

# How does climate change affect soil salinity? The case study of a Mediterranean pasture with saline groundwater

## O impacto das alterações climáticas na salinidade do solo: caso de estudo de uma pastagem mediterrânica com água subterrânea salina

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### ABSTRACT

The case study is located in an agricultural area of alluvial origin, approximately 10 km northeast of Lisbon (Portugal). The area is a peninsula surrounded by River Tejo, its estuary, and by River Sorraia. The peninsula lies 1 to 2 m above sea level, with saline groundwater arising from the estuarine tides. The soil is typically clayey and homogeneous. The future climate projections for the Mediterranean region show a decrease in precipitation, increase in mean temperature, and increase in sea water level. These conditions aggravate the processes leading to salt-affected soils (increased evapotranspiration, decrease in salt leaching during the rainy season, and increase of the groundwater salinity). This work evaluates the influence of climate change on soil salinity and water content in a rainfed spontaneous pasture, using *Hydrus-1D*. Three climate scenarios, comprising series of 30 years obtained with a regional climate model, were used: reference scenario (referent to 1971-2000), RCP4.5, and RCP 8.5 (both for 2011-2040). The results show an increase in the soil salinity in the RCP scenarios compared to the reference and a decrease in the mean yearly water content of the topsoil. Both effects limit the productivity of the pasture and even compromise the plants' growth.

**Keywords:** soil salinity, soil water, soil modelling, climate change.

### RESUMO

O caso de estudo situa-se na Lezíria de Vila Franca de Xira, uma zona agrícola de origem aluvial, a cerca de 10 km a nordeste de Lisboa. A Lezíria é uma península rodeada pelo rio Tejo, pelo seu estuário e pelo rio Sorraia, entre 1 a 2 m acima do nível do mar, com água subterrânea salina resultante da influência marinha no estuário. As projeções climáticas para a região indicam uma diminuição da precipitação, aumento da temperatura média e aumento do nível da água do mar. Estas condições agravam os processos de salinização do solo (aumento da evapotranspiração, diminuição da lixiviação dos sais pela chuva e aumento da salinidade das águas subterrâneas). Este trabalho pretende analisar a influência das alterações climáticas na salinidade do solo e teor de água numa pastagem espontânea de sequeiro, utilizando *Hydrus-1D*. Foram simulados três cenários climáticos, compreendendo séries de 30 anos obtidas a partir de um modelo climático regional: cenário de referência (referente a 1971-2000), RCP4.5 e RCP 8.5 (ambos para 2011-2040). Os resultados mostram um aumento da salinidade do solo nos cenários RCP em relação à referência e uma diminuição no teor de água médio anual na camada superficial do solo. Ambos os efeitos limitam a produtividade da pastagem, podendo comprometer totalmente o crescimento das plantas.

**Palavras-chave:** salinidade do solo, água do solo, modelação, alterações climáticas.

## INTRODUCTION

The peninsula of Lezíria de Vila Franca de Xira is an agricultural area of alluvial origin, approximately 10 km northeast of Lisbon (Portugal). It is surrounded by River Tejo, its estuary, and by River Sorraia. The peninsula lies 1 to 2 m above sea level, with saline groundwater arising from the estuarine tides, which salinity is close to that of the sea, with an electrical conductivity (EC) of 40-50 dSm<sup>-1</sup> (Rodrigues *et al.*, 2019). Climate projections for the Mediterranean region show a decrease in precipitation, increase in mean temperature, and increase in sea water level. These conditions potentiate the accumulation of salts in the soil profile, which may compromise its agricultural use.

*Hydrus-1D* is a modelling tool which has been found to accurately model the soil water and salts dynamics (Kanzari *et al.*, 2018; Ramos *et al.*, 2011). In this study, *Hydrus-1D* was used to evaluate the influence of climate change projections on soil salinity and water content, in a rainfed spontaneous pasture in the south of Lezíria.

## MATERIAL AND METHODS

### Study site

The site is a rainfed spontaneous pasture dominated by *Poaceae*. The soil is classified as a Solonchak, according to the Harmonized World Soil Database (Fischer *et al.*, 2012). The soil texture is relatively uniform along the soil profile and is classified as silty-clay. The site is located 2 m above the sea and at about 2.5 km from the estuary of the River Tejo. Primary salinization occurs due to the influence of the marine water from the estuary in groundwater.

### Calibration of the *Hydrus-1D* model

*Hydrus-1D* is a public domain modelling tool for analysis of one dimensional water flow and solute transport in variably saturated porous media (Simunek *et al.*, 2018).

Five soil layers to a depth of 1.5 m were considered (average depths of 0.15, 0.45, 0.75, 1.05, and 1.35 m). For the model calibration, soil samples were col-

lected from the five soil layers, between May 2017 and October 2018, in a total of 20 samples. The soil volumetric water content ( $\theta$ ) was determined from the soil gravimetric water content ( $\theta_w$ ) and the dry bulk density. The electrical conductivity of the soil saturated paste ( $EC_e$ ) was determined with a conductivity meter in the extract collected with suction filters from the saturated soil paste. The electrical conductivity of the soil solution,  $EC_{sw}$ , was calculated according to the following equation,

$$EC_{sw} = EC_e \frac{SP}{\theta_w} \quad (1)$$

where  $SP$ , is the gravimetric water content of the saturated soil paste (Rhoades *et al.*, 1989). In *Hydrus-1D* the van Genuchten-Mualem model was selected to calculate the water transport, using the saturated and residual water content ( $\theta_s$  and  $\theta_r$ ), the saturated hydraulic conductivity ( $K_s$ ), the inverse of the air-entry value ( $\alpha$ ), the pore-size distribution index ( $n$ ), and the pore connectivity ( $l$ ).  $\theta_s$  and  $\theta_r$  were obtained from the particle size distribution using pedotransfer functions developed by Ramos *et al.* (2014), which were found to be well-suited for the soils in this region. The equilibrium model was used for determination of the solute transport. The inverse modelling tool was used to calibrate  $K_s$ ,  $\alpha$  and  $n$ , and the solute transport parameter, dispersivity ( $D$ ). The final soil parameters used in *Hydrus-1D* are presented in Table 1.

**Table 1** - Soil parameters used in *Hydrus-1D*

Avg. depth	$\theta_r$	$\theta_s$	$\alpha$	$n$	$K_s$	$l$	$D$
0.15 m	0.09	0.57	0.03	1.53	17	0.5	15
0.45 m	0.09	0.57	0.02	1.4	65	0.5	14
0.75 m	0.08	0.56	0.015	1.3	10	0.5	14
1.05 m	0.08	0.55	0.01	1.1	65	0.5	25
1.35 m	0.08	0.55	0.01	1.1	25	0.5	25

The crop evapotranspiration ( $ET_c$ ) was calculated according to the single crop coefficient approach proposed by Allen *et al.* (1998), in which  $ET_c$  is calculated by multiplying the reference crop evapotranspiration ( $ET_o$ ), by a crop coefficient,  $K_c$ .  $ET_o$  was calculated using the Penman-Monteith equation with data from a nearby meteorological station.

The  $K_c$  was set to 0.4 for the initial development and 0.85 in the developed phase, with the cycle length adapted to site conditions. As required by *Hydrus-1D*,  $ET_c$  was fractioned in the components of soil evaporation and potential crop transpiration, which were estimated as a function of the Leaf Area Index (*LAI*) and the corresponding Soil Cover Factor, according to the approach proposed by Ritchie (1972). The *LAI* of the developed pasture was 3.5. In *Hydrus-1D*,  $T$  was integrated over the root domain using the Feddes model for root water uptake with the parameters for pasture proposed by Wesseling *et al.* (1991) and the solute stress was considered using the multiplicative threshold model.

The calibration of the model with the field data resulted in a RMSE of calibration of 0.064 for a  $\theta$  range between 0.2 and 0.55 and a RMSE of 6.5 for a  $EC_{sw}$  range between 5 and 70  $dSm^{-1}$ .

### Simulation of the climate scenarios

*Hydrus-1D* was also used to simulate  $\theta$  and  $EC_{sw}$  for three scenarios comprised by 30-years periods: reference, RCP 4.5, and RCP 8.5. The reference scenario corresponds to the model data for the historical period of 1971-2000. RCP 4.5 and RCP 8.5 represent different levels of greenhouse gas concentration in the atmosphere during the period 2041-70, corresponding to an intermediate and a severe scenario, respectively. The climate data was obtained from the CORDEX experiment, with the Regional Climate Model, RACMO22E (Meijgaard *et al.*, 2008), forced by the Global Climate Model, MOHC-HadGEM2-ES. This combination was found to have better results in climate description for this region of Portugal (Soares *et al.*, 2017).

$ET_c$  was calculated as described for the calibration process, but  $ET_0$  was now calculated using the climate data from the projection model, using the Hargreaves-Samani equation (Hargreaves & Samani, 1985):

$$ET_0 = C \frac{Ra}{\lambda} (t_{avg} + 17.8) \sqrt{(t_{max} - t_{min})} \quad (2)$$

where  $C$  is the radiation adjustment coefficient [ $^{\circ}C^{0.5}$ ],  $Ra$  is extraterrestrial solar radiation [MJ],  $\lambda$  is the latent heat of vaporization equal to 2.45  $MJkg^{-1}$ .

$t_{avg}$  is the average daily temperature, and  $t_{min}$  and  $t_{max}$  are respectively, the minimum and maximum daily temperatures [ $^{\circ}C$ ]. For 'interior' locations, where land mass dominates and air masses are not strongly influenced by a large water body (Allen *et al.*, 1998) proposed  $C=0.16$ .  $t_{min}$ ,  $t_{max}$ , and the precipitation, were obtained from the climate projections. The depth and  $EC$  of ground water was considered content during the simulations (1.2 m), which is an approximation, as its depth varies during the year and is also likely to rise as a consequence of the projected increase in sea water level.

## RESULTS

Because  $EC_e$  allows the analysis of the soil salinity independently of its actual  $\theta$ , it was calculated using  $EC_{sw}$  and  $\theta$  simulated with *Hydrus-1D* in eq. (1), where  $SP$  is  $\theta_s$ . Figures 1 and 2 show that the median of  $EC_e$  increases in both RCP scenarios, when compared to the reference scenario. Furthermore, there is a very large increment in the maximum  $EC_e$  in RCP scenarios, reaching values only tolerable to few plants.  $EC_e$  shows a similar increase for the deeper soil layers. Figure 3 show the yearly average  $\theta$  at 15 cm. In the topsoil a decrease in average  $\theta$  in the RCP scenarios compared to the reference scenario is evident. The decrease in  $\theta$  does not occur at the layers below, which is likely due to the effect of capillary rise of the groundwater to these layers.

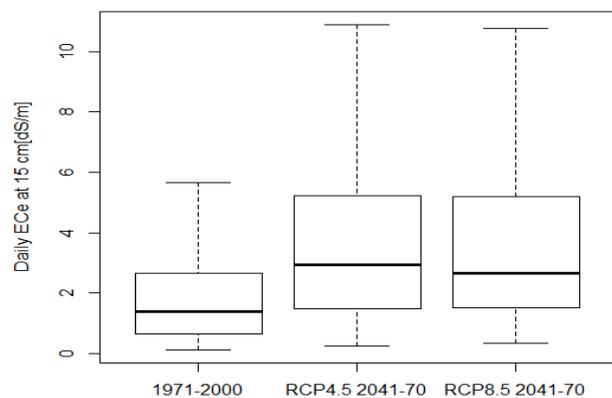
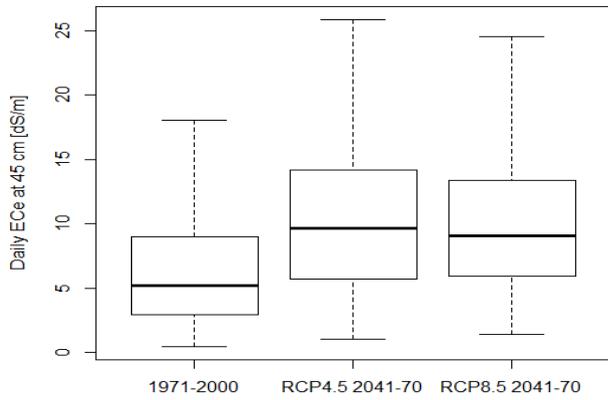
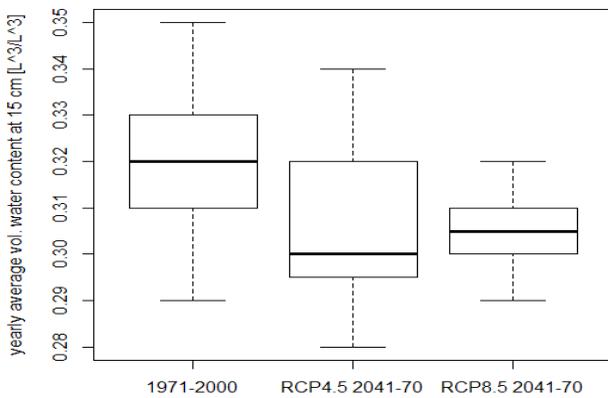


Figure 1 - Daily  $EC_e$  at the average soil depth of 15 cm.



**Figure 2** - Daily  $EC_e$  at the average soil depth of 45 cm.



**Figure 3** - Yearly average  $\theta$  at the average soil depth of 15 cm.

## CONCLUSIONS

The simulations show that soil salinity increases (median and maximum of daily  $EC_e$ ) for all soil layers, in the future climate scenarios comparatively to the reference scenario. Also, the average yearly  $\theta$  of the topsoil decreases in the future scenarios, compared to the reference. Both changes in salinity and water content may limit the productivity of the pasture and even compromise the ability of plants to grow. This evidences the need for adaptation strategies to avoid degradation of these soils due to salinity.

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