**Selcuk Journal of Agriculture and Food Sciences**

http://sjafs.selcuk.edu.tr/sjafs/index

**Research Article**

SJAFS
(2022) 36 (2), 282-291
e-ISSN: 2458-8377
DOI:10.15316/SJAFS.2022.037

# Modeling Soil Profile Salinity with HYDRUS-1D

Sertan AVCI[1,*], Engin YURTSEVEN[1]

1 Ankara University, Faculty of Agricultural, Department of Agricultural Structures and Irrigation, Ankara, Türkiye

**ARTICLE INFO**

**Article history:**
Received date: 07.06.2022
Accepted date: 08.08.2022

**Keywords:**
HYDRUS 1D
Modeling
Salinity

**ABSTRACT**

Salt accumulation within the root zone significantly effects plant growth and development in arid and semi-arid regions. Today, use of low-quality irrigation water in agricultural production is increasing rapidly, because of continuous depletion and pollution of water resources. This means more salt transferred to the soil profile. It is of great importance to predetermine the effects of irrigation practices for sustainable crop production. For this purpose, models and tools that can produce reliable and fast results should be used.

In this study, soil profile salinity was modeled with the HYDRUS-1D software. In present study, Three different irrigation water salinity levels (S1=0.25 – control/municipal tap water, S2=1.5, S3=3.0 dS m-1) and 4 different irrigation volumes (leaching ratio) (LR1=10%, LR2= 20%, LR3=35%, LR4=50%) were modeled in a randomized plots factorial experimental design with 3 replications. Each treatment was carried out in individual PVC lysimeters with a length of 115 cm and a diameter of 40 cm in open-field to determine the efficiency of the model at different salinity levels and leaching rates. Alfalfa (Medicago sativa L.) was preferred as a plant due to its economic value, effective root depth and being a perennial plant. During the growing period, a total of 7 irrigations were practiced and five soil samples were taken from 20, 40, 60, 80 and 100 cm depths at the last day of each month.

Present findings revealed that values modeled with the HYDRUS-1D software were sufficient to determine the soil profile salinity. Relative error values (RE) ranged from 0.048 to 0.307. Increase in salinity and irrigation applications reduced the accuracy of the model. However, it can be said that the values produced by the model were sufficient even under the mentioned conditions. Especially for academic studies, the HYDRUS-1D software can be used to obtain fast and reliable results.

## 1. Introduction

Water is an essential component of agricultural production. Today, unconscious use of water resources and rapid pollution of existing resources resulted in water deficits and made it difficult to meet the water requirements of agricultural crops. To meet this demand, applications made with low quality irrigation water are increasing day by day.

As it is known, regardless of the water quality, there is some salt transferred to the soil profile through irrigations. The extent of this salt transfer increases with decreasing water quality used in irrigations. As many studies have shown, increase in salt accumulation in the soil profile causes yield loss in plant production. As a result of the continuation of applications with low irrigation water quality, sustainability of the soil profile for cultivation practices may be restricted or even become completely impossible. With a good drainage system and leaching practices, salinity factors can be removed from the soil profile. However, determining the salt loads carried by the drainage waters is of vital importance for the sustainability of the discharged water resources. For a sustainable agriculture, it is imperative to determine each parameter of this cycle and to take the necessary precautions.

Salinity, particularly in arid and semi-arid climates, is the event that soluble salts that leached and mixed with groundwater come to the soil surface through capillary rise together with high ground water table and salt accumulation over the soil surface and near the surface through evaporation and separation of water from the soil (Ergene, 1982; Kwiatowsky, 1998).

Salinity and alkalinity continue to be a problem in many countries today. A few years after the initiation of irrigation in different parts of the world, salinity and alkalinity problems that have never been encountered before are revealed. In addition, when the necessary precautions are not taken in areas with salinity and

*Corresponding Author: *sertanavci@gmail.com*

alkalinity problems, the spread of these areas increase and the problem becomes more and more severe (Özcan and Çetin, 2000).

As a result of using low-quality water for irrigation, the balance between plant nutrients in the soil is disturbed, ions that are toxic to plants accumulate, soils become saline and/or alkaline (Burton and Hook, 1979; Kirkham, 1986). As a result, irrigation with low irrigation water quality increases salinity in irrigated agricultural areas and causes a decrease in crop production and also causes deterioration of the soil profile (Maas and Hoffman, 1977; Ben-Hur et al., 1998).

Water, which creates drainage problems in the soil, also creates the problem of salinity and alkalinity. Depending on the degree of salinity, plants cannot grow in these soils or only plants that can live in saline soils can develop (Oğuzer, 1995; Feng et al., 2003).

There is a dynamic equilibrium between the cations in the soil solution and the cations in the adsorption complex and the dissolved and precipitated salts. Soil salt levels exhibit great temporal and spatial variations. Such a variation manifests itself with differentiations in salt content in horizontal and vertical positions (Schofield and Kirkby, 2003; Çullu et al., 2002).

Mathematical simulation models that take into account various soil, climate and plant factors are seen as useful tools to determine the most appropriate management practices for saline conditions (Ramos et al., 2011; Rasouli et al., 2012). In the last few years, various analytical and numerical models have been developed to predict water and solute transfer between the soil surface and groundwater.

The HYDRUS-1D (Šimůnek et al., 2008) software package is one of the software developed to simulate water movement and solute transfer and has a widespread use all over the world.

In this study, mathematical models were used to determine the soil profile salinity. Determining the change in soil profile salinity after agricultural applications means pre-determining the necessary precautions to be taken in order to maintain soil and vegetative production. For this purpose, mathematical models yield fast results. In this study, suitability of the HYDRUS-1D software was assessed.

## 2. Materials and Methods

The HYDRUS-1D software was used to model the soil profile salinity. In present study, 3 different irrigation water salinity levels (S1=0.25 – control/municipal tap water, S2=1.5, S3=3.0 dS m-1) and 4 different irrigation volumes (leaching ratio) (LR1=10%, LR2= 20%, LR3=35%, LR4=50%) were modeled in a randomized plots factorial experimental design with 3 replications. Each treatment was carried out in individual PVC lysimeters with a length of 115 cm and a diameter of 40 cm in open field. Lysimeters were placed on wooden grids placed on the soil and plastic containers were placed under them to collect drainage water. In order to increase the drainage efficiency, the lower parts of the lysimeters were filled with approximately 5 cm of gravel. After each irrigation, the drainage waters were taken immediately, and care was taken to avoid capillary rise. As a plant to be grown, clover was preferred because it has a long effective root depth and is a perennial plant.

Experimental soils have sandy-clay-loam (SCL) texture with a sand content of 58%, silt content of 21% and clay content of 21%. The soil and irrigation water properties used as input to the model are given in Table 1. Meteorological data, which is another input of the model, were taken from the 9th Regional Directorate Station of the General Directorate of Meteorology, Ministry of Environment, Urbanization and Climate Change.

During the growing season, irrigations were initiated on 14$^{th}$ of June. Subsequent irrigations were respectively practiced on 2$^{nd}$ of July, 20$^{th}$ of July, 9$^{th}$ of August, 26$^{th}$ of August, 8$^{th}$ of September and 27$^{th}$ of September (a total of 7 irrigations). Soil samples were taken in May as to represent the initial soil and a total of 5 soil samples were taken in the last days of the following months. Soil samples were taken from the depths of 20, 40, 60, 80 and 100 cm. The soil samples taken were air-dried and 1:2.5 saturation extract was obtained. Total salinity (EC) of the resultant saturation extracts was determined with an electrical conductivity instrument (YSI 3000) at 25ºC in accordance with the principles stated in Anonymous (1954).

Soil salinity values obtained as a result of the analyzes were compared with the model values using “mean absolute error” (MAE), “root mean square error” (RMSE) and “relative error” (RE) statistics. These equations are given below;

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|O_i - P_i| \quad (1)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n-1}} \quad (2)$$

$$RE = \frac{RMSE}{Obs_{avg}} \quad (3)$$

Table 1
Soil and irrigation water characteristics used as model input

| Soil and irrigation water ion content used in the model (mmolc $L^{-1}$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | EC (dS $m^{-1}$) | Alk. | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $HCO_3^-$ | $SO_4^{2-}$ | $Cl^-$ | Tracer |
| Soil | 7,02 | 0,81 | 4,60 | 1,48 | 0,28 | 4,9 | 2,27 | 4,6 | 3,05 | 1,28 | 0 |
| Irr. Water (S1) | 7,08 | 0,25 | 1,60 | 0,45 | 0,07 | 0,73 | 1,22 | 1,55 | 0,31 | 0,62 | 0 |
| Irr. Water (S2) | 6,97 | 1,56 | 1,90 | 2,47 | 0,51 | 10,4 | 2,8 | 5,66 | 1,16 | 9,57 | 0 |
| Irr. Water (S3) | 6,86 | 3,06 | 1,90 | 3,69 | 0,76 | 21,17 | 5,42 | 10,47 | 3,05 | 17,19 | 0 |
| Physical and chemical soil characteristics (initial conditions) | | | | | | | | | | | |
| Sand (%) | | | Clay (%) | | Silt (%) | Texture | | Bulk density (g $cm^{-3}$) | | SAR (mmol$_{(c)}$ $L^{-1}$)$^{0,5}$ | |
| 58 | | | 21 | | 21 | SCL | | 1,31 | | 0,78 | |
| Soil hydraulic parameters | | | | | | | | Exc. cations, mmol$_{(c)}$ $Kg^{-1}$ | | | |
| Ks (cm $day^{-1}$) | | α | N | $\theta_r$ | $\theta_s$ | $Ca^{2+}$ | $Mg^{2+}$ | $Na^+$ | $K^+$ | CEC | (mmol$_{(c)}$ $Kg^{-1}$) |
| 31,44 | | 0.059 | 1,48 | 0,10 | 0,39 | 125,85 | 41,35 | 4,85 | 4,00 | | 177,15 |

where, Oi is the observed data; Pi is the data obtained as a result of the model; N is the number of observations; Obsavg is the average of the observed values.

It is generally expected to find as RMSE ≥ MAE. The small difference between the RMSE and MAE indicates the compatibility of the observation results with the predicted results (Legates and McCabe, 1999; Kobayashi and Salam, 2000). RE can be used to determine the accuracy of RMSE values. If the RE value is less than 10%, the model produced excellent results; between 10 - 20%, the model produced good results, and between 20 - 30%, the model produced poor results. If the RE value is more than 30%, the model produced poor results (Loague and Green, 1991).

Table 2
Statistical analysis results

| | May | | | June | | | July | | | August | | | September | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MAE | RMSE | RE | MAE | RMSE | RE | MAE | RMSE | RE | MAE | RMSE | RE | MAE | RMSE | RE |
| Monthly | 0,04 | 0,05 | 0,13 | 0,24 | 0,33 | 0,20 | 0,26 | 0,34 | 0,17 | 0,22 | 0,30 | 0,16 | 0,19 | 0,27 | 0,13 |
| S1LR1 | 0,02 | 0,03 | 0,11 | 0,03 | 0,04 | 0,14 | 0,03 | 0,04 | 0,12 | 0,03 | 0,04 | 0,14 | 0,02 | 0,03 | 0,08 |
| S1LR2 | 0,02 | 0,04 | 0,13 | 0,03 | 0,05 | 0,16 | 0,03 | 0,04 | 0,16 | 0,02 | 0,02 | 0,08 | 0,03 | 0,04 | 0,10 |
| S1LR3 | 0,01 | 0,02 | 0,06 | 0,04 | 0,04 | 0,15 | 0,02 | 0,02 | 0,07 | 0,03 | 0,04 | 0,15 | 0,02 | 0,02 | 0,07 |
| S1LR4 | 0,05 | 0,08 | 0,25 | 0,02 | 0,03 | 0,09 | 0,01 | 0,02 | 0,07 | 0,01 | 0,01 | 0,05 | 0,03 | 0,04 | 0,12 |
| S2LR1 | 0,04 | 0,05 | 0,14 | 0,38 | 0,47 | 0,30 | 0,34 | 0,44 | 0,17 | 0,22 | 0,28 | 0,12 | 0,37 | 0,46 | 0,19 |
| S2LR2 | 0,02 | 0,02 | 0,06 | 0,31 | 0,38 | 0,21 | 0,37 | 0,43 | 0,17 | 0,34 | 0,42 | 0,21 | 0,22 | 0,35 | 0,17 |
| S2LR3 | 0,04 | 0,06 | 0,16 | 0,30 | 0,36 | 0,20 | 0,41 | 0,49 | 0,28 | 0,43 | 0,50 | 0,27 | 0,25 | 0,34 | 0,19 |
| S2LR4 | 0,04 | 0,05 | 0,15 | 0,27 | 0,34 | 0,19 | 0,42 | 0,48 | 0,26 | 0,37 | 0,43 | 0,31 | 0,29 | 0,33 | 0,22 |
| S3LR1 | 0,07 | 0,08 | 0,19 | 0,36 | 0,49 | 0,19 | 0,45 | 0,53 | 0,14 | 0,41 | 0,48 | 0,13 | 0,28 | 0,42 | 0,10 |
| S3LR2 | 0,02 | 0,02 | 0,05 | 0,33 | 0,46 | 0,17 | 0,33 | 0,47 | 0,13 | 0,38 | 0,45 | 0,13 | 0,23 | 0,28 | 0,07 |
| S3LR3 | 0,04 | 0,05 | 0,13 | 0,50 | 0,60 | 0,20 | 0,43 | 0,51 | 0,16 | 0,28 | 0,33 | 0,10 | 0,24 | 0,36 | 0,09 |
| S3LR4 | 0,05 | 0,07 | 0,15 | 0,31 | 0,38 | 0,12 | 0,24 | 0,36 | 0,10 | 0,18 | 0,22 | 0,07 | 0,24 | 0,33 | 0,11 |

## 3. Results and Discussion

The simulation of the solute movement within the soil profile was made for the dates between 1 May and 30 September with the HYDRUS-1D mathematical model. Soil salinities between these dates were simulated by the model and these values were compared with the salinity values calculated for the soil samples taken in monthly periods. Model and monthly measurement values were compared based on salinity and leaching treatments and the relations between them were examined by using the statistics given in Equations 1, 2 and 3 (Yurtseven et al., 2013). Statistical results are given in Table 2. The graphs of the models and measurement values based on salinity and leaching treatments are given in Figure 1-5. The graph created with the average of the salinity treatments of the model and measurement values to observe the change of soil profile salinity during the growing period is given in Figure 6.

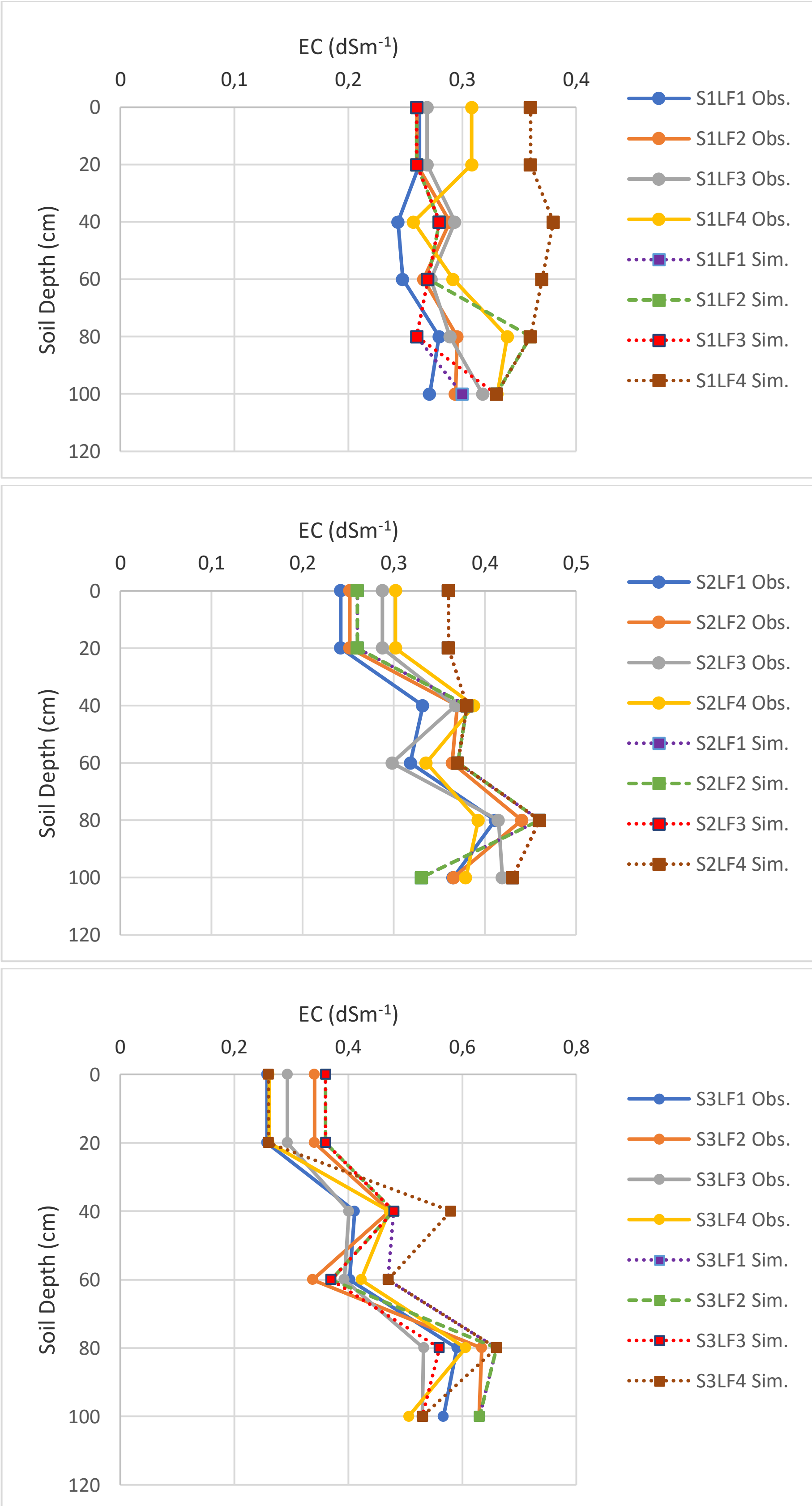


Figure 1

Change in salinity of soil profile in May based on salinity and leaching treatments

Avcı and Yurtsever / Selcuk J Agr Food Sci, (2022) 36 (2): 282-291

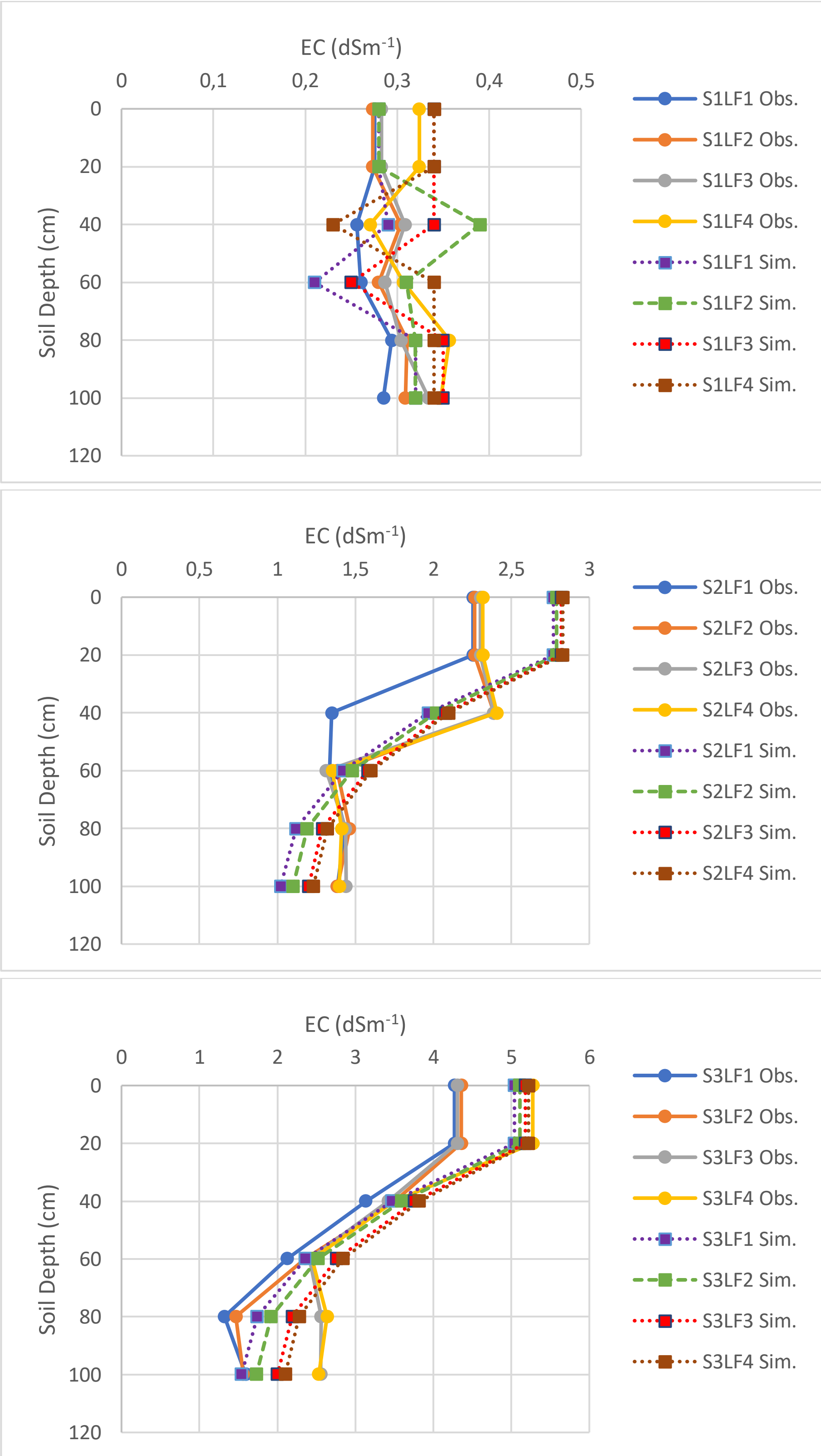


Figure 2

Change in salinity of soil profile in June based on salinity and leaching treatments

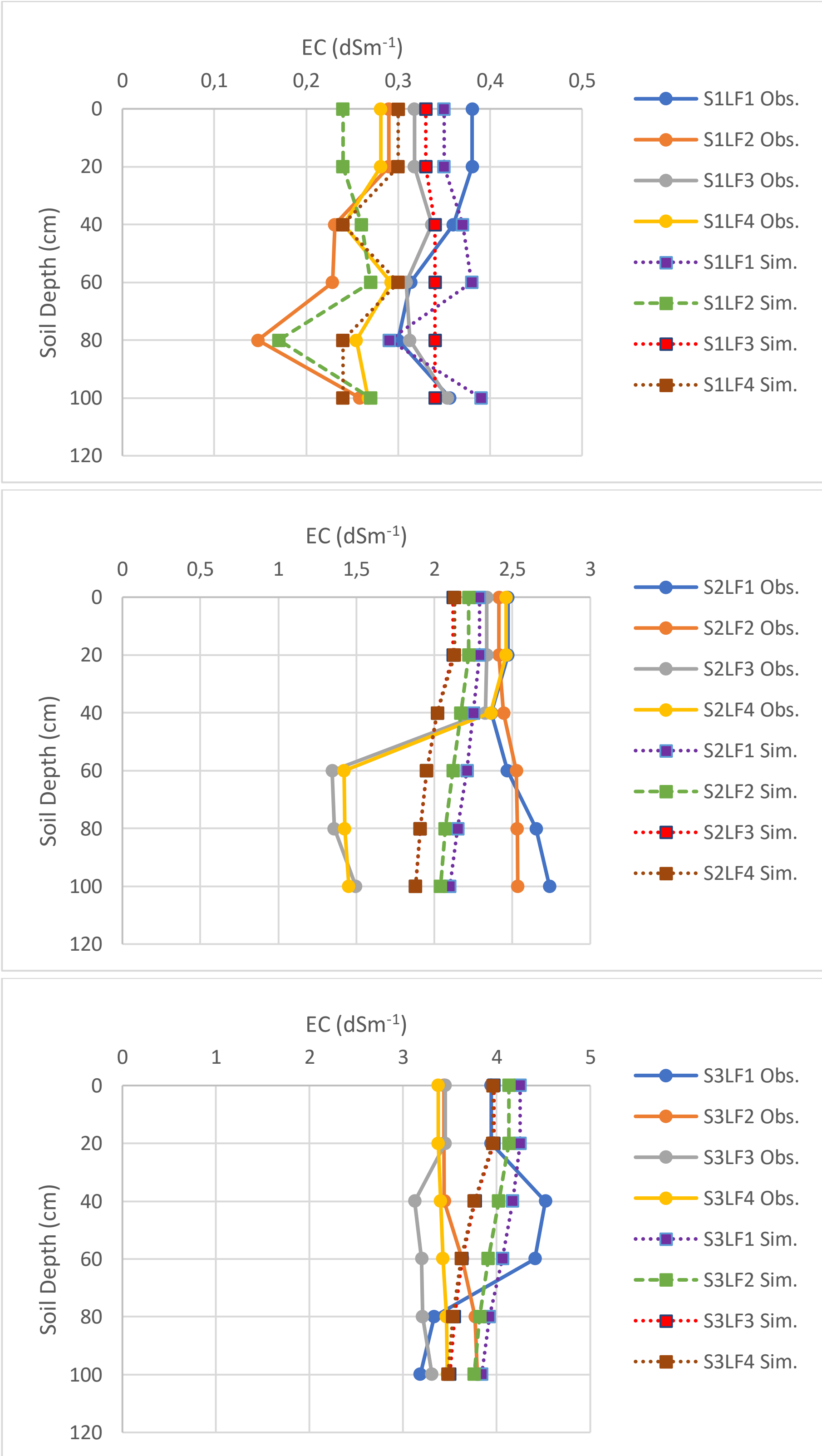


Figure 3

Change in salinity of soil profile in July based on salinity and leaching treatments

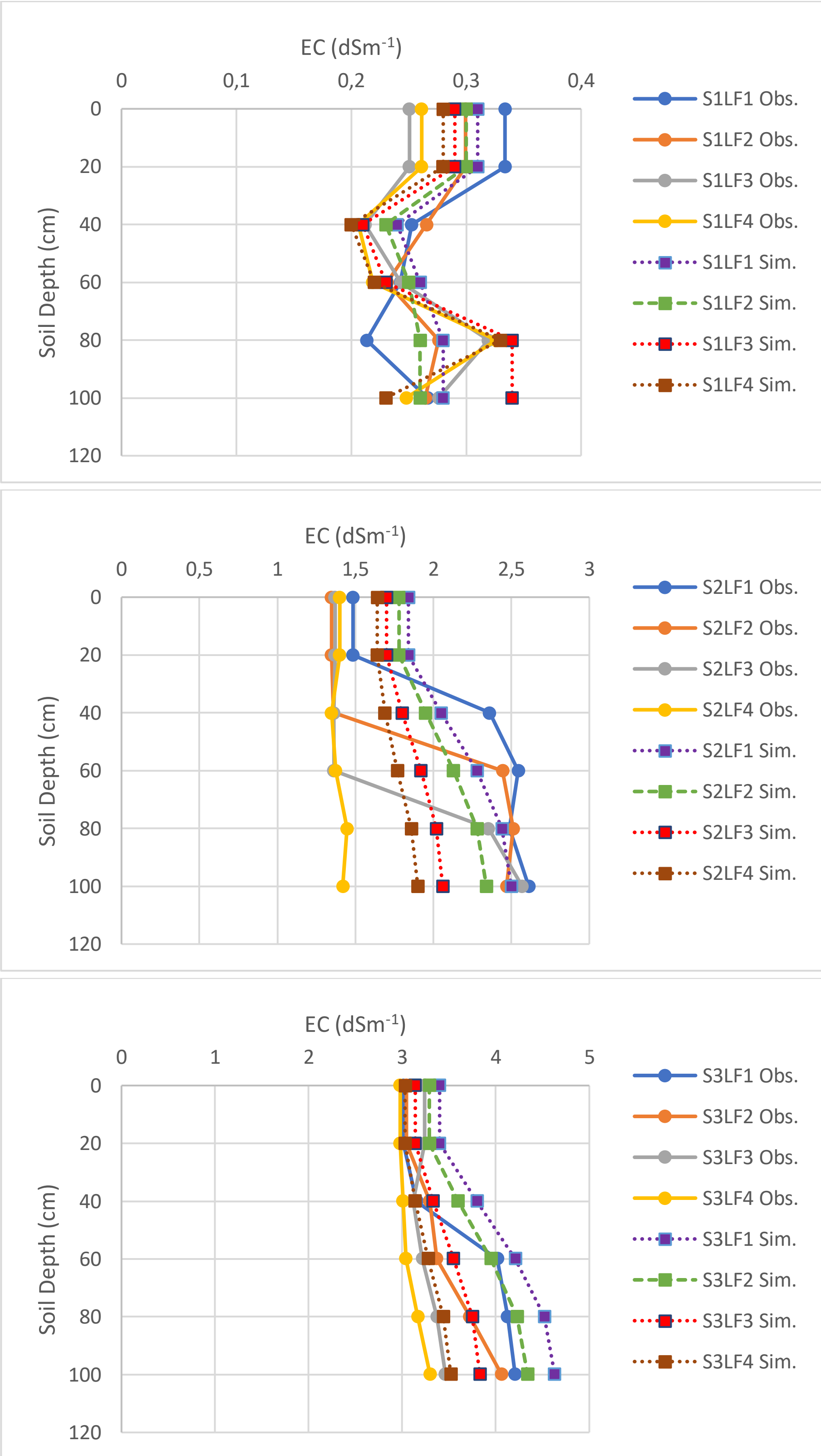


Figure 4
Change in salinity of soil profile in August based on salinity and leaching treatments

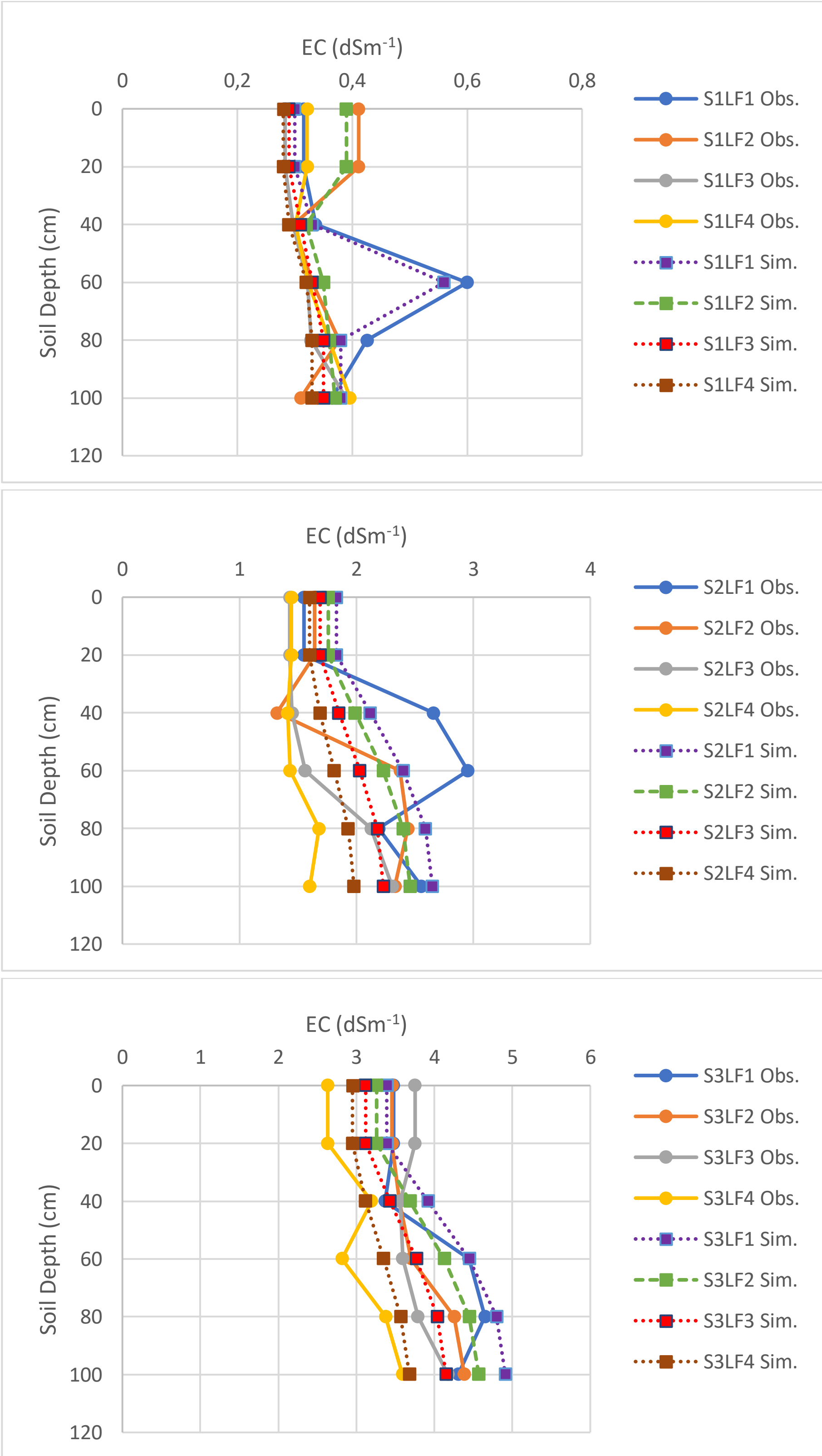


Figure 5
Change in salinity of soil profile in September based on salinity and leaching treatments

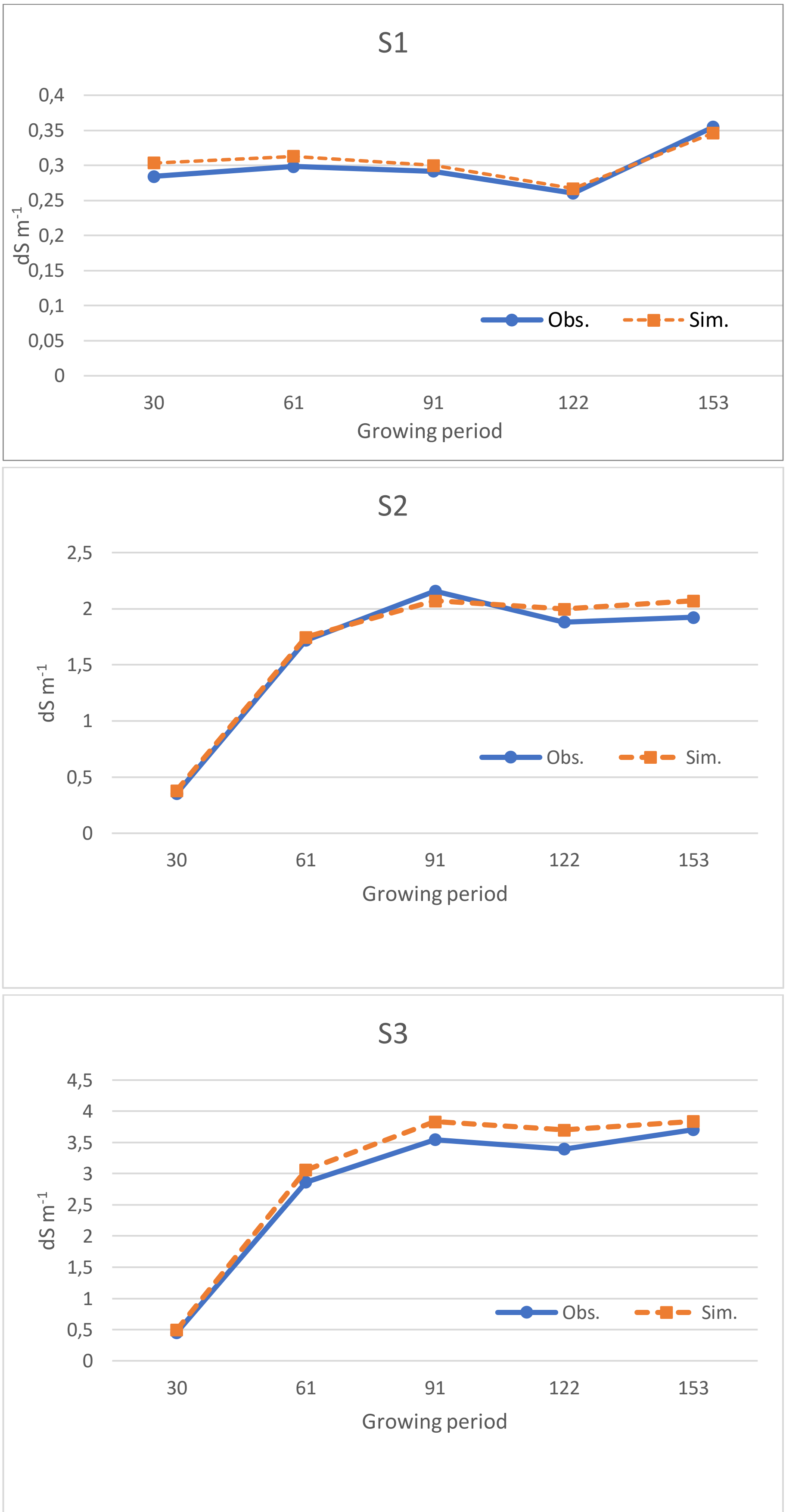


Figure 6

Variation of salinity treatments with the growing period

MAE values varied between 0.074 - 0.497, RMSE values between 0.085 - 0.600 and RE values between 0.221 - 0.307. When the statistical analysis results for the values produced and measured by the model independent of salinity and leaching treatments were analyzed on a monthly basis, it was seen that the lowest values were obtained in May. It was observed that the highest MAE, RMSE and RE values were obtained especially in the months when the irrigation applications increased. Increased RE values indicate that the accuracy of the model decreased. Increasing irrigation applications decreased the accuracy of the values produced by the model. However, statistical analysis results showed that the present model yielded good outcomes even in the months with intensive irrigation practices.

When the graphs obtained according to salinity treatments were examined, it was seen that the values produced by the model were higher for almost every salinity treatment. On the other hand, it was seen that the trend of change in soil salinity during the growing period was predicted in a similar way by the model. When the statistical analysis results were examined, it was seen that MAE, RMSE and RE values were the lowest in T1 treatments, which has the lowest salinity. This is an indication that the values produced by the model yielded better results in irrigation applications where salinity values were low.

## 4. Conclusion

Present findings revealed that the HYDRUS -1D software was suitable for modeling soil profile salinity. However, it was observed that the accuracy of the model decreased with increasing irrigation applications and salinity levels of the irrigation water. However, even in these cases, the model results obtained were found to be statistically appropriate. It can be said that the HYDRUS model will be very useful to use in laboratory and field experiments to determine soil profile salinity. However, it would be appropriate to use it to predict the soil profile salinity after agricultural production and to take the necessary precautions. The software is offered to researchers free of charge and that makes the software as the most widely used one among the modeling programs in which soil water movement and mineral substance transport is carried out.

## 5. References

Ben-Hur M, Agassi M, Keren R and Zhang J (1998). Compaction, aging and raindrop-impact effects on hydraulic properties of saline and sodic vertisols. Soil Sci. Soc. Am. J. 62:1377–1383.

Burton TM ve Hook JE (1979). A mass balance study of application of municipal wastewater to forests in Michigan. J. Environ. Quality, 8, 589-596.

Çullu MA, Almaca A, Şahin Y and Aydemir S (2002). Application of GIS for Monitoring Soil Salinization in the Harran Plain, Turkey. International Conference on Sustainable Land Use and Management. 10-13 June, Çanakkale, Turkey, 326-331.

Ergene A (1982). Toprak bilgisi, Atatürk Üniversitesi Ziraat Fakültesi Yayınları No: 267, Ders Kitapları Serisi No: 42, Erzurum.

Feng GL, Meiri A and Letey J (2003). Evaluation of a model for irrigation management under saline conditions: II. Salt distribution and rooting pattern effects. Soil Science Society of America Journal, 67 (1),77-81

Kirkham MB (1986). Problems of using waste-water on vegetable crops. Hort. Science 21, 24-27.

Kobayashi K and Salam MU (2000). Comparing Simulated and Measured Values Using Mean Squared Deviation and Its Components. Agronomy Journal, 92, 345–352.

Kwiatowsky J (1998). Salinity Classification, Mapping and Management in Alberta. http://www.agric.gov.ab.ca/sustain/soil/salinity/

Legates DR and McCabe Jr GJ,(1999). Evaluating the use of ‘‘goodness-of-fit’’ measures in hydrologic and hydroclimatic model validation, Water Resour. Res., 35, 233–241.

Loague K and Green RE(1991). Statistical and graphical methods for evaluating solute transport models: overview and application, J. Contam. Hydrol., 7, 51–73, 1991.

Maas EV and Hoffman GJ (1977). Crop salt tolerance Current assessment. Irrig.and Drain. Div., ASCE, 103(IR2):115-134.

Oğuzer V (1995). Drenaj ve Arazi Islahı. Ç.Ü. Ziraat Fakültesi Genel Yayın No:106, Ders Kitapları Yayın No.26. Adana.314s.

Özcan H and Çetin M (2000). The Relationship Between Groundwater and Soil Salinity in the Eastern Mediterranean Coastal Region, Turkey. M. Şefik Yeşilsoy International Symposium on Arid Region Soil. 21-24 Sept. Menemen, İzmir, 370-374.

Pereira (2011). Field evaluation of a multicomponent solute transport model in soils irrigated with saline waters, J. Hydrol., 407(1–4), 29–144.

Rasouli F, Pouya AK and Šimůnek J (2012). Modeling the effects of saline water use in wheat-cultivated lands using the UNSATCHEM model, Irrig.Sci., doi 10.1007/s00271-012-0383-8.

Schofield RV and Kirkby MJ (2003). Application of salinization indicators and initial development of potential global soil salinization scenario under climatic change. Global Biogeochemical Cycles, 17 (3), art. no. 1078.

Šimůnek J, Van Genuchten M, Th. and Šejna M (2008). Development and applications of the HYDRUS and STANMOD software packages, and related codes, Vadose Zone J., 7, 587-600.

Yurtseven E, Šimůnek J, Avcı S and Öztürk HS (2013). Comparison of ion(salt) movement in the soil profile subject to leaching with the HYDRUS-1D simulations, Proceedings of the 4th International Conference "HYDRUS Software Applications to Subsurface Flow and Contaminant Transport Problems", edited by J. Šimůnek, M. Th. van Genuchten, and R. Kodešová, March 21-22, 2013, Dept. of Soil Science and Geology, Czech University of Life Sciences, Prague, Czech Republic, ISBN: 978-80-213-2380-3, pp. 395-404.