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EVALUATION OF TWO DRAINAGE MODELS IN SOUTH-WEST IRAN

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ABSTRACT Selecting the correct drain spacing and depth is an important decision in designing a drainage system. Drainage simulation models can be used to determine the combination of depth and spacing to optimize the performance of the system. In this research, two widely used drainage simulation models, DRAINMOD and SWAP, were used in a sugarcane farm in south-west of Iran (Khozestan Province). Soil characteristics as well as climatological data, irrigation depths and schedules, and water table information for 2000 and 2001 were used to calibrate and validate both models. The validated models were used to find the optimum drain spacings and depths based on crop production and drainage water volume. Maximum crop production and minimum drainage water were the objectives of the design. Simulated water tables for both models were satisfactory with the regression coefficient of 0.95 and 0.90 and RMSE between simulated and observed water tables were 18.1 and 19.2 cm for DRAINMOD and SWAP, respectively. DRAINMOD under-estimated the drainage water but SWAP overestimated it. A relative yield of 80 % was achieved when drain spacing and depth were set to 25 m and 1.60 m, respectively using SWAP. For DRAINMOD, these values were 15 m and 1.15 m, respectively.

Keywords: Drainage Modeling, DRAINMOD, SWAP, Crop Yield.

INTRODUCTION Drainage in arid and semi arid regions has been practiced for several years. The main purpose of this practice is to provide a better environment for the plant and increase the productivity without compromising the environment. Therefore, it is important to use the best design in order to prevent productivity loss either by over draining or under designing. In the first case, water will be out of the reach of the plant root and in the later case, excess water stress will reduce the production. Field tests are the best way to find the optimum design criteria but they are time consuming and costly. As an alternative, scientists and engineers have developed numerical models to predict the behaviour of phenomena before it happens in the real world. The purpose of this research is to compare the results of two famous drainage models, DRAINMOD and SWAP.

DRAINMOD (Skaggs, 1980; Skaggs, 1991; Amatya et al., 1997) has been under development for almost three decades and it was successfully applied in several cases around the world (Jin and Sands, 2003; Wang et al., 2006; Luo et al., 2001; Wesstrom, 2002).

SWAP (Soil-Water-Atmosphere-Plant) is the successor of the agrohydrological model SWATR (Feddes et al., 1978) and some of its numerous derivatives. It started in Wageningen and earlier versions were published as SWATR(E) by Feddes et al. (1978), Belmans et al. (1983) and Wesseling et al. (1991), as SWACROP by Kabat et al. (1992) and as SWAP93 by van den Broek et al. (1994). SWAP2.0 was described by van Dam et al. (1997). The current version was published as SWAP3.0.3 by Kroes and van Dam (2003). SWAP employs the Richards equation, including root water extraction, to simulate soil moisture movement in variably saturated soils (Kroes et al., 2008). The SWAP model has been applied to compute the effects of land drainage (12 combinations of drain depth and spacing) on soil moisture conditions in the root zone and their effect on crop yield and soil salinization in the Fourth Drainage Project, Punjab, Pakistan (Sarwar and Feddes, 2000). The optimum drain depth for the multiple cropping system of the FDP-area was found to be 2.2 m. Marinov et al. (2005) used SWAP to simulate water flow in the soil and ANIMO to describe nitrogen movement and transformations. The mean absolute error (MAE) for SWAT was 14.9 cm and for nitrogen simulation was about 10-15 percent.

In this paper, these two widely used simulation models in the field of drainage were applied in a sugarcane field in Khozestan Province located in south-west of Iran. In almost all modern irrigation networks in Khozestan, subsurface drainage is a common practice. Due to the high cost of drainage installation there is a need to find the best combination of depth and spacing to minimize this cost. Simulation models are useful tools to test different alternatives. Therefore, the purpose of this paper was to compare the performances of two simulation models and compare their results against observed data from the Khozestan Province. The results can be used in future designs and project in the province and to considerably reduce the cost.

MATERIALS AND METHODS

Study Area The study area is a 14,000 hectares sugarcane farm located in south of Ahwaz city, Khozestan Province (Figure 1). The area is a flat alluvial plain. It is located in an arid region with 230 mm average annual rainfall and temperature varies from 0 to 54^{o}C . Using available data from climatological weather station located in the farm, evapotranspiration were calculated. Soil properties and hydraulic conductivity measurements are presented in Tables 1 and 2 (Torkzaban, 2000).

Farms are equipped with subsurface corrugated plastic pipes. Average depth of the installation is 2 m and drain spacing is 50 m. Depth of impervious layer is about 2.5 m and calculated drainage coefficient is 2 mm/day.

In order to monitor the water table in soil, a pilot farm with an area of 25 ha was selected. Four monitoring wells were installed between two drainage lines. Daily water table fluctuations were measured from 21 March 2001 to 11 September 2002.

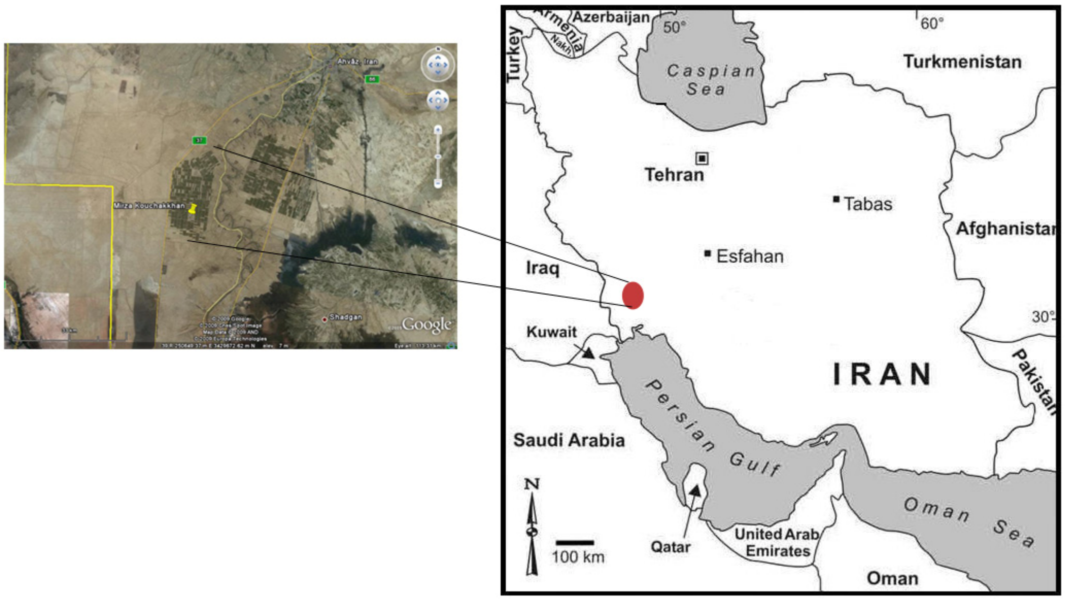

Figure 1. Study area location in south-west of Iran

Table 1. Soil texture analysis (Torkzaban, 2000)

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil Texture
0 – 30	11.6	45	43.4	Silty Clay
30 – 60	10	47.6	42.4	Silty Clay
60 – 100	22	36.6	41.4	Silty Clay

Table 2. Results of hydraulic conductivity tests in m/day (Torkzaban, 2000)

Maximum	Minimum	Average	Standard Deviation
0.75	0.11	0.48	0.078

DRAINMOD Model: Daily rainfall was introduced to the model and HISARS utility in the model converted these daily data into hourly rainfalls with equal distribution over 24 hours. Evapotranspiration were calculated using the Penman-Monteith method and then entered into the model. The soil properties including hydraulic conductivity, Green-Ampt coefficients, capillary pressure, and hysteresis relationships were calculated using field measurements and ROSETA function which works as a module in DRAINMOD. Table 3 shows the resulting soil properties used for the van Genuchten and Mualem equations. For upper boundary irrigation, rainfall, and Penman-Monteith evapotranspiration were considered and for lower boundary, a free drainage condition was selected.

Table 3. Parameters calculated for van Genuchten and Mualem equations for each soil layer in DRAINMOD model

Soil Depth (cm)	θ_{res} (cm^3/cm^3)	θ_{sat} (cm^3/cm^3)	K_{sat} (cm/day)	α	n	L
0 – 30	0.0947	0.468	48	0.00913	1.39060	-0.6717
30 – 60	0.0960	0.483	60	0.00977	1.31878	-0.5891
60 - 250	0.0878	0.429	48	0.01309	1.05987	-0.8583

SWAP Model Data needed for the SWAP model is almost the same as those for DRAINMOD including meteorological, pedological, plant and irrigation information. SWAP can consider 8 different boundary conditions and in this study, an exponential function of water table was selected for lower boundary. Upper boundary was similar to DRAINMOD including irrigation, rainfall and Penman-Monteith evapotranspiration. In SWAP, hydraulic functions of the soil are estimated using van Genuchten and Mualem functions. A built-in module calculates the van Genuchten and Mualem parameters based on soil texture, specific weight, and saturated hydraulic conductivity. Table 4 shows these parameters values for each soil layer.

Table 4. Parameters calculated for van Genuchten and Mualem equations for each soil layer in SWAP model

Soil Depth (cm)	θ_{res} (cm^3/cm^3)	θ_{sat} (cm^3/cm^3)	K_{sat} (cm/day)	α	n	L
0 – 30	0.01	0.437	48	0.010	1.020	-1.0025
30 – 60	0.01	0.453	60	0.023	1.035	-1.7348
60 - 250	0.01	0.402	48	0.026	1.030	-1.7977

Statistical Analysis To evaluate the model performance, parameters like correlation coefficient (R), root mean squared error (RMSE), and coefficient of residual mass (CRM) have been calculated. The related relationships are as the following:

$$RMSE = \left(\frac{\sum (S_i - O_i)^2}{N} \right)^{1/2}$$

$$MAE = \frac{|S_i - O_i|}{i}$$

$$CRM = \frac{\sum_{i=1}^{N} P_i - \sum_{i=1}^{N} O_i}{\sum_{i=1}^{N} O_i}$$

where S_i and O_i show the simulated and measured values, respectively and N shows the number of data.

The first 6 month of measured data were used for calibration purpose and the rest, 12 months, were applied in verification phase.

After calibration and verification of models, 28 different combinations of depth and spacing were considered. Drain spacing of 15, 25, 50, 100 m with depths of 50, 100, 150, 200, 220, 230, and 240 cm were simulated using both models. Then, the best combination that produces the minimum discharge and maximum crop yield will be the optimum design.

RESULTS AND DISCUSSIONS Figure 2 to 5 show the observed and calculated soil water table fluctuations for both the DRAINMOD and SWAP models for the calibration and verification phases. The correlation coefficient, root mean square error (RMSE) and coefficient of residual mass (CRM) for calibration and verification phases are shown in Table 4. Correlation coefficients report the scatter of the simulated values compared with the measured data. The RMSE tests the accuracy of the model, which is defined as the extent to which simulated values approach a corresponding set of measured values (Loague and Green, 1991). The coefficient of residual mass (CRM) was used to measure the tendency of the model to overestimate or underestimate the measured values (Xevi et al., 1996).

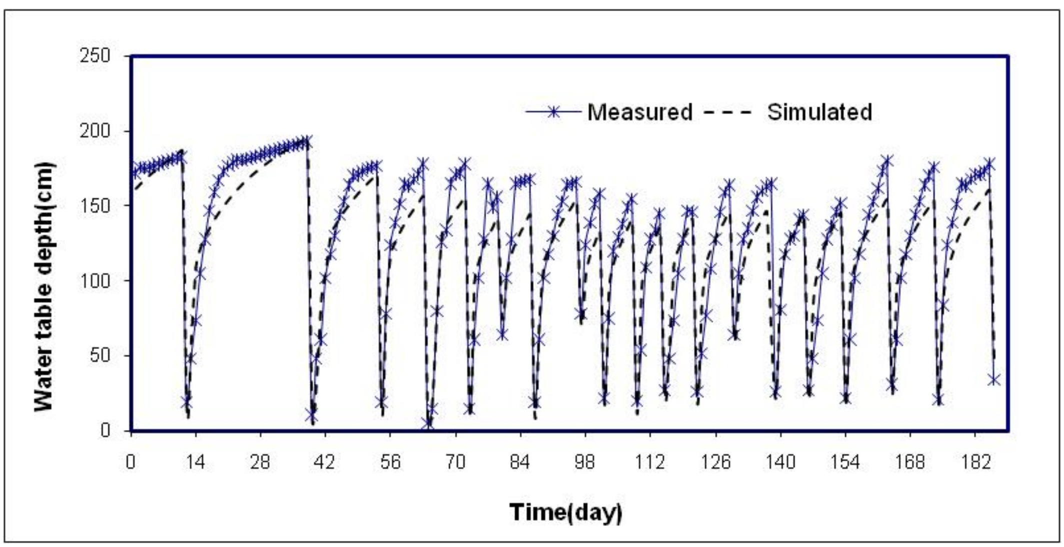

Figure 2. Simulated daily groundwater levels using DRAINMOD for calibration data

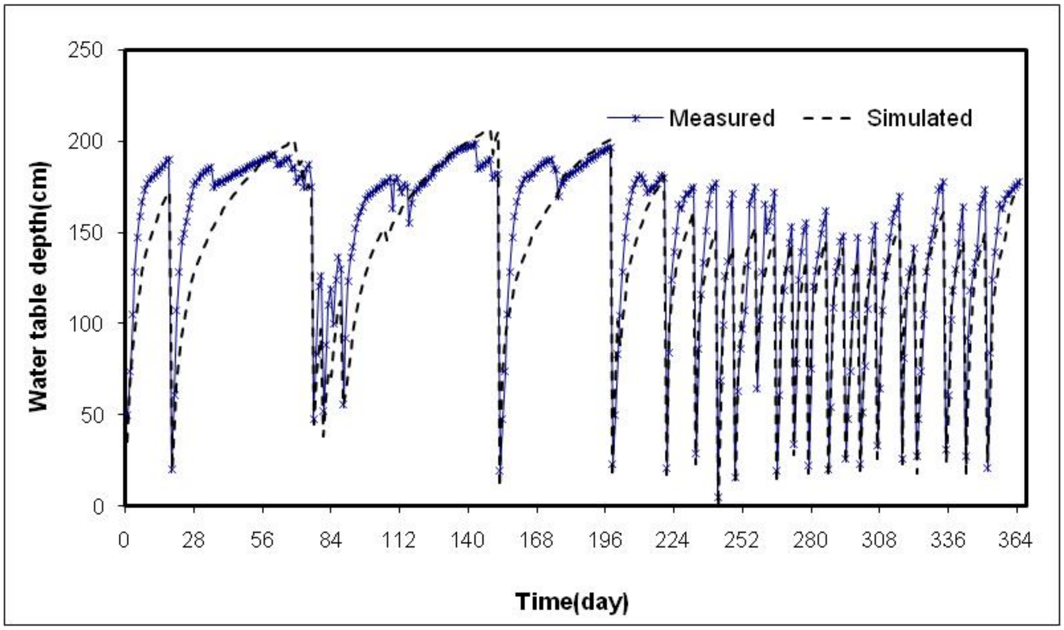

Figure 3. Simulated daily groundwater levels using DRAINMOD for verification data

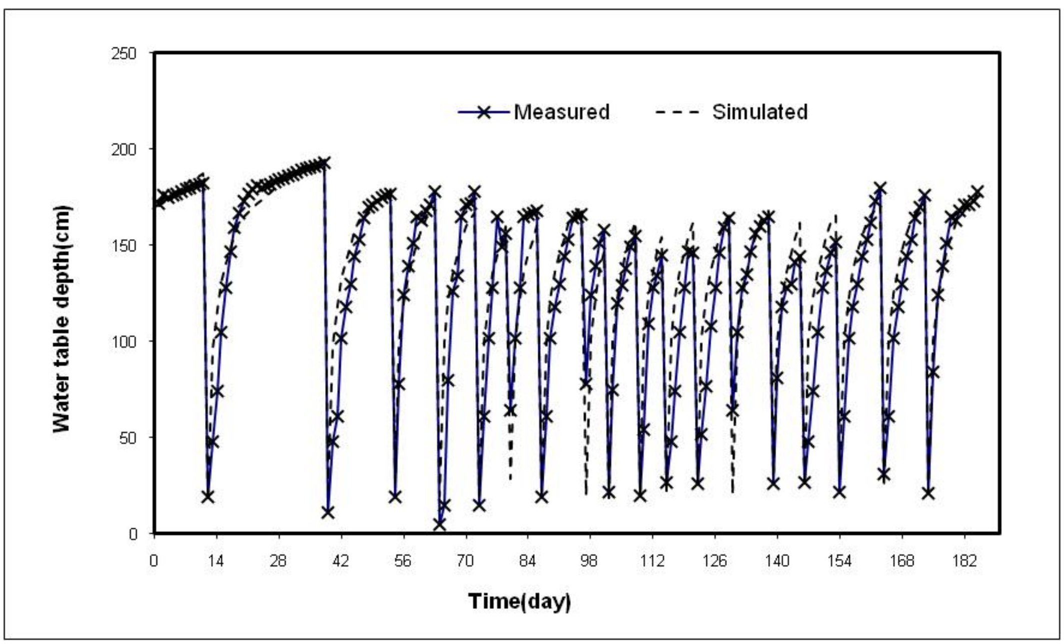

Figure 4. Simulated daily groundwater levels using SWAP for calibration data

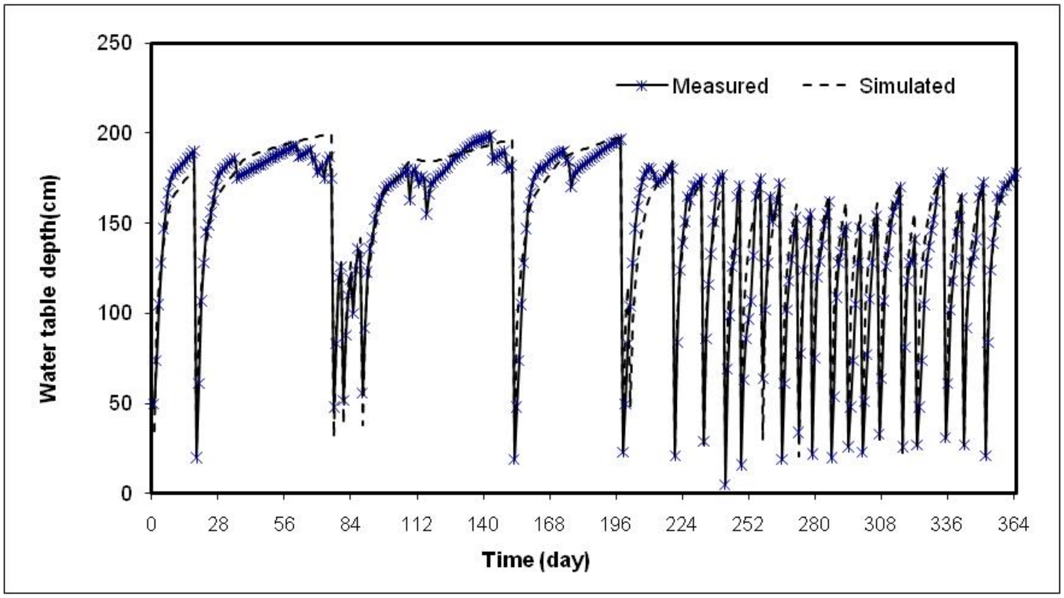

Figure 5. Simulated daily groundwater levels using SWAP for verification data

The RMSE for DRAINMOD is about 15 cm which is in accordance of Skaggs (1980) research which found RMSE between 7.5 to 19.6 cm. CRM is negative for DRAINMOD and indicates a tendency of the model toward overestimation (Figure 6).

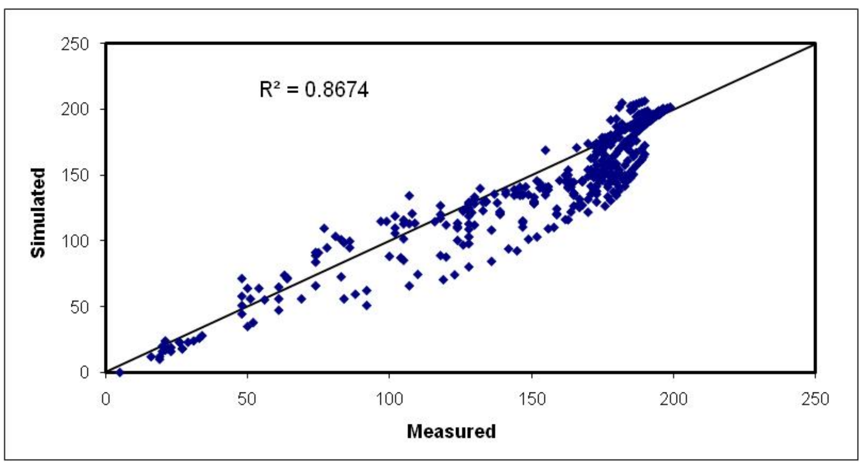

Figure 6. Comparison between observed and simulated water table depths for the DRAINMOD models.

RMSE for the SWAP model is close to the results of Marinov et al. (2005) which was 14.9 cm. CRM is positive for both calibration and verification and specify the tendency of the model to overestimate (Figure 7).

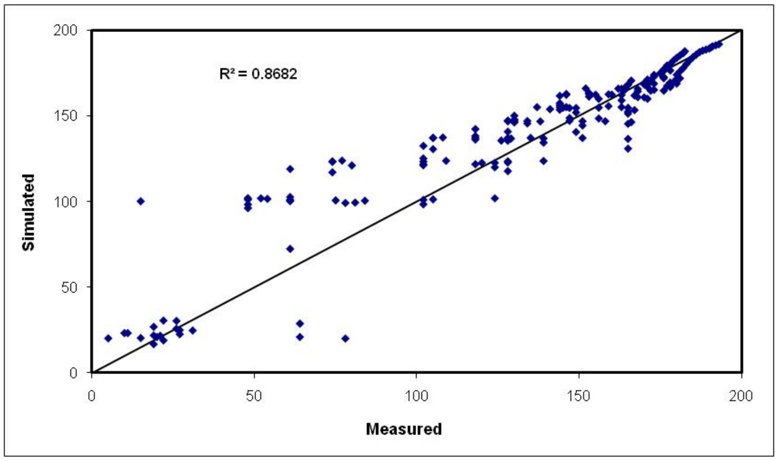

Figure 7. Comparison between observed and simulated water table depths for the SWAP model.

Optimum depth and spacing In order to determine the optimum depth and spacing, crop yield and discharged water were calculated with both models for different depths and spacing. As it is shown in Figures 8 to 11, simulated results indicate that keeping the space constant and increasing the installation depth caused increase in crop yield. Beyond 2 m depth, the increase is not noticeable. Increasing drain spacing for constant depth caused the decrease in crop yield.

On the other hand, drained water from soil increases by increasing the depth or decreasing the spacing. Overdrainage causes removal of water from plant root zone and limiting the access of plant to water.

DRAINMOD is more sensitive to changes in depth and spacing and causes more changes in crop yield. For example, for drain spacing of 50 m, increasing depth from 100 cm to 200 cm caused 5 percent decrease in crop yield but the same conditions showed 1 percent decrease in crop yield with SWAP model. The drained water difference was 30 cm for DRAINMOD and 20 cm for SWAP. The reason can be attributed to the different lower boundary condition. It was not possible to consider the same condition for both models and calibrate the model with enough accuracy.

Accepting 80% minimum crop production, 4 combinations have found to be suitable. Among them, the one with the minimum drain discharge was selected as optimum drain spacing and depth. For DRAINMOD, a drain spacing of 15 m and drain depth 115 cm had better performance and these values were 25 m and 160 cm for the SWAP simulations, respectively.

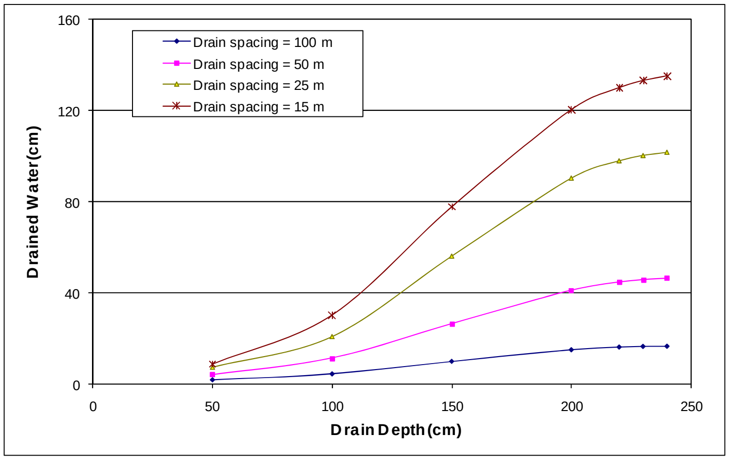

Figure 8. Drained water versus different drain depth and spacing using DRAINMOD

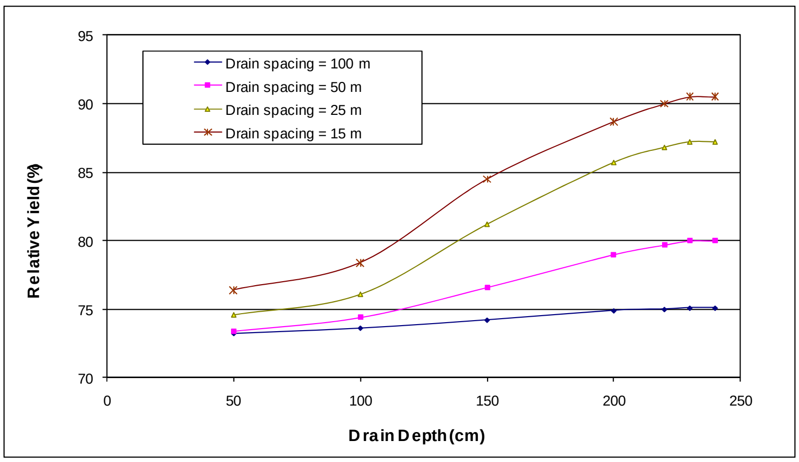

Figure 9. Relative crop yield versus different drain depth and spacing using DRAINMOD

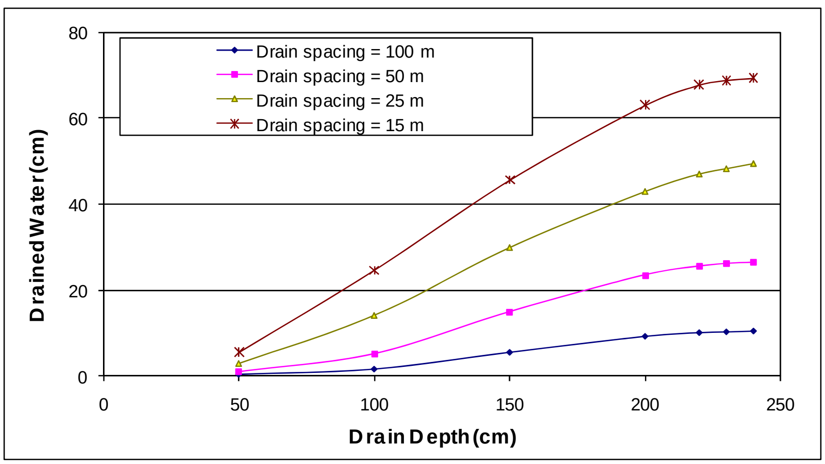

Figure 10. Drained water versus different drain depths and spacing using SWAP

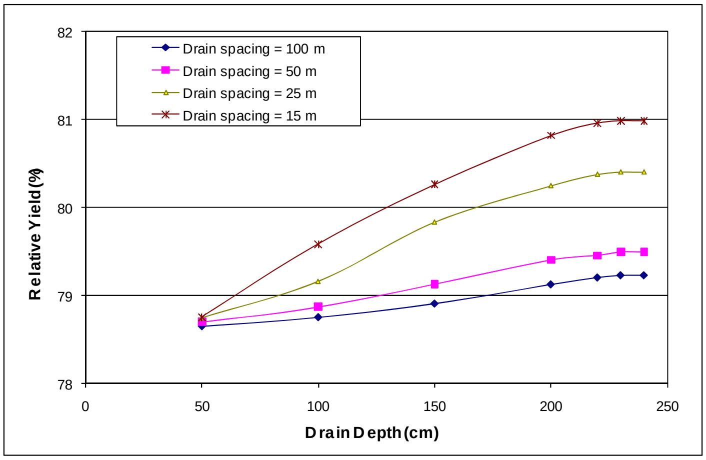

Figure 11. Relative crop yield versus different drain depth and spacing using SWAP

CONCLUDING REMARKS Simulation models are important tools for decision makers to predict the effects of different alternatives. In this research, two widely used drainage models were applied to a case study in a sugarcane farm. Both models showed satisfactory results in the arid condition of this case study. RMSE for SWAP and DRAINMOD were 14.85 and 20.69 cm, respectively. Different combinations of depth and spacing were examined using calibrated models to find maximum crop yield and minimum drained water. Increasing depth showed a better aeration and increase in crop yield, the same result as decreasing drain spacing. Increasing the depth or reducing the spacing more than optimum values will result in excess water and nutrients discharged and ultimately a reduction in crop yield.

REFERENCES

Amatya, D.M., R.W. Skaggs, and J.D. Gregory. 1997. Evaluation of a watershed scale forest hydrologic model. Agricultural water management, 32: 239-258.

Belmans, C., J.G. Wesseling and R.A. Feddes. 1983. Simulation model of the water balance of a cropped soil: SWATRE. Journal of Hydrology, 63: 271-286.

Feddes, R.A., P.J. Kowalik and H. Zaradny. 1978. Simulation of field water use and crop yield. Simulation Monographs. Pudoc. Wageningen. pp 189.

Jin, C.X. and G.R. Sands. 2003. The long term scale hydrology of subsurface drainage systems in a cold climate. ASAE, 46: 1011-1021.

Kabat, P., B.J. van den Broek and R.A. Feddes. 1992. SWACROP: A water management and crop production simulation model. I.C.I.D. Bulletin 41(2): 61-83.

Kroes, J.G., J.C. van Dam, P. Groenendijk, R.F.A. Hendriks, and C.M.J. Jacobs. C.M.J.2008. SWAP version 3.2. Theory description and user manual. Alterra-report 1649, Wageningen, The Netherlands, pp. 262.

Kroes, J.G. and J.C. van Dam. 2003. Reference Manual SWAP version 3.0.4. Wageningen, Alterra, Green World Research, Alterra-report 773. The Netherland, pp. 211.

Loague K.M., R.E. Green. 1991. Statistical and graphical methods for evaluating solute transport models. Journal of Contaminant Hydrology, 1991(7): 51-73.

Marinov, D., E. Querner and J. Roelsma. 2005. Simulation of water flow and nitrogen transport for a Bulgarian experimental plot using SWAP and ANIMO models. Journal of Contamination Hydrology, 77: 145-164.

Luo, W., R.W. Skaggs, A. Madani, S. Cizikci and A. Mavi. 2001. Predicting field hydrology in cold conditions with DRAINMOD. ASAE, 44: 825-834.
Sarwar, A. and R.A. Feddes. 2000. Evaluating drainage design parameters for the fourth drainage project, Pakistan by using SWAP model: part Π- modeling results. Journal of Irrigation and Drainage Systems, 14: 281-299.
Skaggs, R. W. 1991. Drainage, In: J. Hanks and J. Ritchie, (eds.), Modeling Plant and Soil Systems, Agronomy Monograph No. 31, American Society of Agronomy, Madison, WI, 205-243.
Skaggs, R.W. 1980. DRAINMOD Reference Report: Methods for design and evaluation of drainage water management system for soils with high water tables. United States Department of Agriculture.
Torkzaban, S. 2000. Evaluation and calibration of DRAINMOD model, M.Sc. Thesis, Dept. of Irrigation Engineering, University of Tehran, Karaj, Iran.
van Dam, J.C., J. Huygen, J.G. Wesseling, R.A. Feddes, P. Kabat, P.E.V. van Walsum, P. Groenendijk and C.A. van Diepen, 1997. SWAP version 2.0, Theory: Simulation of water flow, solute transport and plant growth in the Soil-Water-Air-Plant environment. Technical Document 45, DLO Winand Staring Centre, Wageningen. Report 71, Department Water Resources, Wageningen Agricultural University.
van den Broek, B.J., van Dam, J.C., Elbers, J.A. 1994. SWAP1993: Input instructions manual, Report 45, Subdepartment Water Resources, Wageningen University.
Wang, S., S.O. Prasher, R.M. Petal, C.C. Yang, S.H. Kim, A. Madani, P.M. Macdonald and S.D. Robertson. 2006. Fate and transport of nitrogen compounds in a cold region soil using DRAINMOD. Computers and Electronics in Agriculture, 53(2): 113-121.
Wesseling, J.G. and J.G. Kroes. 1998. A global sensitivity analysis of the model SWAP. Report 160. DLO Winand Staring Centre. Wageningen, The Netherlands.
Wesstrom, I. 2006. Controlled drainage and subirrigation water management options to reduse point source pollution from agriculture land. Department of Soil Sciences Swedish University of Agricultural Sciences, 145-148.
Xevi E., J. Gilley and J. Feyen. 1996. Comparative study of two crop yield simulation models. Agricultural Water Management. 30: 155-173.