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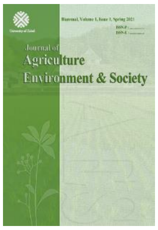

SWAP: a robust planning tool for quantifying the effect of deficit irrigation on the agricultural water productivity indices (case study: wheat farm)

Mohammad Naderianfar *[a], Hadi Dehghan [b], Arsalan Faryabi [a]

[a] Water Science and Engineering Department, University of Jiroft, Jiroft, Iran
[b] Water Science and Engineering Department, Kashmar Higher Education Institute, Kashmar, Iran

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ABSTRACT

Due to the scarcity of water resources worldwide, it is essential to determine the water productivity indices. In this study, the SWAP model was used to determine the agricultural water productivity indices for three wheat farms in the arid regions of Iran. The model was calibrated and validated for each study farm using a large number of field-measured data. The results showed that the model could satisfactorily predict moisture profiles. SWAP model calculated water productivity. Due to the results of this study, it is possible to increase wheat yield by 14%, if the irrigation scheduling is correctly planed. Deficit irrigation by 30% showed no significant effect on reducing yield. Appropriate irrigation scheduling has increased WP_{ETdp} (yield to crop actual evapotranspiration plus deep percolation ratio) and WP_{Irr} (yield to total applied water ratio) by 48 and 61%, respectively. High evaporation at the initial stages of growth decreases WP_{ET} (yield to crop actual evapotranspiration ratio) by 28% compared to WP_T (yield to crop actual transpiration ratio). Improving agricultural operations such as mulch or soil application using subsurface irrigation methods can improve WP_{ET}. Reducing the applied irrigation depth had a negligible impact on the WP_{ET} and WP_T indices, but the WP_{ETdp} and WP_{Irr} indices exhibited a significant increase.

Highlights

- In this study, the SWAP model was used to determine the agricultural water productivity indices for three wheat farms.
- The paper shows that irrigation scheduling has increased WP_{ETdp} and WP_{Irr} by 48 and 61%, respectively.
- The paper shows that Deficit irrigation has little impact on the WP_T and WP_{ET} indices.

1. Introduction

Wheat is considered the most strategic agricultural crop in Iran**.** Approximately 5 to 6 million hectares, representing 60% of the total cultivated area, are dedicated to wheat cultivation annually. The measurement and analysis of water productivity indices hold a prominent position in Iran's agricultural sector. The issue of water productivity improvement to produce food production is fundamental in many different countries, especially countries like Iran with a low amount of water (Ehsani and Khaledi, 2003). Water productivity, an indicator of the output or benefit generated per unit of water used, encompasses the diverse aspects of water management. Also, water productivity serves as a valuable indicator for evaluating water resources, particularly in arid and semi-arid regions (Molden et al., 2001**,** Singh et al., 2006, Zhao et al., 2020). Field trials to determine and analyze the different irrigation managements are useful but are expensive and time-consuming if the simulation models can be calibrated for the irrigation of different options with low cost and short time (Droogers et al., 2000).

The SWAP (Soil-Water-Atmosphere-Plant) model is a one-dimensional model that, in its new version, can simulate water movement, solute transport, heat transfer, and irrigation scheduling, primarily employed at large scales. The governing equations of this model are solved using the method of finite differences (Van Dam et al., 1997). The applicability of the SWAP model for simulating agricultural water flow, solute transport, and crop performance across diverse geographical regions,

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[*] Corresponding author.
E-mail address: Naderian.mohamad@ujiroft.ac.ir
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including Iran, has been evaluated. The model's predictions demonstrated good agreement with field measurements (Singh et al., 2006; Mandare et al., 2008). Akbari et al. (2009) studied the effect of irrigation planning on agricultural water productivity using the SWAP model in networks' cascade. The results showed that irrigation reform programs, barley, and wheat yield significant quantities (15 percent) increase. On the other hand, with improved crop management and reduced 20 percent of water depth, no significant change was obtained. In a study conducted by Vazifedoust et al. (2008), the SWAP model was evaluated and calibrated to simulate water balance components such as transpiration, soil evaporation, and deep infiltration, and to predict crop performance. The results showed that the model is a valuable tool for predicting plant variables such as crop yield and dry weight with high accuracy. The SWAP model in the research farm for two years (2001-2002 and 2002-2003) in the land under wheat cultivation in the north of Gorgan and Homay and Kiani (2007) were evaluated. Statistical analyses revealed that the SWAP model effectively simulated soil moisture, soil salinity, and relative wheat yield under diverse field conditions. In all cases, the coefficient of determination (R^2) exceeded 80%, and the mean squared error (MSE) was consistently lower than the standard deviation (SD) of the data. A study conducted in the Zaragoza region of Spain compared the simulated evapotranspiration (ET) values obtained using the Penman-Monteith and Priestley-Taylor methods with those simulated by the SWAP model developed by Utset et al. (2004). The results showed that the SWAP model, when provided with accurate input data, can effectively predict ET values.

Eitzinger et al. (2004) examined plant performance in three models of Special WOFOST, CERES, and SWAP simulated water content in the soil during the growing season compared. Output models evaluate all three models with experimental data obtained from Lysimeter on different soil types in 2000-2001 crop for the crop of winter wheat and spring barley in the main agricultural region in Australia Marchfld compared. The results showed: 1- CERES and SWAP models unlike WOFOST weight of barley and wheat were well simulated, 2- All three models in soil water content profiles with the same results they bring, 3- none of the models, the total amount of soil profiles did not predict well, 4- CERES and SWAP model of water movement in the depth of 0.3 upper meters of soil, estimates were good. Jiang et al. (2015) investigated the irrigation efficiency and water productivity in the Heihe basin using the SWAP-EPIC model and geographic information system (GIS) on a regional scale. Experiments were conducted during 2012-2013. The results showed that water productivity was low due to excessive irrigation. The average crop evapotranspiration (ETc) was 589 mm, while deep percolation amounted to 125 mm, collectively accounting for an average of 21% of the total irrigation water applied. The results of various scenario analyses showed that improvement in water transfer efficiency and accurate irrigation planning resulted in a 30% reduction in deep percolation and a 15% saving in irrigation water without harming the performance. Ma et al. (2015) estimated the optimal irrigation program and deep percolation using the SWAP model in three experimental sites with wheat and corn plants. The results showed that implementing optimized irrigation scheduling could reduce net irrigation water application by 24.9% to 77.2% compared to conventional irrigation practices in the region. Kumar et al. (2015) used the SWAP model to simulate salt distribution within the soil profile and wheat yield under saline water irrigation conditions. The model calibrated using 2009-2010 trial data and validated using data from 2010-2011. The results showed that model performance is better in predicting the relative performance in salinity tolerant cultivars than unlikely varieties in terms of using saltwater with different qualities. Xue and Ren (2016) investigated plant water productivity under sprinkler irrigation regimes using the SWAP-WOFOST model. The results showed that spring wheat, spring maize, and sunflower seeds improved 16.9%, 8%, and 11.4%, respectively, compared to the surface irrigation scenario, and average water productivity increased by 7.9%, 5%, and 14.1%. Xue and Ren (2017) investigated water productivity using an agro-hydrological model in the Hetao irrigation network. The results showed if the proposed irrigation scenario was applied, it increased the average performance of product and water productivity for wheat, corn, and sunflower plants compared to the baseline scenario. Xu et al. (2019) examined agro-hydrological processes and water use optimization using the SWAP-EPIC model in the Heihe River Basin. The results showed that only 53% of applied water was applied through actual evapotranspiration. While, deep percolation losses and canal conveyance losses accounted for 22% and 25% of the total water consumed, respectively. Also, the results showed that about 15% of the amount of irrigation water was saved with a reasonable allocation of water. A substantial body of research has been conducted in the Neyshabour Plain, encompassing investigations into groundwater level forecasting, water resource management, and watershed studies (Izadi et al., 2007; Farajzadeh et al., 2005). Zhao et al. (2020) modified the SWAP model, and the result showed the yield and water use efficiency respectively 38.9% and 54.3% under mulching conditions improved compared to no mulching field.

Although these studies and hydrologic conditions and groundwater resource management are described in the plains area, the field scale is not the right solution for planning irrigation and agricultural water to increase productivity. This study has two primary objectives. The first stage focuses on simulating water balance components and predicting soil moisture content. Subsequently, the second stage evaluates water productivity under existing conditions, employing an irrigation planning model.

2. Materials and methods

2.1. Study area

Neyshabour Plain, one of the significant plains in Razavi Khorasan Province, was selected as the study area for this research (Figure 1). The Neyshabour plain's water crisis disrupts hydrological balance, with the escalating demand for water resources since 1986 identified as a subsequent contributing factor. The flatland portion of the CalShore basin, situated within the elevation range of northeastern Binalood in Iran's Central Desert, encompasses a significant geographical area. Encompassing a total catchment area of 7,300 square kilometers, the basin comprises 3,900 square kilometers of flatlands, with the remaining portion consisting of mountainous terrain. The basin is characterized by arid and semi-arid climate, with an average annual temperature of 12 degrees Celsius and an average basin-wide precipitation of 292 millimeters. The annual evaporation rate in the Neyshabour Plain is 2335 millimeters. In 1992, groundwater levels in the plain experienced an average annual decline of approximately 0.2 meters. The study area, a plain with a total discharge of 788 million cubic meters, boasts fertile land exceeding 80% suitable for irrigation and cultivation. This characteristic contributes to Neyshabour's status as a leading agricultural center in Khorasan, with over 70% of its crops classified as "blue water" crops, signifying their dependence on freshwater resources. The cultivation of water-intensive grain crops and garden produce is fundamentally incompatible with the prevailing water-scarce conditions in the region (Farajzadeh et al., 2005).

2.2. Essential Data Requirements for the SWAP Model

The SWAP ecohydrological model stands out as a comprehensive tool for simulating water, heat, and solute transport processes in both saturated and unsaturated soil environments. The SWAP model incorporates physically based models to simulate irrigation management practices and plant growth processes. Water movement is simulated using Richards' equation, employing the finite difference numerical method, incorporating imposed boundary conditions, and utilizing soil hydraulic functions. Soil hydraulic functions are defined as mathematical relationships that describe the interplay between hydraulic conductivity, soil moisture content, and soil water pressure head. The SWAP model employs analytical functions based on the equations proposed by Van Genuchten (1980) and Molden (1997) to effectively represent the soil water retention curve. The upper boundary condition is dynamically determined by the interplay of potential evapotranspiration (ET_P, mm/day), irrigation (Ir, mm/day), and precipitation (P, mm/day) fluxes. Potential evapotranspiration (ET_P) is estimated employing the FAO_{56} Penman-Monteith equation, utilizing daily weather data encompassing solar radiation, air temperature, humidity, wind speed, and crop characteristics, including minimum crop resistance, surface albedo, and crop height (Van Dam et al., 1997; Allen et al., 1998).

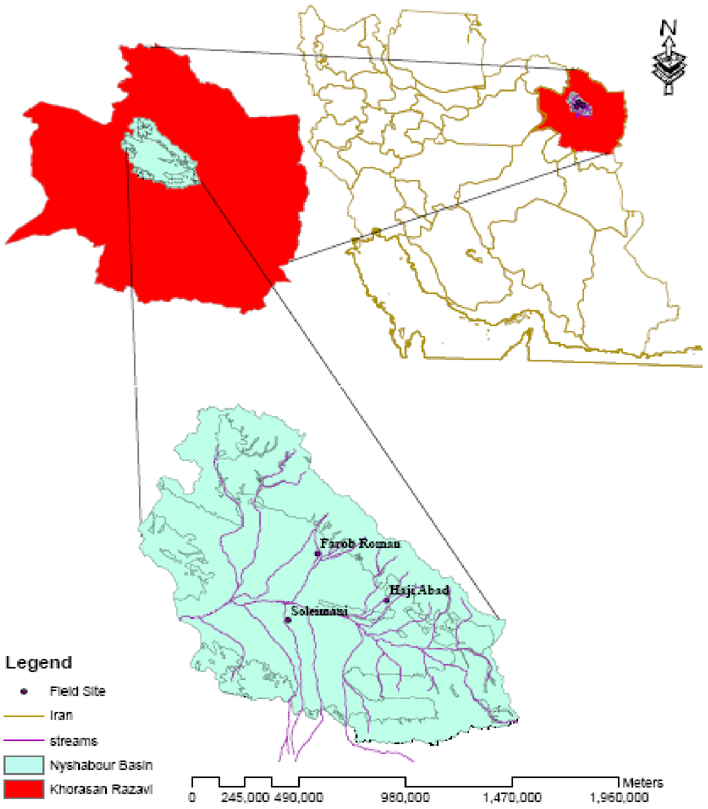

Figure 1. Spatial distribution of selected farms within the Neyshabour Basin

In Neyshabour Plain, wheat cultivation occupies the largest area, with production exceeding 121,000 tons. Consequently, wheat was selected for model evaluation and calibration using the SWAP model. Three wheat farms, namely Farob Roman, HajiAbad, and Soleymani, were chosen to represent the entire plain and collect the data required for the SWAP model (Figure 1). These farms were carefully selected based on their representative agroecological conditions and widespread cultivation of the selected wheat varieties, ensuring that the data collected accurately reflected the agricultural practices and yield potential across the entire region. Daily data from the Neyshabour synoptic station for the 2008-2009 cropping season were used to obtain meteorological data, including solar radiation, precipitation, minimum temperature, maximum temperature, relative humidity, and wind speed at 2 meters height. To acquire the agricultural data required by the model throughout the growing season, irrigation dates, irrigation water volume and salinity, root development depth, leaf area index (LAI), and plant height were measured in the selected fields. Also, at the end of the growing season, harvest date and yield rate were measured and recorded.

The irrigation depth was determined by multiplying the irrigation water flow rate by the irrigation duration and dividing the result by the field area. Furrow irrigation was employed in Farob Roman farm, basin irrigation in HajiAbad farm, and furrow irrigation along contour lines in Soleymani farm. To obtain soil hydraulic parameters, the RETC software package was used so that each layer of soil profile as soil texture, bulk density, and moisture content at the point of field capacity (FC) as the input data model and the equation parameters Van Genuchten including residual moisture θ_{res}, soil saturated moisture content θ_{set}, saturated hydraulic conductivity $K_{sat}(cmd^{-1})$ and soil parameters including $\alpha(cm^{-1})$, $\lambda(-)$, $n(-)$ as output was obtained (Van Genuchten et al., 1997). Some physical and chemical properties of soil in the fields of study are shown in Table 1. Soil moisture directly from the depths of 0-10, 10-20, 20-30, 30- 40, 40-50, 50- 60, 60 -70, and 70- 80 cm during the growing season in all experimental fields using psychrometer TRIME-FM type made in Germany on a two-week interval were measured. The observed soil moisture data were divided into two sets. The first part was used in the calibration procedures, and verification for the second model was used. To assess the performance of the model in simulating soil moisture values, the root mean square error (RMSE) was employed, calculated as follows (Pan et al., 2020):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \{\theta_{obs}(t_i) - \theta_{sim}(t_i)\}^2}{N}} \tag{1}$$

High humidity in the equation and θ_{obs} moisture observations simulated by the model θ_{sim} are.

2.3. The calculation of water productivity

In agricultural production systems, water productivity is determined by dividing the total crop yield by the volume of water consumed (Molden, 1997). Furthermore, water productivity can be defined in different ways. It refers to different types of crop production, i.e. dry matter or grain yield, and amount of water used, i.e. transpiration, evapotranspiration, and irrigation (Molden et al., 2001). Water productivity can be conceptualized and measured in various ways, employing different equations. For instance, crop yield can be quantified as either dry matter or total biomass, while water consumption can be defined as transpiration, evapotranspiration, irrigation, or evapotranspiration plus deep percolation. The flexibility inherent in water productivity definitions allows for the development of insightful indicators to assess water use efficiency. These indicators can guide decisions regarding water conservation strategies and identify opportunities for optimizing water management practices. The specific indicators employed in this study include:

$$WP_T = \frac{Y(kg/ha)}{Tr(mm)} \tag{2}$$

$$WP_{ET} = \frac{Y(kg/ha)}{ET_a(mm)} \tag{3}$$

$$WP_{ET_{dp}} = \frac{Y(kg/ha)}{ET_{dp}(mm)} \tag{4}$$

$$WP_{Irr} = \frac{Y(kg/ha)}{Ir(mm)} \tag{5}$$

Where: Y is grain yield (kg/ha), Tr is plant transpiration (mm), ET_a is actual evapotranspiration (mm), ET_{dp} is total actual evapotranspiration and deep percolation (mm), Ir is water irrigation (mm), WP_T is ratio of grain yield to plant transpiration, WP_{ET} is ratio of grain yield to actual evapotranspiration, WP_{ETdp} is ratio of grain yield to total actual evapotranspiration and deep percolation, WP_{Irr} is ratio of grain yield to water irrigation.

2.4. Evaluation and calibration model

The application of simulation models necessitates conducting sensitivity analysis, calibration, and validation procedures. In this study, they were used to perform these steps to transfer parts of water and crop growth. Sensitivity analysis of the model was conducted using the method proposed by Lane et al. (1990). This method has also been used in other studies (Akbari et al., 2009). To conduct a sensitivity analysis of the model's response to soil hydraulic parameters, output data from the RETC model for various soil layers and selected fields were utilized as a reference.

To conduct the sensitivity analysis, each input parameter was systematically varied in turn. For each parameter, two perturbations were applied: a positive and a negative change, both of 50% magnitude. The remaining input parameters were held constant during each perturbation. The model was then executed under each new set of conditions to assess its sensitivity to the altered parameter. The results of these two modes with the results compared to the base case sensitive model parameters were determined. To calibrate wheat yield under diverse irrigation regimes, the Soil Water Assessment Tool (SWAP) model was employed. In this study, all measured parameters from various fields, including irrigation dates, irrigation water salinity, plant height, leaf area index, root depth, and harvest date, were utilized. Input data required for the model were prepared and calibrated using information from various fields, as follows: 1- Model performance under different simulated experimental fields, 2- Comparison of measured performance with simulated performance under identical conditions, 3- If the simulated performance did not match the measured performance, the plant yield sensitivity coefficient (K_y) was adjusted. Subsequently, the aforementioned steps were repeated until the simulated results closely matched the measured performance, 4- The calibrated model was employed to investigate the impact of various irrigation scheduling strategies on crop yield.

Table 1. Some soil physical and chemical characteristics of experimental fields (SiL: Silt, L: Loam, S: Sand)

Fields	Soil physical properties							
	Layer	ρ_d	Soil	Clay	Silt	Sand	Gravimetric Water Content at Field Capacity	EC
	(cm)	(gr/cm^3)	Texture		(%)		(%)	(dS/m)
Farob Roman	0-30	1.51	SiL	18	52	30	20.1	1.06
	30-60	1.57	L	22	44	34	17.1	0.68
	60-90	1.78	L	20	46	34	19.7	0.8
HajiAbad	0-30	1.43	L	18	36	46	15.5	1.56
	30-60	1.49	SL	18	22	60	12.9	2.69
	60-90	1.71	L	16	36	48	11.7	2.02
Soleymani	0-30	1.72	SiL	17	55	28	17	6.96
	30-60	1.70	SiL	16	62	22	23	7.5
	60-90	1.71	SiL	16	60	24	18.2	8.2

3. Results and discussion

3.1. Simulated soil moisture profiles

The sensitivity analysis model to soil hydraulic parameters using the method of Lane et al. (1990), showed the model to *α*, *n* and θ_{sat} parameters, the average degree of sensitivity and other parameters for input sensitivity was low. Among the sensitive parameters *α* and n were moderate and the most sensitive parameters. Thus, phase calibration model parameters were changed; therefore, the best match between observed and simulated moisture was achieved. Calibration parameters and other soil hydraulic parameters (θ_{res}, θ_{set}, K_{sat} and λ) are shown in Table 2. The amount of soil moisture and root mean square error (RMSE) in different fields between 0.02 and 0.039 was fluctuating (Table 3). These results indicate that soil moisture could be modeled at different times and depths for good simulation. Some differences between predicted and measured moisture values may be due to the limitations of inherent models. For example, the phenomenon effects of residual moisture (Hysteresis) and preferential water flow from the large gaps in the model are in order. Another reason may reduce accuracy due to the simple model extracted which is related to some parameters. For example, daily rainfall amounts to the assumption that the model is used to rain all day uniformly distributed, the constant, while may not be accurate both in the model enters (Khaksari et al., 2006). Also, field observations of variability and error may be the difference between observed and simulated values is a fundamental role (Figure 2). RMSE values during calibration and verification procedures in field Farob Roman respectively, 0.035 and 0.020 were calculated. RMSE value observed during both phases is relatively low and acceptable.

Table 2. Soil Hydraulic Properties at Different Depths in Experimental Fields

Fields	Layer (cm)	θ_{res} (cm^3/cm^3)	θ_{sat} (cm^3/cm^3)	K_{sat} (cm/day)	α (cm^{-1})	λ $(-)$	n $(-)$
Farob Roman	0-30	0.044	0.353	20.61	0.021	0.5	1.39
	30-60	0.050	0.343	20.44	0.026	0.5	1.13
	60-90	0.041	0.300	9.04	0.037	0.5	1.24
Haji Abad	0-30	0.051	0.381	41.51	0.039	0.5	1.80
	30-60	0.059	0.382	115.41	0.048	0.5	1.10
	60-90	0.042	0.304	41.40	0.062	0.5	1.44
Soleymani	0-30	0.036	0.298	15.95	0.038	0.5	1.27
	30-60	0.040	0.321	11.96	0.008	0.5	1.10
	60-90	0.035	0.302	16.29	0.031	0.5	1.27

3.2. Estimation of Soil Water Balance Components Using the SWAP Model

Using data collected as input soil hydraulic parameters, irrigation depths and other data, water balance components in different fields were simulated by the SWAP model. The accurate simulation of water balance components for the calculation of productivity indices is necessary. Table 4 simulated water balance components in different fields of Neyshabour plains. Rainfall during the growing season is an important source of wheat crop evapotranspiration. The amount of rainfall during the growing season is 280 mm.

With this level of winter precipitation, unnecessary irrigation applications can be eliminated. The water irrigation ranges from 420 to 920 mm. Under actual field conditions, crop evapotranspiration values ranged from 451 to 498 millimeters. The average wheat evapotranspiration was estimated to be 472 mm. Evapotranspiration rates in Haji Abad and Soleymani farms are comparable under identical irrigation volumes. Irrigation management practices at Farob Roman farm are not optimized due to reliance on a surface irrigation system not designed for efficient water distribution. This results in significant water losses through deep percolation and runoff, estimated to be 60% of the total applied irrigation water and precipitation. Due to the improper design of the surface irrigation system in Farob Romen Farm, approximately 60% of the total irrigation and rainfall water is lost from plant access through deep percolation and surface runoff. Therefore, it is shown that while the amount of irrigation in this field is higher than in other fields because the actual evapotranspiration losses inevitable deep percolation and runoff is almost about other fields. Due to heavy irrigation farms in the Farob Roman farm, deep percolation and runoff were higher than in other fields. The SWAP model to separate evapotranspiration plant to evaporation (non-effective water) and transpiration (effective water) using LAI at different plant growth stages. In Figure 3, the amount of daily evaporation and transpiration during the growing season in the field of Farob Roman is shown. As observed in the figure, at the beginning of the growing season, the contribution of evaporation is greater than that of transpiration due to the small size of the plant cover. As the growing season progresses towards its mid-to-late stages, the contribution of evaporation decreases while that of transpiration increases. Consequently, by the end of the growing season, evaporation reaches zero and transpiration reaches its maximum value. This observation highlights the significance of the reduced evaporation component at the beginning of the growing season, which can be considered in farm water management strategies.

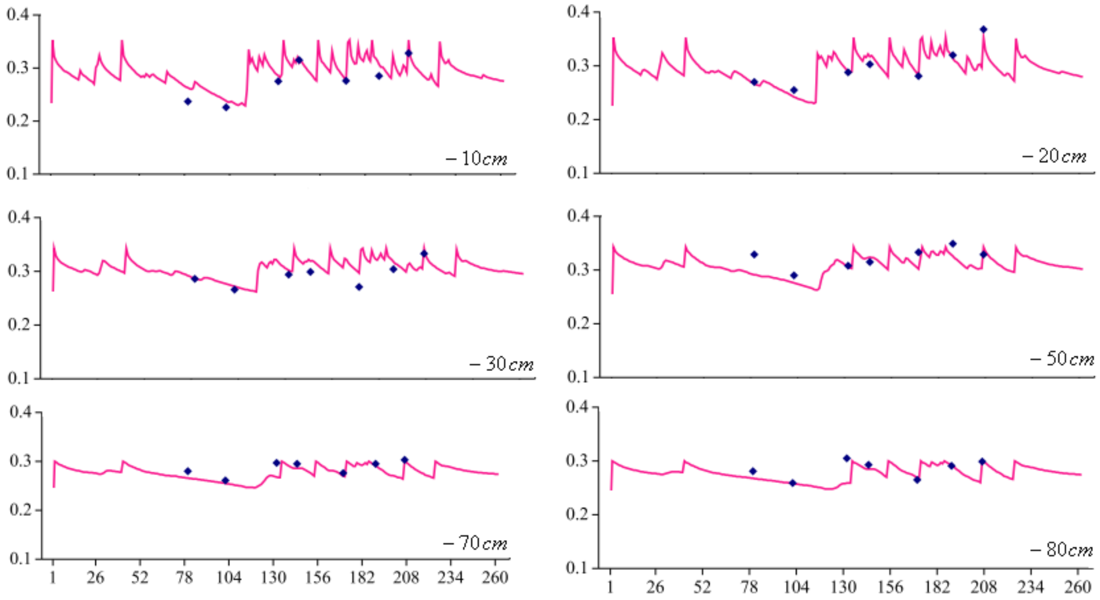

Figure 2. Observed and simulated moisture field in different soil depths Farob Roman

3.3. Water productivity under agriculture management

Water productivity indicators were calculated using water balance components simulated by the SWAP models. These components included irrigation, actual evapotranspiration, crop evapotranspiration, deep percolation, soil moisture storage within the profile, and field-measured yield data. Table 5 shows the values of water productivity indicators in different farms of Neyshabour plain. The WP_{T} value exhibits variability, ranging from 0.85 to 1.67. The average value of WP_{T} was calculated to be 1.28. Vazifedoust et al. (2008) estimated the WP_{T} value for wheat in the Borkhar of Esfahan region 1.18 kg/m^{3} which is similar to the value obtained in this study. The intermediate indicators, WP_{ET}, WP_{ETdp} *and* WP_{Irr} in the studied fields were 0.99, 0.6, and 0.88 kg/m³, respectively. High levels of evaporation in the early period of plant growth due to traditional irrigation methods in the study farms decreased by 28 percent compared WP_{ET} to WP_{T}. Improving agricultural operations such as mulch or soil application subsurface irrigation can be improved WP_{ET}. In addition and most important reason WP_{Irr} and WP_{ETdp} to WP_{ET} reduce the high amount of deep percolation due to heavy irrigation treatments in the Farob Roman farm. Due to a review of 82 literature sources with results of experiments in the last 25 years, Zwart and Bastiaanssen (2004) established global benchmark values of WP_{ET}, expressed as Y/ET (Kg/m^{3}), at 1.08 for wheat. The average WP_{ET} for wheat in Neyshabour Plain was calculated to be 0.99. Singh et al. (2006) calculated index values WP_{T}, WP_{ET}, and WP_{ETdp} for wheat in the Sirsa district, India as 1.88, 1.39, and 1.04 kg/m^{3}, respectively. These values compared with the indices are higher than can be due to increased crop evapotranspiration and deep percolation to the research done in India. In addition, the demonstrably higher wheat yield in the Sirsa district, averaging 5.4 tons/ha compared to 4.7 tons/ha in Neyshabour, could be another contributing factor. Results of studies show that improved water management, an effective and important step in increasing efficiency and optimal use of water and irrigation water use efficiency (WP_{Irr}) and agricultural products are produced. Zwart and Bastiaanssen (2004) estimated global water use efficiency (WUE) for wheat to range between 0.6 and 1.7 kg/m³, with an average of 1.09

kg/m³. The results of this study showed that the index of WUE can largely decrease the amount of irrigation water which increases deficit irrigation practices. Heydari et al. (2005) conducted a study to determine the water use efficiency (WUE) of major agricultural products in five regions of Iran: Kerman, Hamedan, Moghan, Golestan, and Khozestan. Their findings indicate that the average WUE for wheat was 0.75 kg/m^3. Heidari and Haghayeghi Moghaddam (2001) due to the results of two national projects carried out in the field of productivity (efficiency) irrigation experts in the country by the Engineering Research Institute of Agriculture, crop water use efficiency of different methods of surface irrigation management to farmers were calculated. The results showed that these irrigation methods and management of important influence to increase the efficiency of water irrigation and the bulk of issues and problems in irrigation efficiency and water use efficiency (WUE) of irrigation management issues related to the improvement, need little investment and no but an effort to correct management and planning needs. Their irrigation water use efficiency of wheat in Khorasan province, on average 0.57 was calculated. In this study, the amount of irrigation water uses efficiency for wheat in the Neyshabour Plains with average 0.88 kg/m^3. This number compared with the numbers mentioned in previous investigations improved due to practice improvements over the last decade in different parts of the Agricultural Research and Development, so that the value of this index shows an increase at 17% in the country and 54% in Khorasan province.

3.4. Scenario planning irrigation

Due to the field measurements between 2008-2009, the dates and amount of irrigation water applied in the fields Soleymani and HajiAbad optimum level and is suitable for irrigation planning and scenario modeling exercise on wheat yield had no significant effect. The highest water level in the field was the first time Farob Roman was 230 mm, and on other occasions (six times) was estimated at around 115 mm. Runoff and deep percolation of water from the applied field Farob Roman showed that irrigation.

Table 3. Mean square error and number of observations in the calibration and validation stages of moisture

Fields	Calibration θ (cm^3cm^{-3})		Validation θ (cm^3cm^{-3})	
	N	RMSE	N	RMSE
Farob Roman	18	0.035	13	0.020
HajiAbad	21	0.039	21	0.037
Soleymani	17	0.033	12	0.032

Table 4. Simulated water balance components (mm) in the fields studied (farmer management conditions)

Water balance components	Fields		
	Farob Roman	HajiAbad	Soleymani
P	280	280	280
Ir	920	400	420
E_a	108	109	101
T_a	359	389	350
ET_a	467	498	451
R	188	25	26
ΔW	-20	-3	-19
Q_{bot}	-565	-160	-242
$Y(ton/ha)$	6	5.23	3

Table 5. Water productivity indicators in agriculture management (kg/m^3)

Water productivity indicators	Fields		
	Farob Roman	HajiAbad	Soleymani
WP_T	1.67	1.34	0.85
WP_{ET}	1.28	1.05	0.66
$WP_{ET_{dp}}$	0.58	0.79	0.43
WP_{Irr}	0.65	1.3	0.71

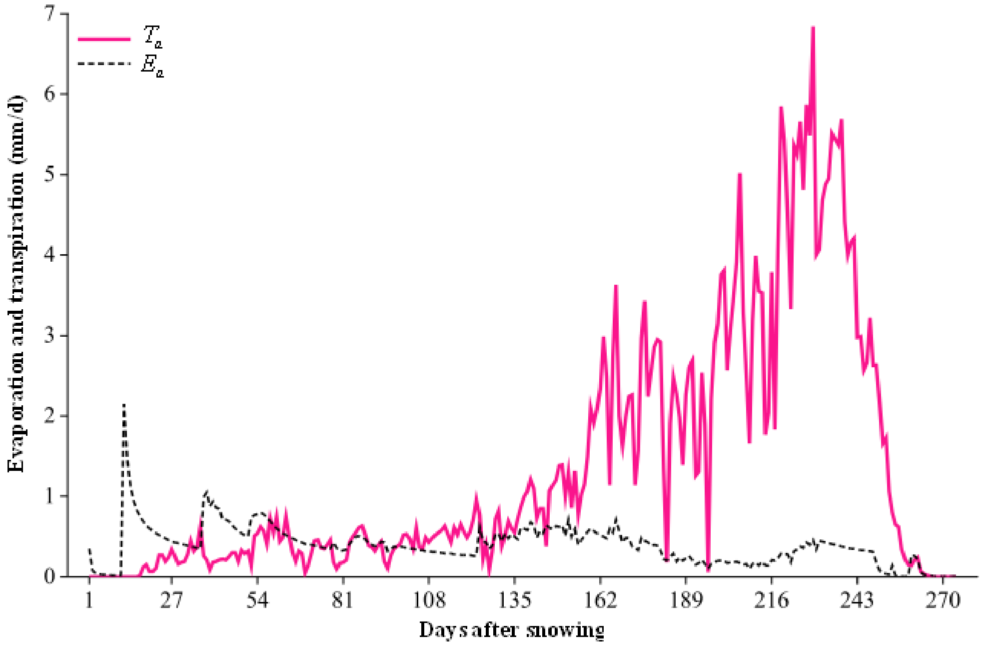

Figure 3. Daily simulated evaporation and transpiration rates for the Farob Roman farm

At this time due to the occurrence of rainfall field season is not adequate for plant growth and irrigation at the right time (the proposed planning model) deep percolation and runoff respectively 42 and 40 percent and 14 percent yield increase.

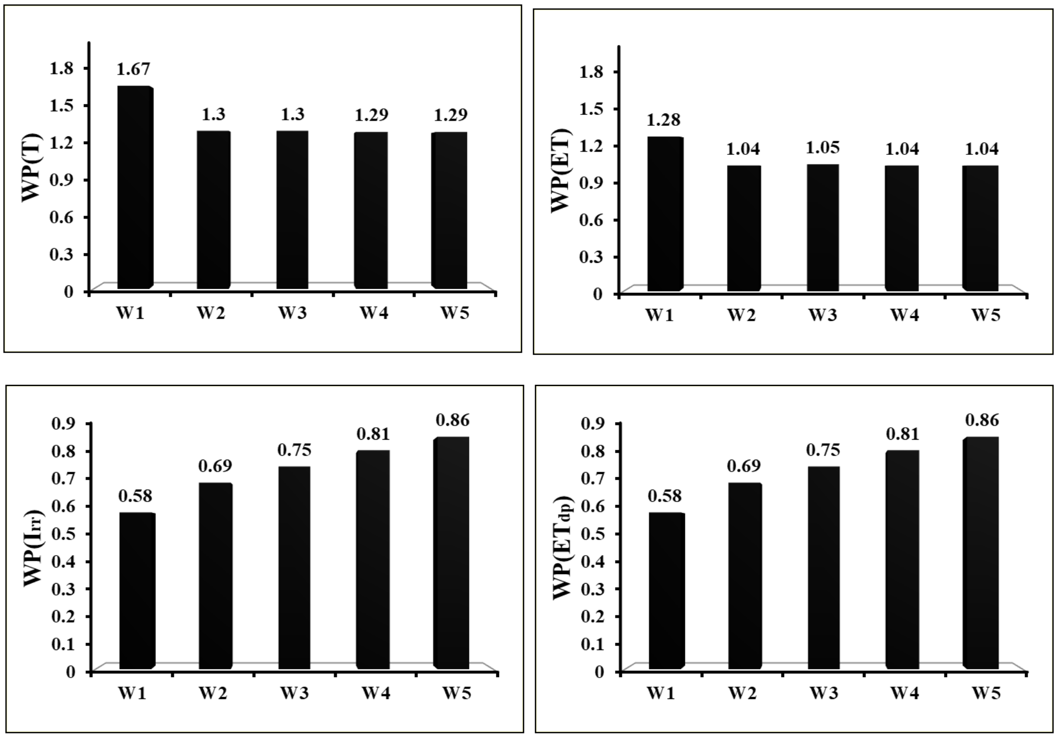

Figure 4. The relationships among the indicators of productivity of water management scenarios in the field of agriculture and Farob Roman (W_1: farmer management conditions, W_2: scenario planning irrigation, W_3, W_4, and W_5, respectively, 10, 20 and 30 percent less irrigation)

The results show the water depth applied due to the soil characteristics and plant characteristics of wheat is higher than the amount required. The simulation results conducted by the SWAP model under different scenarios showed reducing irrigation water depth applied to 30 percent had no significant effect on yield. Although reducing the depth of irrigation reduced the deep percolation and runoff at the farm level, may cause long-term accumulation of minerals and soil salinity. Therefore, reducing the amount of irrigation depth should be a prudent action. The traditional irrigation system and circulatory distribution of water between farmers and water right-holders, reducing irrigation depth and operation very reasonable and seem to be the best option in the present conditions, proper planning of irrigation, and the irrigation amount are at the right time. Figure 4 shows the relationship between water productivity indicators in agriculture and the management of scenarios in, Farob Roman field is shown. As in Figure 4, it is shown in water productivity indices (WP_T and WP_{ET}) independent of deficit irrigation and irrigation planning scenarios, and applying this scenario does not show the effect on these indices. The results by other researchers, including Vazifedoust et al. (2008) have also been confirmed. Deficit irrigation increased significantly in the indices WP_{ETdp} and WP_{Irr} due to deep percolation beeing reduced. For example, applying the correct planning of irrigation and deficit irrigation rate of 30% of indicators WP_{ETdp} and WP_{Irr} were about 48 and 61 percent are growing.

4. Conclusions

The results showed that demonstrated the feasibility of enhancing water management and efficiency through implementing effective irrigation scheduling strategies. Also, some farms with deficit irrigation management practices experienced a substantial decline in water depth (30%), crop yield (14%), and the water productivity indices WP_{ETdp} and WP_{Irr} (48% and 61% decrease, respectively). Conversely, implementing improved irrigation practices resulted in significant promotion of water productivity indices (about 48% and 61% increase, respectively). Deficit irrigation has little impact on the WP_T and WP_{ET} indices. Given the deep groundwater levels in the Neyshabour Plain, the impact of deep percolation on groundwater recharge may take years to manifest. Therefore, it is recommended that deep percolation and surface runoff losses at the field level be minimized to the greatest extent possible by meticulously leveling agricultural lands, employing mechanized surface irrigation methods, or utilizing pressurized irrigation techniques, thereby enhancing water productivity. Given the traditional irrigation system and rotational water distribution among farmers and water rights holders, it is recommended that proper irrigation scheduling practices, enhanced on-farm water management, and fertilizer and other agricultural input management be taught to farmers through extension classes to improve water productivity. It is recommended that this model be further validated and calibrated for other major crops in the Neyshabour Plain, such as forage maize, barley, sugar beet, cotton, and tomato, in subsequent research. The findings should be disseminated to farmers in the form of extension publications.

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