APPLICATION OF DRAINMOD AND SWAP IN SOUTH-WEST OF IRAN FOR OPTIMAL DESIGN OF DRAINAGE NETWORK

APPLICATION DE DRAINMOD ET DE SWAP POUR LA CONCEPTION OPTIMALE DU RESEAU DE DRAINAGE AU SUD-OUEST DE L'IRAN

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ABSTRACT

Land productivity in arid and semi-arid regions is a function of aeration and salt contents of the soil in root zone. An optimal design of drainage network can reduce the cost of construction and increase the productivity by providing a better condition for plant growth. 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, climatological data, irrigation depths and schedules, and water table information for 2000 and 2001 were used to calibrate and validate both the models. The validated models were used to find the optimum drain spacing and depth based on crop production and drainage water volume. Achieving maximum crop production and minimum drainage water were the objectives of the design.

Water tables simulated by both the models were satisfactory with the R^2 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.

Key words: *Drainage Modeling, DRAINMOD, SWAP, Crop Yield.*

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RESUME

La productivite de la terre dans les regions arides et semi-arides est une fonction d'aeration et de teneur en sel du sol dans la zone racinaire. Une conception optimale du reseau de drainage peut reduire le cout de construction et augmenter la productivite en fournissant une meilleure condition de la croissance de plante. Les modeles de simulation de drainage peuvent etre utilises pour determiner la combinaison de profondeur et d'ecartement de drain pour optimiser la performance du systeme. Dans cette recherche, deux modeles de simulation de drainage - drainmod et swap - ont ete utilises sur un champ de canne a sucre au sud-ouest de l'iran (province de khozestan).

Les caractéristiques du sol, les données climatologiques, les profondeurs et les régimes d'irrigation, et les informations sur la nappe phréatique pour les années 2000 et 2001 ont été utilisés pour calibrer et valider tous les deux modèles. Les modèles validés ont été utilisés pour rechercher l'écartement et la profondeur de drain optimaux compte tenu de la production agricole et du volume d'eau de drainage. La conception vise à atteindre la production agricole maximale avec l'usage d'eau de drainage minimum.

Les nappes phréatiques simulées par les modèles étaient satisfaisantes avec R2 de 0,95 et 0,90; RMSE entre les nappes phréatiques simulées et observées étant de 18,1 et 19,2 cm respectivement pour DRAINMOD et SWAP. DRAINMOD a sous-estimé l'eau de drainage mais SWAP l'a surestimée. Un rendement relatif de 80% a été réalisé quand l'écartement et la profondeur de drain étaient de 25 m et 1,60 m respectivement pour SWAP. Pour DRAINMOD, ces valeurs étaient de 15 m et 1,15 m, respectivement.

Mots clés : *Modélisation de drainage, DRAINMOD, SWAP, rendement agricole.*

1. INTRODUCTION

In arid and semi arid regions, drainage systems are used to control salinity and water logging. Because of the complexity of water management systems, simulation models are the suitable tools to simulate water flow and storage in soil profile. The main purpose of drainage 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 latter case, waterlogging will reduce the production. Field tests are the best way to find the optimum design criteria but it is time consuming and costly. As an alternative, numerical models are used to predict the behaviour of sub-soil water and salt scenario for different designs. In this research the results of using two well-known drainage models namely, DRAINMOD and SWAP were compared.

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 was 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 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) had used SWAP to simulate water flow in the soil and ANIMO to describe nitrogen movement and transformations. The mean absolute error (MAE) for SWAP 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. Almost in all modern irrigation networks in Khozestan, subsurface drainage is a common practice. High cost of drainage installation makes it imperative to find the best combination of depth and spacing to minimize 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 also to compare both with observed data. The results can be used in future designs in the province.

2. MATERIALS AND METHODS

A pilot project area under sugar cane cultivation and equipped with subsurface corrugated plastic pipes at an average depth of 2 m and 50 m spacing in Khosestan Province, near Ahwaz city was selected for this study (Fig. 1). Depth of impervious layer is about 2.5 m and the calculated drainage coefficient is 2 mm/day. Subsurface water level was measured in the middle of two adjacent drain pipes. Daily water table fluctuations were measured from 21st March 2001 to 11th September 2002.

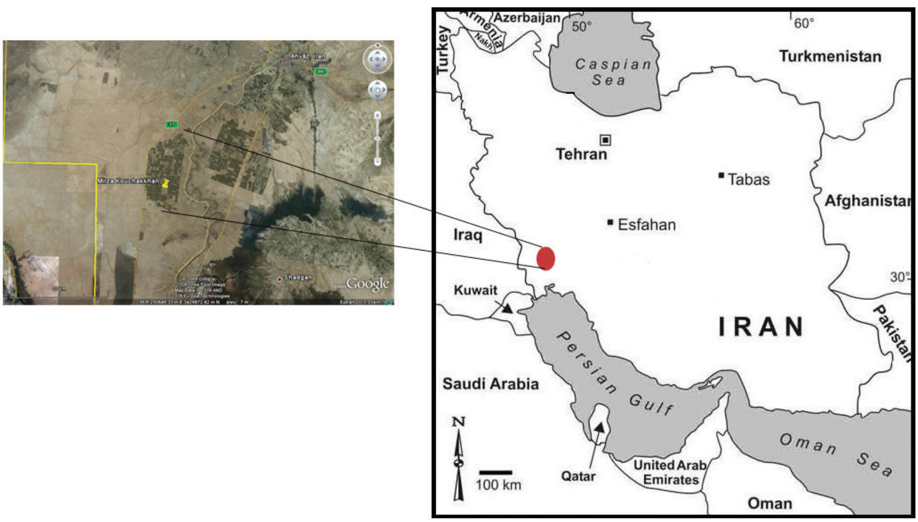

Fig. 1. Study area location in south-west of Iran

In DRAINMOD, daily rainfall was introduced and the model converted them to hourly rainfalls. Evapotranspiration (ET) were calculated using 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 work as a module in DRAINMOD. Table 3 shows the soil properties used in van Genuchten and Mualem equations. For upper boundary, irrigation, rainfall, and Penman-Monteith ET were considered and a free drainage condition was selected at the lower boundary.

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 will calculate the van Genuchten and Mualem parameters based on soil texture, specific weight, and saturated hydraulic conductivity.

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

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

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

3. RESULTS AND DISCUSSION

Water table fluctuations simulated by DRAINMOD and SWAP and comparison with observed data for calibration and verification periods are presented in Figures 2 to 5. 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).

As it is evident, RMSE is about 15 cm which is within the findings of Skaggs (1980), which were between 7.5 to 19.6 cm. CRM is negative for DRAINMOD and indicates a tendency of the model toward overestimation (Fig. 6).

Values simulated by SWAP model almost matched the measured data. RMSE is close to the results of Marinov et al. (2005) which was 14.9 cm. CRM is positive, which implies the tendency of the model to overestimate (Fig. 7).

For arriving at the optimum depth and spacing, crop yield and discharged water were calculated with both models for different depth-spacing combinations. Simulated results indicate that keeping the spacing constant and increasing the depth caused increase in crop yield. Beyond 2 m depth, the increase is not noticeable. Increasing drain spacing for constant depth caused decrease in crop yield.

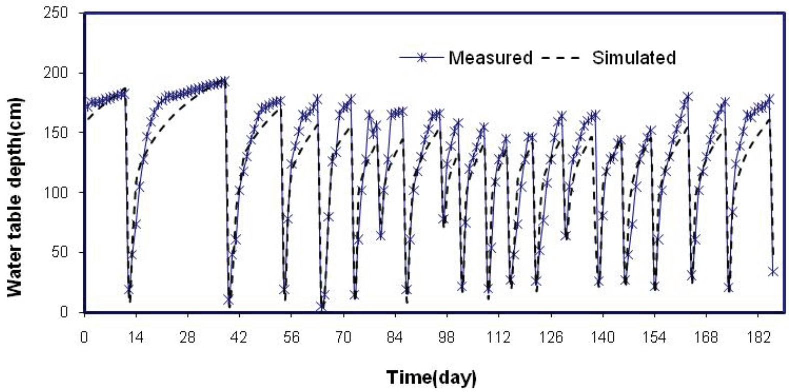

Fig. 2. Simulated daily groundwater levels using DRAINMOD for calibration data

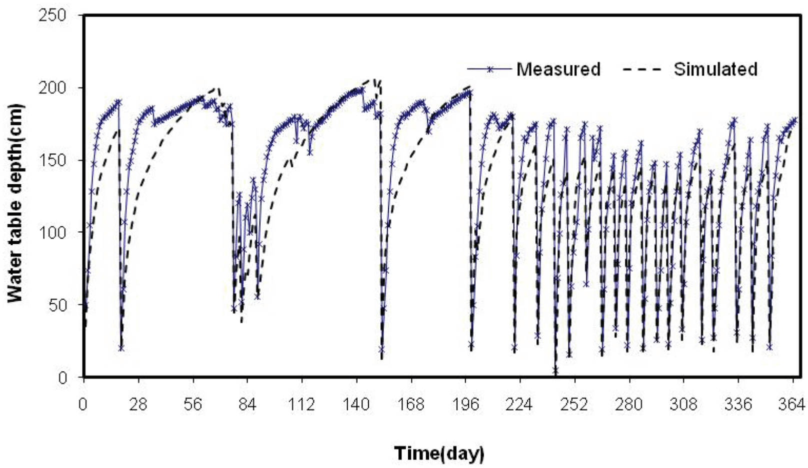

Fig. 3. Simulated daily groundwater levels using DRAINMOD for verification data

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.

A total 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.

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.

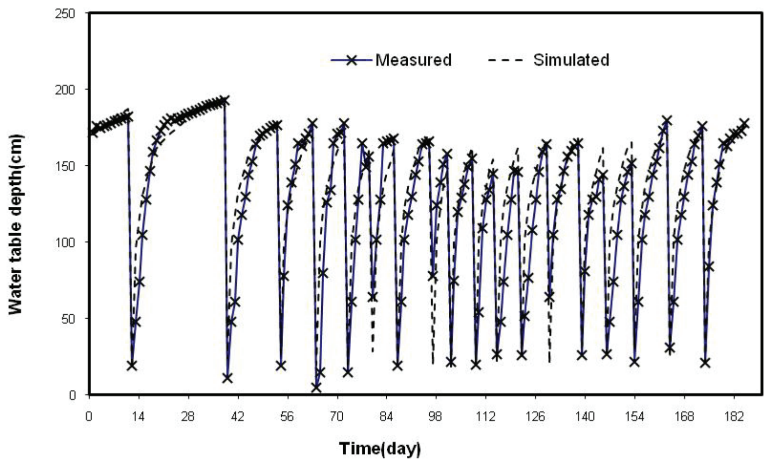

Fig. 4. Simulated daily groundwater levels using SWAP for calibration data

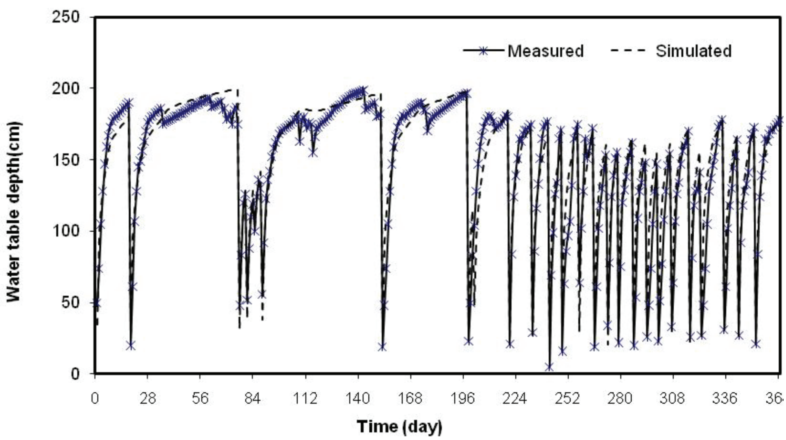

Fig. 5. Simulated daily groundwater levels using SWAP for verification data

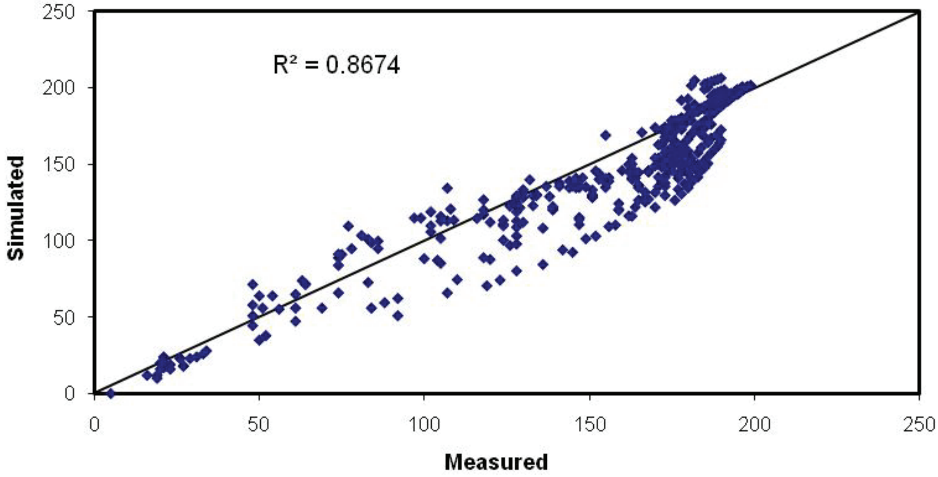

Fig. 6. Comparison between observed and simulated DRAINMOD results

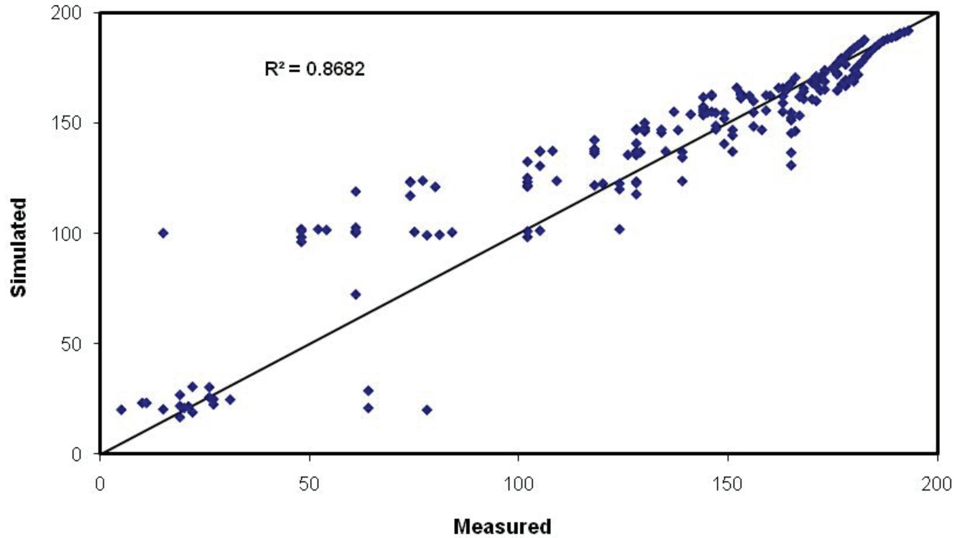

Fig. 7. Comparison between observed and simulated SWAP results

Accepting 80% of the potential as the minimum acceptable crop production, 4 combinations of drain depth and spacing were found suitable. Among them, the combination that gave the minimum drain discharge was selected as optimum drain spacing and depth. For DRAINMOD, drain spacing of 15 m and drain depth 115 cm gave better performance and these values for SWAP are 25 m and 160 cm, respectively.

4. SUMMARY AND CONCLUSIONS

In order to determine the optimum depth and spacing, crop yield and drain discharge were calculated using DRAINMOD and SWAP, for different depths and spacing. Simulated results indicate that at constant spacing, increasing the depth caused increase in crop yield. Beyond 2 m depth, the increase is not noticeable. Increasing drain spacing for constant depth caused 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, limiting the access of plant to water.

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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 area. 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.

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