences the rate of salinization of bare soil more than the quality of the groundwater. The rate of salinization is high when groundwater salinity is high. However, the difference between the rates of salinization from groundwater of 4 dS/m, and of 10 dS/m, is insignificant when the water table is at 1 m.
3. Pre-monsoon cultivation of surface layers will increase the rate of leaching due to an increase in macro porosity. The rate of reclamation in cultivated soils is similar even if the groundwater quality is different.
4. The rate of leaching in cultivated soils is inadequate under shallow water table conditions. However, salinity in cultivated soils is lower than in uncultivated soils even if the water table is shallow.
5. In areas where water tables are at or below 1 m, abandoned saline soils can be reclaimed by annual pre-monsoon surface cultivation within 3 years. Continuation of this practice will prevent re-salinization of such soils.

The soils of the Indus Basin vary widely, from very fine to coarse texture. On the basis of a textural analysis, these soils are classified into 5 major soil series. The Punjab Province possesses the largest proportion of coarse to moderately coarse soils, followed by the Sindh Province. The extent of these soils in the Punjab and Sindh Provinces is 45–21 percent of the total cultivated area (Ahmad and Chaudhry 1988). The coarse to moderately coarse textured soils fall under the Jhang soil series, for which this study has been conducted.

The results of this study are of great importance for the reclamation of abandoned saline soils for the Punjab and Sindh Provinces of Pakistan, where large areas are abandoned due to salinity and poor groundwater qualities. Most farmers usually use animal-driven wooden equipment for cultivation of up to a depth of 0.3 m. Therefore, cultivating the top 0.3 m of the soil to reclaim saline soils without major investment will enjoy wide acceptability among the farming community.

Presently, IIMI-Pakistan is conducting a field trial to evaluate the proposed method in collaboration with MONA Reclamation and Experimental Project (MREP), Bhalwal, Punjab, Pakistan.

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