OPTIMAL LAYOUT AND SALINITY MANAGEMENT OF DRIP IRRIGATION SYSTEMS

DISPOSITION OPTIMALE ET GESTION DE SALINITÉ DES SYSTÈMES D'IRRIGATION AUGOUTTE À GOUTTE

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ABSTRACT

Under scarcity of freshwater resources the necessity of minimizing leaching requirements in salt-affected lands becomes more significant. To study the potential of drip irrigation for leaching practices, simulation-based investigations were performed. Leaching was investigated for a synthetic field scenario which exhibited a typical initial salt accumulation when irrigating with saline water. Subsequently, the performance of three irrigation types, namely: sprinkler, surface drip and subsurface drip irrigation, was investigated along with possible combinations of the individual techniques. The leaching performance was assessed by an optimization framework, which employed the model Hydrus-2D and investigated the typical management parameters of the irrigation systems, such as total operation time of the systems, sprinkler intensity and drip line positioning. The framework evaluates the leaching performance by the amount of total applied water and the remaining salt mass in the soil profile as contrary objective functions. The results showed that, a combination of a surface sprinkler irrigation followed by subsurface drip irrigation achieves the best leaching performance. In-depth analysis revealed, that deeper line positions for the subsurface drippers dominated the best results. The study showed that soil texture as well as drip line depth significantly affected the leaching efficiency. However, changing surface dripper location on soil surface had only a minor influence on the leaching performance.

RÉSUMÉ

Étant donné de la raretédes ressources en eau douce, la nécessité de minimiserlesexigences de lixiviationdans les terresaffectées par le seldevient plus importante.Pour étudier le potentiel de l'irrigation goutte à goutte pour la lixiviation, des investigations basées sur simulation ont été effectuées. Cela a été fait pour un scénario synthétique qui a montré une accumulation initiale typique desel lors de l'irrigation avec de l'eau saline. Par la suite, la performance de trois types d'irrigation (par aspersion, goutte à goutte de surface et goutte à goutte souterrain) aété étudiéeainsi que les combinaisons possibles de ces techniques. La performance de lixiviation a été évaluée parun cadre d'optimisation, qui a employéun modèleHydrus 2D et étudié plusieursparamètres de gestion typiques pour lessystèmes d'irrigation. Le cadre a évalué la performance de lixiviation par la quantité d'eauappliquée et la masse restante de seldans le solas contrary objective functions,et cela à été réalisé pour sol de loam et de silt.Les résultats montrent qu'une combinaison d'une irrigation par aspersion suivie d'une irrigation goutte à goutte souterraine permet d'obtenir la meilleure performance de lixiviation. L'analyse en profondeur montre que les positions de ligne les plus profondes pour goutte à goutte souterrain ont dominé les meilleurs résultats.

Keywords: Drip irrigation, soil salinity, optimization, HYDRUS-2D

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1. Introduction

Soil salinity is considered one of the most important and widespread soil and agricultural problems. More than 800 million hectares (6% of the total area of the word) worldwide are salt-affected lands (FAO, 2005; Munns, 2005). The availability of freshwater resources, which can be used for leaching, declined appreciably in the last few decades (Silber et al. 2015). Accordingly, soil salinity becomes more critical, and the necessity of minimizing leaching requirements in salt-affected lands becomes more significant.
Drip irrigation (DI) is considered as a precise and efficient water supply system . Moreover, it was documented that traditional irrigation techniques (flood, furrow and sprinkler irrigation) have a lower water use efficiency and water productivity when compared with DI (Godoy et al. 2003; Alam et al. 2002 and Hutmacher et al. 2001). Many studies reported that DI has a considerable localized leaching pattern even under deficit water application (Hanson et al. 2008, Hanson et al. 2006, Hanson and May 2004). Beside the amount of applied water, one of the important factors that regulates the salt distribution in the roots zone under DI is the relative position of the drip lines to the plant on or/and under soil surface (Hanson and May 2011). Hanson and May (2011) reviewed the dependency of salinity distribution on the saline groundwater level for a subsurface dripper, where the upward flow from a shallow groundwater level increased soil salinity levels and decreased the leached area around the dripper. Burt and Isbell (2005) showed the efficiency of using multiple drip-lines for a reclamation leaching for trees crops by applying water only to the affected areas instead of the whole field, which reduced the leaching requirements to one third.

In the presented work simulation-based investigations were performed to evaluate the performance of drip irrigation under saline conditions to study its potential for leaching practices.

2. Material and Methods

In this study, the HYDRUS-2D software (Simunek et al. 1999) was used in a systematic optimization framework to investigate the potential of reducing the reclamation leaching requirements. The framework involved three irrigation water application techniques, namely: (i) sprinkler (S), (ii) surface drip (SI) and (iii) subsurface drip irrigation (SDI). Moreover, the combinations of the individual techniques were tested, with the assumption that the process is continuous and started with a surface source (S or SI).The investigated management parameters are: operation time of the systems, sprinkler intensity (SF) and drip line positioning horizontally (SI) and vertically(SDI). Thereafter, the results were evaluated by two contrary objective functions to be minimized: the relative amount of total applied water (OF_1) and the relative remaining salt mass in the soil profile (OF_2), which are as follow:

$$\mathrm{OF}_1 = \frac{\mathrm{AW} - \mathrm{AW}_{\min}}{\mathrm{AW}_{\max} - \mathrm{AW}_{\min}}, \qquad \mathrm{OF}_2 = \frac{\mathrm{SM}}{\mathrm{SM}_0}$$

Where AW is the applied water for the specific scenario [L], $AW_{max,\ min}$ are the maximum and minimum applied water for all scenarios [L], and SM and SM_0 are the final and initial salt mass in the layer of interest [M]. The OFs have a value range between zero and one, and both of them should be minimized, or in other words the applied water and the remaining salt mass in the soil should be minimized.
A 2D (x- z) soil domain (30 cm- 100 cm) was used for the simulations with synthetic initial salt distributions, which were created by preliminary simulations so that they consider the main drivers of salt accumulation in real field conditions (evaporation and roots water uptake). Furthermore, the domain was divided in depth to three layers: upper 40 cm which represents the main RZ, then a middle 40 cm layer representing the rest of the root zone (RZ), and the lower 20 cm is the rest of the domain. The RZ was defined assuming that maize is the crop of interest. This subdivision allows evaluating the final results for different sub regions.
Good drainage conditions (existing of a good drainage system) were assumed by assigning a free drainage boundary condition (BC) to the bottom of the domain. "No flux" BC was defined for the domain sides except the case of SDI system, in which a semi circle was defined at the left side of the domain and a variable flux BC was assigned to it. Furthermore, an atmospheric BC was specified for the top of the domain with potential evaporation of 6 mm.d-1 and a precipitation value equal to SF when sprinkler was considered . Additionally, when SI was considered a length of 2.5 cm excluded from the atmospheric BC and a variable flux was assigned to it. Four locations for SI were used: 5, 10, 15 and 20 cm form the left upper corner of the domain (plant), and 7 depths for SDI: 10, 15, 20, 25, 30, 35, and 40 cm form the plant.
Finally, the procedure was applied for two different soil texture (loam and silt) with similar initial conditions (same initial salt mass).

3. Results and Discussion

Only the investigations results for loam are presented in this section, which have been obtained from more than 60,000 individual simulations (combinations).
A continuous leaching was applied for loam by combining S with SI and S with SDI for a total time of 120 h. Fig. 1 presents the resulting objective functions (OFs) from changing the duration of S (0 to 110 h) on X axis and its flux (0 to 1

cm. h^{-1}) on Y axis as contour plots for the different drip line positions. In Fig. 1 the scale color bar refers that a blue area means either a minimum used water (OF_1) or a totally leached soil (OF_2).
Since a constant dripper flux (3.15 cm. h^{-1}) was used for both SI and SDI, the total applied water (OF_1) for both scenarios S+SI and S+SDI were identical. The findings depict that changing SI location had a minor influence on OF_2 (Fig. 1 left). However, increasing the SDI depth increased the minimum operational time of S which is required to totally clean up the soil, and less significantly decreased the minimum required flux.

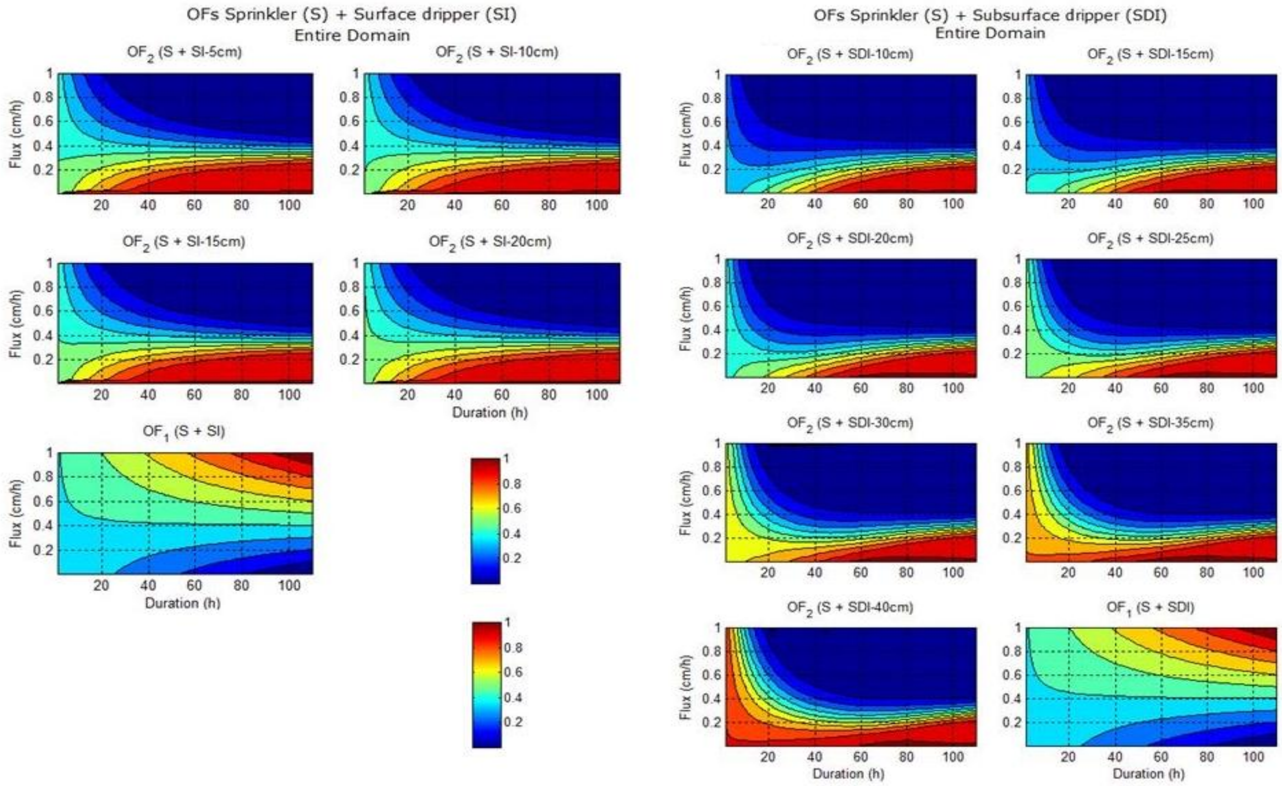

Figure 1.: Contour plots of the objective functions (OFs) for loam of the whole domain: S+SI (left) and S+SDI (right)

In the mentioned framework, which has two conflicting OFs, Pareto analysis was applied to find the optimal parameter combinations (trade-offs) or as called Pareto front. According to the layer of interest the optimal solution (Pareto front) could significantly change. Fig. 2 shows the OFs of all investigated scenarios for the whole domain (A) and for only the upper 40 cm from it (B). The Pareto fronts depict that combining S with SDI dominate the optimal results. Moreover, A middle deep SDI (relative depth to the layer depth) was found to be the most dominant (S+SDI-35 and 40 cm for the domain, and S+SDI-20 cm for upper layer). By comparing Pareto fronts for both cases it can be seen that leaching the main root zone is easier than the whole domain. For instance when applying 40 % relative water amount (OF_1 = 0.4) 90 % of the salts are leached out from the main root zone (OF_2 = 0.1). In contrast, it was able only to leach 70 % of the initial salt mass from the entire domain (OF_2 = 0.3)

4. Summary and Conclusions

In this Study, the potential of involving drip irrigation in reclamation leaching practices was investigated by performing simulation- based investigations using HYDRUS-2D model in a systematic optimization framework. Two variants of drip irrigation systems, surface and subsurface dripper, along with sprinkler irrigation were evaluated within this framework with possible combinations. Moreover, the typical management parameters of the mentioned irrigation systems were the core of the investigations to find the best parameter combinations. The results were assessed by two contrary objective functions: the relative amount of total applied water and the relative remaining salt mass in the soil profile. Since the problem was defined with two conflicting objectives, there was no single optimal solution. Instead, the optimal solution was in form of multiple parameter combinations (trade-offs), as defined by Pareto front. The results showed that a combination of a sprinkler irrigation followed by subsurface drip irrigation achieved the best leaching performance. In-depth analysis showed that middle deep drip line for the subsurface drippers dominated the best results. However, changing surface dripper location on soil surface had only a minor influence on the leaching performance.
The presented framework can be expanded to cover more decision variables such as the dripper flux, orcan be implemented for other soil textures. Moreover, it can be also modified to study the maintenance leaching thorough a crop season.

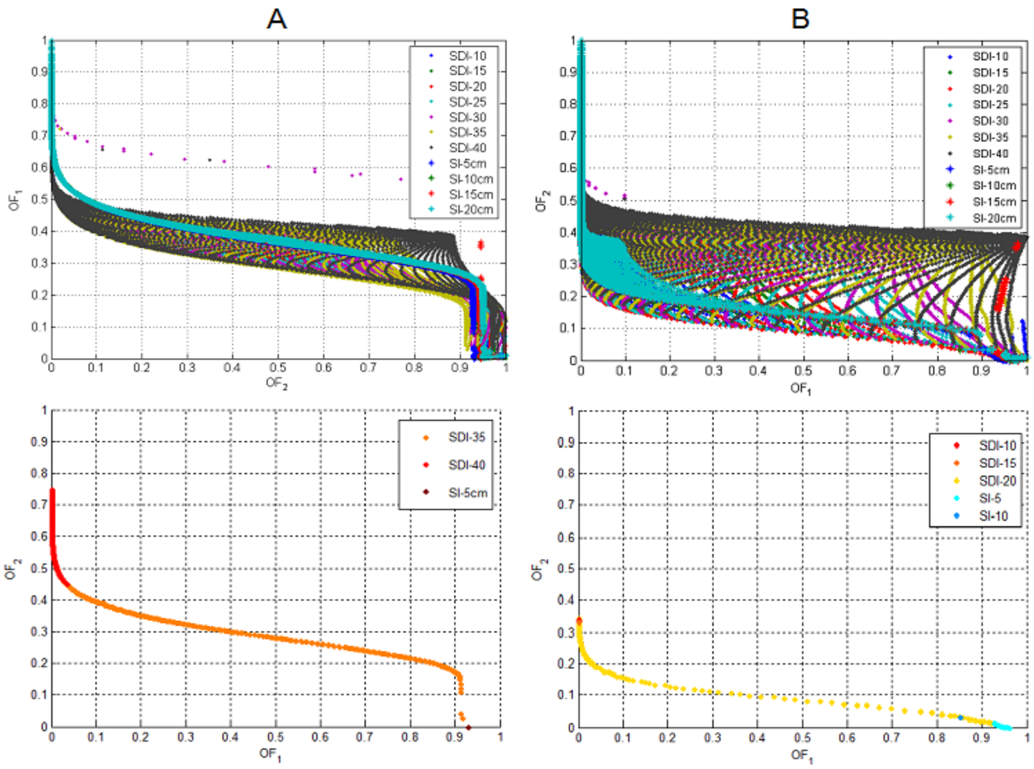

Figure 2.: Objective functions (upper Figures) and Pareto front (lower Figures) for loam: Entire domain (A), and main root zone (B).

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