SIMULATION MODELING TO INCREASE WATER PRODUCTIVITY USING LOW QUALITY WATER

MODELISATION DE SIMULATION POUR AUGMENTER LA PRODUCTIVITE DE L'EAU UTILISANT L'EAU DE BASSE QUALITE

Safoora Asadi Kapoorchal[1*], Azim Ashayeri[2], Majid Vazifedoust[3], Esmaeel Ebrahimi[4]

ABSTRACT

Water scarcity and low water quality are the main problems of irrigated agriculture in arid and semi-arid regions. The opportunity for increasing water productivity under saline conditions relies on the accurate implementation of the leaching requirement to prevent unnecessary percolation below the root zone. Evapotranspiration from irrigation water leaves the remaining water more concentrated with salts. The leaching fraction of the applied irrigation water percolates through the root zone to maintain soil salinity at an acceptable level. The leaching requirement increases with the salinity of the water supply and the sensitivity of the crop to salinity. To increase water productivity under water scarcity and saline conditions, field scale strategies have been studied using a physically based agro-hydrological SWAP model. One of the major crops (wheat) on the three main soils have been simulated with the SWAP model for different irrigation applications and salinity levels, resulting in yields, water balance components and water productivity. The paper illustrates how uncertainty about salinity levels and leaching fraction, resulting in part from uncertainty about yield-salinity relations, imposes constraints on the possible improvement of water productivity under saline conditions. The paper points out implications for the successful production of crops with a mixture of saline and good quality irrigation water.

Key words: *Modeling, SWAP (Soil- Water- Atmosphere- Plant), water productivity.*

1 PhD student, soil science expert of Mahab Ghodss Consulting Engineering Co. E-mail: safoora.asadi@yahoo.com Tell: +982122259891, address: !7, Takharestan St, shahid Vahid Dastgerdy Ave., Tehran, Iran.
2 Manager of Environment, water and soil lab, Mahab Ghodss Consulting Engineering Co. E-mail: ashayeri_a@yahoo.com
3 Faculty member, Water Engg. Deptt., Guilan University, E-mail: majid.vazivedoust@yahoo.com
4 Employer of of Mahab Ghodss Consulting Engineering Co.

RESUME

La pénurie d'eau et la qualité inférieure de l'eau sont les principaux problèmes de l'agriculture irriguée dans les régions arides et semi-arides. La possibilité d'augmenter la productivité de l'eau dans les conditions salines dépend de la mise en œuvre correcte de l'exigence de lessivage pour empêcher la percolation inutile sous la zone racinaire. L'évapotranspiration de l'eau d'irrigation laisse le reste de l'eau plus concentrée en sel. La fraction de lessivage de l'eau d'irrigation appliquée percole par la zone racinaire pour maintenir la salinité du sol à un niveau acceptable. L'exigence de lessivage augmente avec la salinité de l'approvisionnement en eau et la sensibilité des cultures à la salinité.

Pour accroître la productivité de l'eau dans les conditions de pénurie et de salinité de l'eau, les stratégies ont été étudiées au niveau de la parcelle en utilisant un modèle SWAP agro-hydrologique à base physique. Avec l'aide du modèle SWAP, l'une des grandes cultures (blé) ont été simulées sur les trois principaux sols par différentes applications d'irrigation et différents niveaux de salinité, qui donnent lieu aux rendements, aux composantes du bilan hydrique et à la productivité de l'eau. Le rapport évoque comment l'incertitude des niveaux de salinité et de la fraction de lessivage due au rapport entre rendement-salinité cause des contraintes sur la possibilité d'améliorer la productivité de l'eau dans les conditions salines. Le document souligne l'impact du mélange de l'eau salée avec l'eau d'irrigation de bonne qualité sur la réussite de la production agricole.

Mots clés : *Modélisation, SWAP (sol-eau-atmosphère-plantes), productivité de l'eau.*

1. INTRODUCTION

Water scarcity and salinization are major threats to sustainable irrigation in Iran. When water and not the land is the limiting factor, it would be better to express productivity not in terms yield in kg/ha or dollar/ha, but in terms of water used in kg/m^3 or dollar/m^3. This concept is known as Water Productivity (WP).

It is true that the adoption of technologies uses less water per unit area, leading to an increase in water productivity on fields. But to determine whether water was saved or not, we have to examine what happened to the water that was not used. If it is used by the same farmer on another piece of the same farm, then there is no net change in water use by that farmer and the water productivity increases, but there is no overall water saving. Water 'savings' at one place are likely to reduce return flows to other users downstream in the basin (Seckler, 1996). Any attempt to increase the productivity of water should therefore originate from changes in agricultural practices, including irrigation system management, crop selection, soil management, field scale water management, salinity control; among others. Obviously, changes in water allocation between different sectors might change basin-wide productivity as well.

Simulation models are useful tools to explore options for future water management, including impacts of exogenous factors such as climate change, climate variability, economic growth and population increase. These models can differ in their spatial scale and the rigours of physics included. On the contrary, field scale analysis does not require fully physically based models. The amount of detail included in the model to be applied depends mainly on which question to be addressed and some other factors as: data accessibility, level of expertise and time available. Simulation models have proved to be very useful in two ways. First of all, they can be used to fill the data gaps in measurements in terms of spatial and temporal resolution and also for difficult-to-measure properties. An example of the latter is the distinction between soil evaporation, considered as a loss in agronomy terms, and crop transpiration. This distinction is difficult to measure, but estimates can be made using simulation models (Droogers et al., 2001). A second application of models is scenario analyses, to answer questions in the form of: what happens if…?

The appropriate model to select should therefore have a strong emphasis on salt-water-soil-crop interactions. The SWAP model is equipped to deal with these processes and was therefore selected as a tool to explore options for field scale management.

For the Doroodzan Area SWAP was used to explore salinity processes for three soil type and one crop (wheat). That study focused on using the model as a tool to understand processes rather than as a tool for scenario analysis and on the exploration of options for improved field scale water productivity.

The objectives of this study are to provide for wheat at major soil types in Doroodzan: yield functions, soil evaporation and water productivity figures, and use this information to perform scenario analysis for improved farm management practices given a certain set of limitations. Also links scale up to the basin level will be provided.

2. MATERIALS AND METHODS

Study area

The study area is located in Fars province and covers an area of about 123846 hectares. The province is situated between 52°, 4' and 53°, 27' East longitude, and 29°, 18' and 30°, 25' North latitude. Average height of plain is about 1500 meters above the sea level.

The Climate

The average monthly temperature is about 5°C-27.1°C. The annual relative humidity of the region is 47%. Its annual rainfall is 435 mm and most of the rainfall occurs in the winter. The average annual evaporation exceeds 1749.8 mm. most of the evaporation occurs in the summer months from July to August. From the climatic point of view, the region can be described as arid and semi-arid.

Simulation model

For this study, different combinations of irrigation depth, water salinity and soil types were used.

SWAP Model (Soil-Water-Atmosphere-Plant Model)

The Soil-Water-Atmosphere-Plant (SWAP) model was applied to simulate all the terms of the water and salt balance and to estimate relative yields (actual over potential yield).

The SWAP is a one-dimensional, physically based model for heat, water and solute transport in the saturated and unsaturated zones. SWAP includes modules for simulating irrigation practices at field level, so that different combinations of irrigation depth and application dates can be tested. It also allows for different levels of water salinity to be incorporated into the calculations. The water transport module is based on Richard's Equation, which is a combination of Darcy's Law and the continuity equation. Crop yields are estimated in two ways: a simple growth algorithm based on the FAO procedure, or a detailed crop growth module using carbohydrate partitioning at different stages of plant growth. Actual soil evaporation and crop transpiration are simulated based on the potential evapotranspiration and leaf area index development, combined with the amount of soil moisture in the top layer or root zone.

The first version of the SWAP model was developped in 1978 (Feddes et al., 1978) and from then on a continuous development of the program started. After that, version of SWAP2.0 was described by Van Dam et al. (1997). The version used for this study is SWAP3.0.3.

A schematic diagram of the main components of the SWAP is presented in Figure 1.

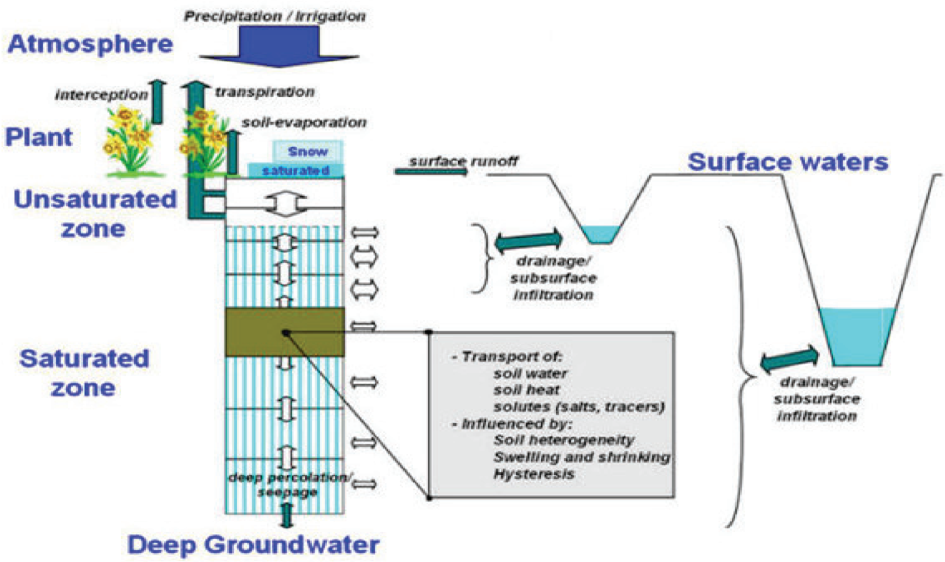


Fig. 1 Main components of the SWAP model

Input data

Soils. In order simulate the flow of water the soil hydraulic functions, water retention and hydraulic conductivity curves, are required. These soil hydraulic functions are often not available and, moreover, require specific equipment to determine these properties. Pedo-transfer functions can be used to derive these difficult-to-measure soil hydraulic functions from easily obtainable data such as texture and soil bulk density (e.g. Tietje and Tapkenhinrichs, 1993). These pedotransfer functions were used to obtain the soil hydraulic properties required as described according the Mualem-Van Genuchten equations (Van Genuchten, 1980). Table 1 shows the measured soil properties and the derived soil hydraulic characteristics.

Table 1. Soil properties and derived soil hydraulic functions, as described according to the Van Genuchten parameter set

Soil texture	Horizon	clay	silt	OM	Bd	Y_{res}	Y_{sat}	;	n	K_{sat}	L
		%	%	%	gr/cm^3	m^3/m^3	m^3/m^3	cm^{-1}	-	Cm/d	-
Clay loam	Top soil	29	40	1.2	1.01	0.01	0.56	0.018	1.22	103.74	-1.80
	Sub soil	31	45	0.91	1.03	0.01	0.57	0.016	1.18	59.85	-1.48
clay	Top soil	34	59	1.48	1.05	0.01	0.55	0.017	1.19	38.44	-1.83
	Sub soil	65	28	1.13	1.4	0.01	0.47	0.016	1.06	2.23	-2.11
Silty clay	Top soil	36	47	0.71	1.1	0.01	0.54	0.018	1.19	59.17	-1.56
	Sub soil	48	48	0.8	1.3	0.01	0.49	0.016	1.09	10.21	-2.38

Climate data. Monthly meteorological data was available for a station in the vicinity of the Doroodzan area over a period of 10 years. SWAP requires daily input data so it was assumed that the daily data was similar as the monthly average ones. In addition, for rainfall the monthly maximum and the day this maximum occurred, was available, and was used in SWAP.

Crops. Three of the most common crops in the area are winter wheat and barley and maize. For this study we selected to analyze the effect of different irrigation depth and water salinity scenarios on wheat. The wheat crop was considered, as this is an important industrial crop in the area.

Irrigation. Irrigation applications according to normal farmer practices are very high in an attempt to compensate for the poor water quality. As no detailed information was available on the exact date of irrigation applications, it was assumed that farmers irrigated the crop at the most appropriate time. Groundwater levels are reported to be around150- 200 cm below surface and no drainage was considered.

Model Setup

The SWAP model has been setup for each soil and for different salinity levels of irrigation water at different irrigation depths. The salinity levels considered are 5, 10, 15 and 20 dS m^{-1}, according to levels found in the basin. Irrigation depths applied currently are in the range from 50-200 mm, depending on water availability, soil and crop type.

Scenarios

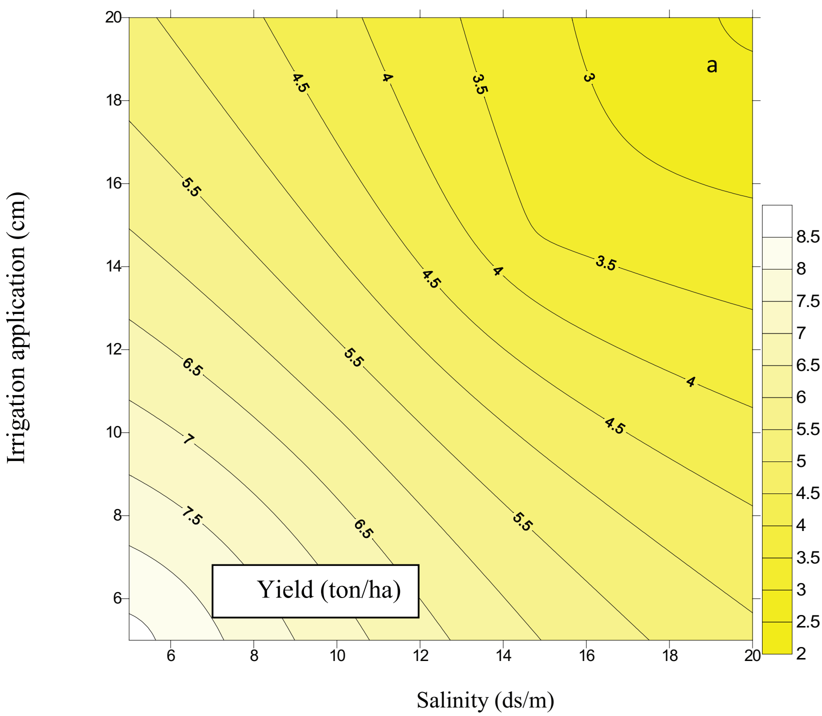
In order to explore the effect of different irrigation depth and water salinity, scenarios were defined. The scenarios are based on changes in water quantity and quality and their effect on the water and salt balance and crop yields.

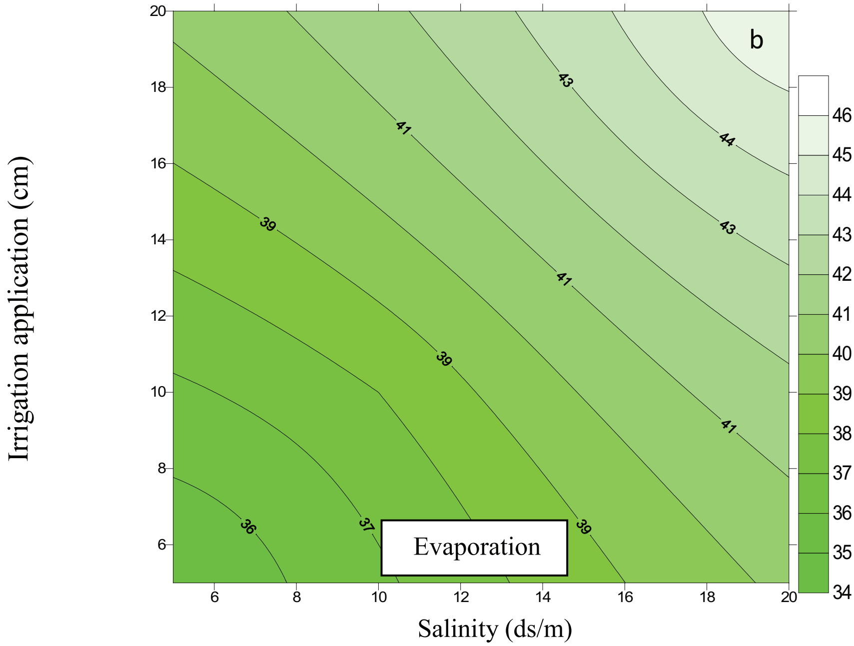
3. RESULTS

Results will be first presented in detail for one combination of soil and crop (wheat on clay loam) and later expanded to other soil types. It should be made very clear that results presented are the outcome from simulation modeling and might therefore differ from actual values. At the same time, the SWAP model has been successfully tested, validated and applied for many cases and many conditions. As a final point it should be considered that reliability in terms of relative differences in general higher is then absolute values, making simulation models suited for scenario analysis. One of the main output figures for this study is the relationship between irrigation application, salinity level and simulated yields (Figure2-a). Yields from fields receiving water of 5 dS m^{-1} are about 90% of the ones receiving fresh water, and yields higher than 8,000 kg ha^{-1} are impossible for these farmers. But, when water salinity was 20 dS m^{-1}, yield reduced to 2400 kg ha^{-1} (about 25% of the ones receiving fresh water).

Evaporation is the most important process. It is not affected by salinity and only slightly by the irrigation application All other water uses are non-beneficial or reusable (Droogers, 2002). If water is too saline roots have difficulty in taking up sufficient water. From all the water applied by irrigation only a fraction is used for transpiration, for freshwater and low irrigation applications this is close to 90%. At higher application rates and high salinity levels this fraction reduces to a merely 25%. Figure 2-b shows trend of soil evaporation. With increasing water application and salinity, soil evaporation was increased.

For the wheat crop on clay the WP values, expressed in kg m^{-3}, are displayed in Figure2-c. WP values were between 1.7- 0.12 for salinity of 5 dSm^{-1} to 20 dSm^{-1}, respectively. Figure 2-c also shows that highest WP (kg m^{-3}) can be obtained at low irrigation applications for saline water and WP for salinity of 5 dSm^{-1} is higher than other salinities. Figure 3 shows yield of wheat in different irrigation depth (20, 15 and 10 cm) from left to right. Figure 3 shows the yields as function of water applied by irrigation and water quality. Figure 4 and 5 show evaporation and WP in different irrigation depth (10, 15 and 20 cm), respectively.





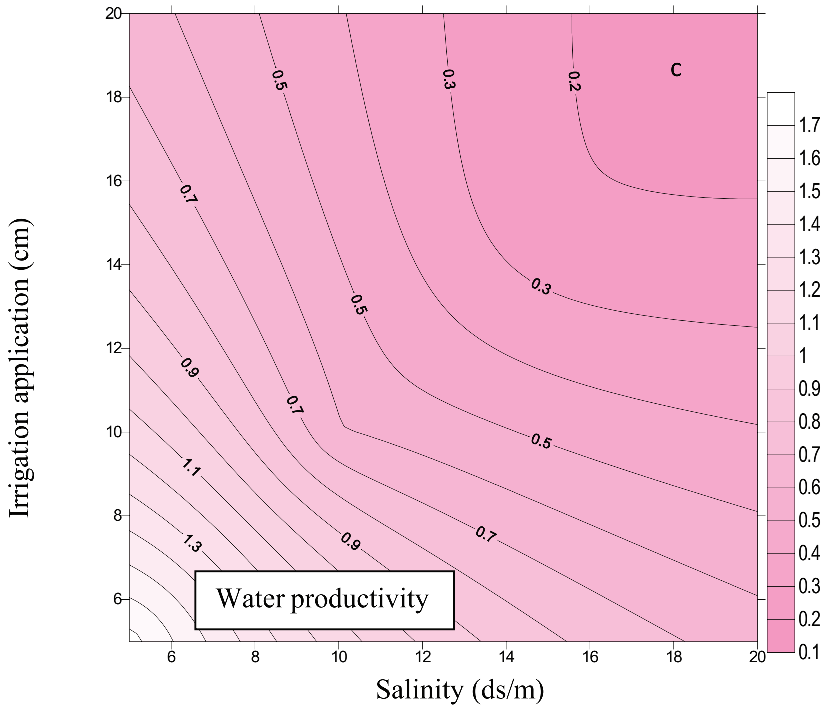


Figure 2.Output from the SWAP model for wheat. Yield, Evaporation and Water Productivity are expressed in Ton/ha, mm/yr and kg/m^3, respectively.

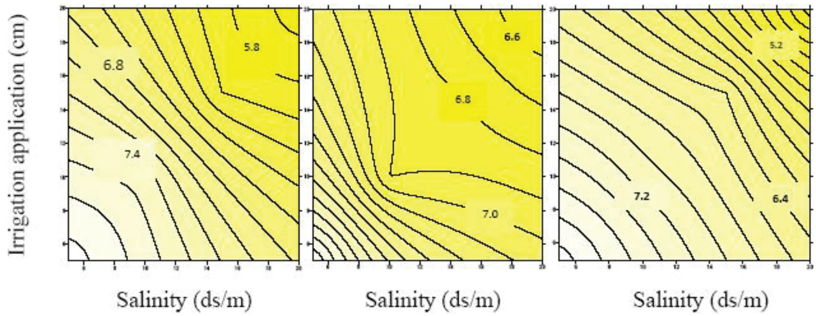


Figure 3.Output from the SWAP model for wheat yield for different water depth on clay loam

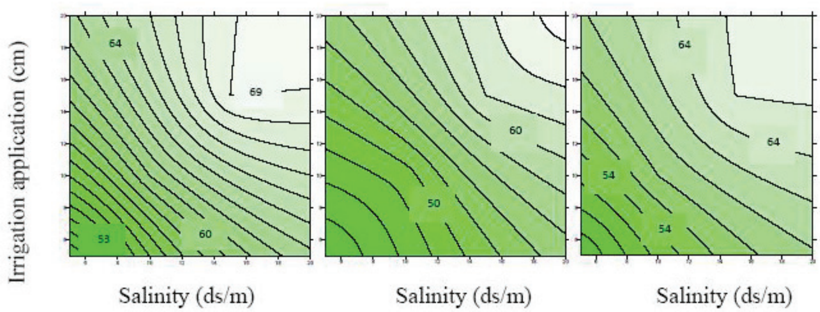


Figure 4. Evaporation expressed in mm/yr for different irrigation depth on clay loam

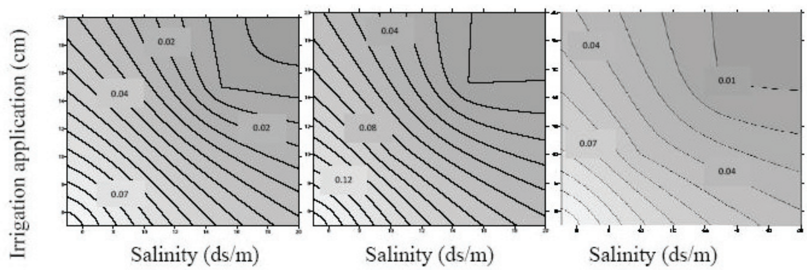


Figure 5. Water productivity expressed in kg/m^3 for wheat on clay loam. for different irrigation depth

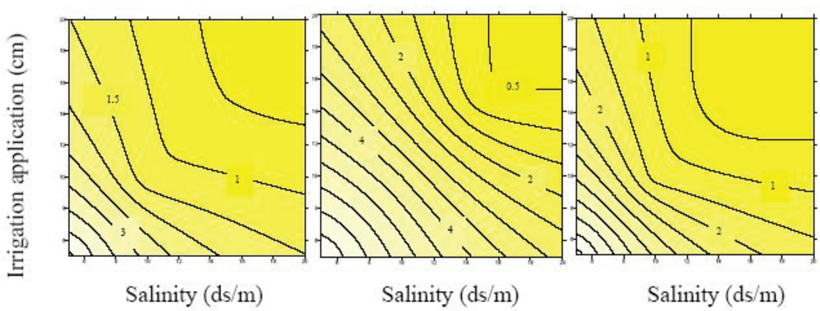


Figure 6.Output from the SWAP model for wheat yield for different water depth on clay

According to Figure 6, wheat yield on clay was less than that in clay loam. Clay and Silty Clay does not affect yield substantially and generate similar yields. For this reason, yield map is shown only for clay.

Finally, in three soil types, yields from clay-loam are more than two another soil types and highest WP-kg can be obtained at low irrigation applications for saline water. Also, part of yield reduction in high amount of irrigation in heavy soils is related to remaining of water and reducing of soluble oxygen in depth of plant roots. The general pattern that more irrigation water and lower salinity levels generate more crops can be observed. Graphs can be used to assess directly the impact of changes in water application or salinity levels on crop yield, as demonstrated in the detailed wheat-clay-loam description previously.

REFERENCES

Droogers, P., H.R. Salemi, A. Mamanpoush. 2001. Exploring basin scale salinity problems using a simplified water accounting model: the example of Zayandeh Rud Basin, Iran. Irrigation and Drainage. 50: 335-348.

Droogers, P. and M. Torabi. 2002. Field scale scenarios for water and salinity management by simulation modeling. IAERI-IWMI Research Reports 12.

Feddes R.A., P.J. Kowalik & H. Zarandy. 1978. Simulation of field water use and crop yield. Simulation Monographs. Pudoc. Wageningen, The Netherlands.

Seckler, D. 1996. The new era of water resources management. Research Report 1. International Irrigation Management Institute, Colombo, Sri Lanka.

Tietje, O., and M. Tapkenhinrichs. 1993. Evaluation of pedo-transfer functions. Soil Sci. Soc. Am. J. 57: 1088-1095.

Van Dam, J.C., J. Huygen, J.G. Wesseling, R.A. Feddes, P. Kabat, P.E.V. VanWalsum, P. Groenendijk, and C.A. van Diepen. 1997. Theory of SWAP version 2.0. Technical Document 45. Wageningen Agricultural University and DLO Winand Staring Centre.

Van Genuchten, M.Th. 1980. A closed form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44: 892-898.