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Ecological and economic impacts of different irrigation and fertilization practices: case study of a watershed in the southern Iran

Azar Sheikhzeinoddin[1] · Abdoulkarim Esmaeili[1]

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Abstract Best management practices, such as conservation tillage, the optimum level of irrigation, fertilization, are frequently used to reduce non-point source pollution from agricultural land and improve water quality. In this study, we used the soil and water assessment tool to model the impacts of different irrigation (adjusted to crop need), cropping and fertilization practices on total nitrogen loss. The economic impacts of these practices on crop net farm income were also evaluated. For this purpose, the model was calibrated through comparing model outputs with observations to ensure reliable hydrologic, crop yield and nitrate leaching simulations. The results showed that by reducing water or fertilizer or combination of both, we can reduce nitrate leaching. For wheat and corn, the best scenario was S1n1 (combination between reduction by 10 % of water and nitrogen fertilizer application, simultaneously) and S2n3 (combination of 20 and 30 % reduction in water and fertilizer application), respectively. These scenarios are both ecologically and economically desirable. Also, decreasing nitrogen fertilization by 50 % for corn would decrease the nitrate pollution from 101.1 to 32.3 kg N ha^{-1}; therefore, this strategy is ecologically desirable but economically unsound. So, there are opportunities for environmental decision makers to encourage farmers to implement these strategies. Also, since the nitrogen leaching cannot decrease without a reduction in net farm income for crops such as corn; hence, the losses of farmers should be compensated.

Keywords Environmental preference · Fertilization management · Irrigation management · Nitrate losses · Net farm income

✉ Abdoulkarim Esmaeili
esmaeili68@yahoo.com

Azar Sheikhzeinoddin
azeinoddin@yahoo.com

[1] College of Agriculture, Shiraz University, Shiraz, Iran

1 Introduction

Nutrient input comes mainly from non-point source (agricultural activities) pollution (Behrendt et al. 1999). Now a global problem is the nitrogen leaching from agricultural lands, so land management practices such as nutrient management, tillage operations, and irrigation management are used to reduce pollution and improve water quality. Some studies such as Smukler et al. (2012), Daroub et al. (2011) and Inamdar et al. (2001) have shown the positive effects of best management practices (BMPs) on water quality and nutrients loads.

Nutrient leaching has caused eutrophication and pollution of ground waters. Ground waters contamination by nitrates has been observed in areas where cultivated lands or livestock production are located near the groundwater. Therefore, reducing pollution from agricultural activities requires knowledge of sources and process of spread pollution and evaluation of potential long-run impacts on the environment. Fohrer et al. (2005) showed that the application of hydrological models can elucidate the processes and support management decisions. In areas where non-point source pollution is dominant, hydrological models are often the only practical way to evaluate the impacts of change in land use on the concentration of nitrate contamination. Hydrological models that are able to compute the nitrogen cycle (fate and transfer) are useful tools to specify the impacts of agricultural activities on environmental.

Many eco-hydrological simulation models have been developed within recent decades for evaluating the best management practices. Among them, The Soil and Water Assessment Tool (SWAT) model includes the greatest number of agricultural management activities (Arnold et al. 1998).

Vagstad et al. (2009) in their study used SWAT model to assessment the impacts of fertilization strategies, livestock management, and land use change on nutrient load. They showed that decreasing inorganic fertilization by 20 % would decrease the annual nitrogen load by 15 and 3 % for the Enza and Zelivka Rivers, respectively. Also, reducing organic nitrogen by 20 % did not any significant change in the nitrogen load. In addition, converting 20 % of the arable land to forest reduced the total nitrogen load by approximately 40 and 5 % in the Enza River and Zelivka River, respectively.

Cools et al. (2011) in their study determine the most cost-effective measures for reducing nitrogen pollution in a river basin. For this purpose, they joined SWAT model with an economic optimization model (ECM[1]). Results showed that the most cost-effective measures are productive dairy cattle, winter cover crops, modified efficiency of waste water treatment plants and enhanced fodder efficiency for pigs.

Lam et al. (2011) used SWAT model to assessment various management practices to improve water quality. For this purpose, they examined different scenarios of crop management, decreased fertilization application (by 20 %), a decrease of grazing intensity (from 2 to 1.1 livestock unit per hectare) and application of buffer strips (10 m width). Results showed that the use of winter rye in a crop rotation leading to improving soil quality, as well as reduces nitrogen leaching. The reduction by 20 % of the nitrogen application rate caused to a decrease in the nitrate load by approximately 10 %. Also, implementation of the buffer strips, by reducing the annual nitrate load by 15 %, had a significant impact on water quality.

Nguyen et al. (2014) investigated the tradeoffs between nitrate leaching and net farm income. They examine effects of different nitrogen best management practices (NMBP) in

[1] Environmental Costing Model.

nitrate leaching and net farm income. Results showed that the use of plastic mulch, fertilizer placement only in ridges, split fertilization and combination of these NBMP, reduced the nitrate leaching. Thus, there are opportunities for policy makers to incite farmers to adopt split fertilization and combine NBMP.

The Sun and Ren (2014) for winter wheat and maize simulated crop yield and crop water productivity (CWP) using the SWAT model. Results showed that net irrigation amount in scenario 3 was reduced 23.1 and 18.8 % for winter wheat and maize in comparing to scenario 1, respectively, and CWP was increased respectively 12.1 and 8.2 %. Also, optimal irrigation scenario could save 8.8×10^8 m^3 water and reduce groundwater overuse approximately 16.3 % in winter wheat growth period.

The Ahmadzadeh et al. (2015) used the SWAT model to assessment the impacts of changing irrigation system from surface to pressurized on water productivity and water saving. In this study, authors used the SWAT model to simulate different irrigation systems by a change of management variables. The results showed that changing the surface irrigation to a pressurized system can increase water productivity up to 15 % due to the increases in crop yield, better water distribution, and greater actual evapotranspiration.

This current research specifically aims to (1) model the variability of nitrate leaching and crop growth for the present agricultural activities by using SWAT program; (2) assess the impacts of irrigation and fertilizer scenarios on crop growth and nitrate leaching; and (3) examine the tradeoffs between nitrate leaching and net farm income of different irrigation and fertilization scenarios for the cultivation of wheat, barley, rice and corn, which are traditional and important crop in this region (TASHK-BAKHTEGAN basin). These researches are required for supporting management decisions to preserve the fertility of soil, healthy population and the environment.

2 Materials and methods

2.1 Study area

The TASHK-BAKHTEGAN catchment is located northeast of Fars province, Iran, between longitudes 51°45 and 53°30 E and latitude 29°30 and 31°N. The total land area of the catchment is 31,452 km^2. The elevation ranges from 1509 to 3758 m above sea level with an average elevation 2065. The mean min and max air temperature and annual precipitation during a recent 32 year period (1979–2010) are 6.76, 21.55 °C and 305.7 mm, respectively.

In the TASHK-BAKHTEGAN watershed, the dominant soil texture (51 %) is loam. Also, about 43.55 % of TASHK-BAKHTEGAN plain's soil is clay loam. They are mainly deep and moderately well-drained. Land use in the TASHK-BAKHTEGAN watershed is predominantly pasture and shrubland (72 % of the total land use) and agricultural (22 % of the total land use), with major crops being wheat, barley, rice, and corn.

2.2 SWAT model

SWAT is a continuous-time model that is able to simulate the impact of land management practices on water quality and crop growth, simultaneously (Neitsch et al. 2005). In this study, we focus on the hydrologic, plant growth, nutrients (nitrate leaching), and agricultural management components of the SWAT model. At first, SWAT is divided a watershed into multiple sub-basins and then further subdivided into HRUs (homogeneous response units).

Some studies like Bouraoui and Grizzetti (2008), (Akhavan et al. 2010) and Bossa et al. (2012) investigated impacts of agricultural activities on nitrate leaching at watershed scale by SWAT.

Finally, for calibration and validation of SWAT model was used SUFI-2[2] (Abbaspour et al. 2007). This program is currently linked to SWAT in the calibration package SWAT-CUP[3] and contains GLUE[4] (Beven and Binley 1992), ParaSol[5] (Van Griensven and Meixner 2006), and MCMC[6] (Vrugt et al. 2003) algorithm. Previous studies showed that SUFI-2 program is very efficient in calibration and uncertainty quantification of large watersheds (Faramarzi et al. 2009; Schuol et al. 2008a, b; Yang et al. 2008) and small (Abbaspour et al. 2007; Rostamian et al. 2008).

The basic data required for SWAT model are topography, soil, land use, climatic and management operation. In this study, the SWAT model divided the TASHK-BAKHTE-GAN basin into 133 HRUs. Since the management information (such as crops grown, date of planting and harvesting, fertilizer application date and amount, water application date and amount, and tillage operation) obtained from the questionnaires in the 10 sub-basins of the 133 sub-basins, hence we used from outputs of these sub-basins. It should be noted that predominate soil type in these sub-basins is loam-clay with agriculture land use and slope with less than 5.

The presented model is set up for the period 1979–2010. It was calibrated for the period 1984–2002 and validated for the period 2003–2010 for flow, crop yield (wheat, barley, corn and rice) and nitrogen components. Firstly, the SWAT model is calibrated for flow. The Nash-Sutcliff Efficiency (NSE) is 0.75. Secondly, the crop yield is calibrated. Finally, the nitrogen components are calibrated against the residual between the modeled and the observed average concentrations (Table 1).

Table 1 Simulated management scenarios using SWAT model

	Scenario	Description
Deficit irrigation	S1	10 % reduction water application during the growth period
	S2	20 % reduction water application during the growth period
	S3	30 % reduction water application during the growth period
Deficit fertilizer	N1	10 % reduction fertilizer application during the growth period
	N2	20 % reduction fertilizer application during the growth period
	N3	30 % reduction fertilizer application during the growth period
	N4	40 % reduction fertilizer application during the growth period
	N5	50 % reduction fertilizer application during the growth period
	N6	60 % reduction fertilizer application during the growth period
	N7	70 % reduction fertilizer application during the growth period

[2] Sequential Uncertainty Fitting, ver. 2.

[3] SWAT Calibration Uncertainty Procedures.

[4] Generalized Likelihood Uncertainty Estimation.

[5] Parameter Solution.

[6] Monte Carlo Markov Chain.

Table 1 continued

	Scenario	Description
Deficit irrigation and fertilizer	S1n1	10 % reduction in water and fertilizer application during the growth period
	S1n2	10 and 20 % reduction in water and fertilizer application during the growth period, respectively
	S1n3	10 and 30 % reduction in water and fertilizer application during the growth period, respectively
	S1n4	10 and 40 % reduction in water and fertilizer application during the growth period, respectively
	S1n5	10 and 50 % reduction in water and fertilizer application during the growth period, respectively
	S1n6	10 and 60 % reduction in water and fertilizer application during the growth period, respectively
	S1n7	10 and 70 % reduction in water and fertilizer application during the growth period, respectively
	S2n1	20 and 10 % reduction in water and fertilizer application during the growth period, respectively
	S2n2	20 % reduction in water and fertilizer application during the growth period
	S2n3	20 and 30 % reduction in water and fertilizer application during the growth period, respectively
	S2n4	20 and 40 % reduction in water and fertilizer application during the growth period, respectively
	S2n5	20 and 50 % reduction in water and fertilizer application during the growth period, respectively
	S2n6	20 and 60 % reduction in water and fertilizer application during the growth period, respectively
	S2n7	20 and 70 % reduction in water and fertilizer application during the growth period, respectively
	S3n1	30 and 10 % reduction in water and fertilizer application during the growth period, respectively
	S3n2	30 and 20 % reduction in water and fertilizer application during the growth period, respectively
	S3n3	30 % reduction in water and fertilizer application during the growth period
	S3n4	30 and 40 % reduction in water and fertilizer application during the growth period, respectively
	S3n5	30 and 50 % reduction in water and fertilizer application during the growth period, respectively
	S3n6	30 and 60 % reduction in water and fertilizer application during the growth period, respectively
	S3n7	30 and 70 % reduction in water and fertilizer application during the growth period, respectively

For the sensitivity analysis, 21 parameters related to stream flow (Lenhart et al. 2002; Holvoet et al. 2005; White and Chaubey 2005; Abbaspour et al. 2007), 7 parameters related to nitrate leaching (Abbaspour et al. 2007; Akhavan et al. 2010) and 4 parameters related to crop growth (Ruget et al. 2002; Ziaei and Sepaskhah 2003; Wang et al. 2005) were initially selected (Table 2).

Table 2 SWAT model parameters included in calibration

Parameter	Definition	Initial range	Final range	*t* value
Discharge parameters				
r__CN2.mgt	SCS runoff curve number for moisture condition II	−0.5–0.5		−1.62
v__ALPHA_BF.gw	Base flow alpha factor (days)	0–1	0.93	−0.003
v__GW_DELAY.gw	Groundwater delay time (days)	200–500	355.25	1.22
v__REVAPMN.gw	Threshold depth of water in the shallow aquifer for 'revap' to occur (mm)	0–500	314.68	−0.79
v__GW_REVAP.gw	Groundwater revap. coefficient	0.02–0.2	0.123	1.13
v__RCHRG_DP.gw	Deep aquifer percolation fraction	0–0.5	0.127	−2.07
v__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0–5000	604.34	0.004
v__EPCO.hru	Plant uptake compensation factor	0–1	0.96	0.33
v__ESCO.hru	Soil evaporation compensation factor	0–1	0.66	−1.01
v__OV_N.hru	Manning's n value for overland flow	0–0.3	0.21	1.21
v__CANMX.hru	Maximum canopy storage	0–100	11.96	11.62
v__CH_N2.rte	Manning's n value for main channel	0.01–0.1	0.059	1.57
v__ALPHA_BNK.rte	Base flow alpha factor for bank storage (days)	0–1	0.886	3.74
v__SFTMP.bsn	Snowfall temperature (°C)	−5–5	−4.81	−0.28
v__SMTMP.bsn	Snowmelt base temperature (°C)	−5–5	−2.91	1.12
v__SMFMX.bsn	Maximum melt rate for snow during the year (mm $°C^{-1}$ day^{-1})	0–10	1.15	−0.19
v__SMFMN.bsn	Minimum melt rate for snow during the year (mm $°C^{-1}$ day^{-1})	0–10	1.86	−12.93
v__TIMP.bsn	Snow pack temperature lag factor	0–1	0.45	0.48
v__MSK_CO1.bsn	Calibration coefficient used to control impact of the storage time constant for normal flow	0–10	6.97	0.37
v__MSK_CO2.bsn	Calibration coefficient used to control impact of the storage time constant for low flow	0–10	3.86	1.61
v__SURLAG.bsn	Surface runoff lag time	0.05–1	0.9	−0.36
Crop yield parameter				
v__HI.mgt (winter wheat)	Harvest index	0–1	0.4	–
v__HI.mgt (winter barley)		0–1	0.4	–
v__HI.mgt (corn)		0–1	0.5	–
v__HI.mgt (rice)		0–1	0.5	–
v__PHU.mgt (winter wheat)	Total heat unit for crop to reach maturity	0–3500	2000	–
v__PHU.mgt (winter barley)		0–3500	1800	–
v__PHU.mgt (corn)		0–3500	1400	–
v__PHU.mgt (rice)		0–3500	1500	–
v__BIO_INI.mgt (rice)	Initial dry weight biomass (kg/ha)	0–200	100	–
v__LAI_INI.mgt (rice)	Initial leaf area index	0–8	2	–

Table 2 continued

Parameter	Definition	Initial range	Final range	*t* value
Nitrate parameter				
CDN.bsn	Denitrification exponential rate coefficient	0–3	1.03	0.93
SDNCO.bsn	Denitrification threshold water content	0–1	0.987	19.04
N_UPDIS.bsn	Nitrogen uptake distribution parameter	0–100	22.96	0.57
NPERCO.bsn	Nitrogen percolation coefficient	0–1	0.055	4.31
ERORGN.hru	Organic N enrichment ratio	0–5	1.096	0.79
FIXCO.bsn	Nitrogen fixation coefficient	0–1	0.193	1.25
CMN.bsn	Rate factor for humus mineralization of active organic nitrogen	0.001–0.003	0.0018	1.09
RSDCO.bsn	Residue decomposition coefficient	0.02–0.1	0.051	0.027

Table 3 Final statistics from hydrological calibration (validation) and nitrate results of SWAT model

	Name of station	P-factor	R-factor	R^2	NS	bR^2
Discharge	Chamrize	0.42 (0.38)	0.32 (0.3)	0.75 (0.7)	0.75 (0.69)	0.57 (0.56)
	Pol Khan	0.64 (0.57)	0.99 (0.89)	0.54 (0.52)	0.45 (0.43)	0.355 (0.34)
Nitrate	Pol Khan	0.59	0.08	0.73	0.73	0.52

Table 2 has a listing of the SWAT model parameters included in the calibration process and their sensitivity statistics. The *t* value (Table 2) provides a measure of sensitivity (larger values are more sensitive) (Abbaspour et al. 2007).

Also, the calibration and validation statistics for the two discharge stations and one nitrate station is shown in Table 3. The measures of calibration and validation were all within the good range for each station (P-factor near one, $R-factor<1, R^2>0.6$, $NS>0.5, bR^2>0.3$) (Ramanarayanan et al. 1997; Santhi et al. 2001; Moriasi et al. 2007; Xu et al. 2009; Tuppad et al. 2010). Although, R^2 and NS in Table 3 is less than above range for Pol Khan station.

In Fig. 1, calibration and validation results are shown for two discharge stations. Also, in Fig. 2, calibration results are shown for monthly nitrate loads. Due to lack of observed data for nitrate leaching, the model was not validating for nitrate. With this background in mind, we used this model for simulation for the period 1984–2010.

2.3 Model input

In this study, we used ArcSWAT for ArcGIS 9.3.1 and SWAT_CUP 2012 programs. Available GIS maps for topography, land use, and soils of the study area (TASHK-BAKHTEGAN basin) were used. Also, information about management data such as crops grown, date of planting and harvesting, fertilizer application date and amount, water application date and amount, and tillage operation for different crops were collected by questionnaire.

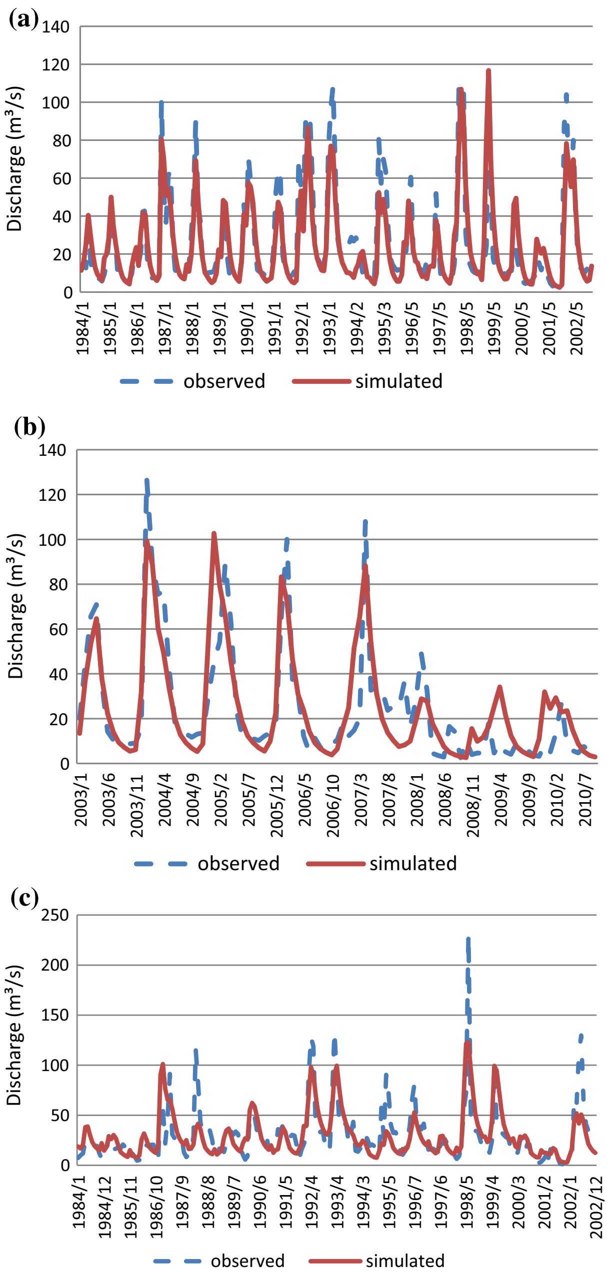


Fig. 1 Calibration (*left graph* 1984–2002) and validation (*right graph* 2003–2010) results for discharge at two stations: **a** and **b** Chamriz, **c** and **d** Pol Khan

The meteorological data include precipitation; minimum and maximum temperature, relative humidity, the wind and solar radiation on the daily basis for 30 stations were collected for the period 1979–2010.

Required data for calibration and validation of SWAT model are monthly river discharge from 2 gauging stations (Chamrize and Khan Bridge), monthly nitrate data from 1

Fig. 1 continued

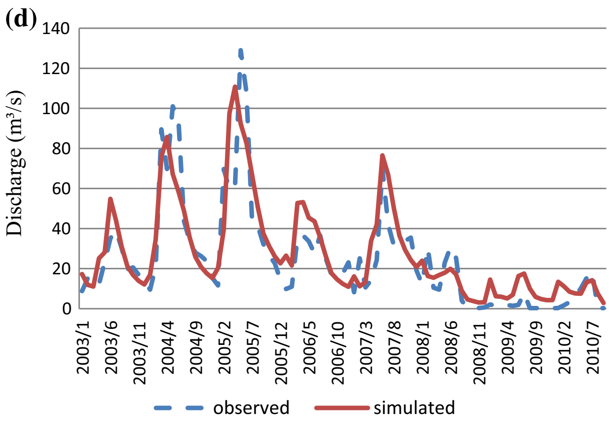
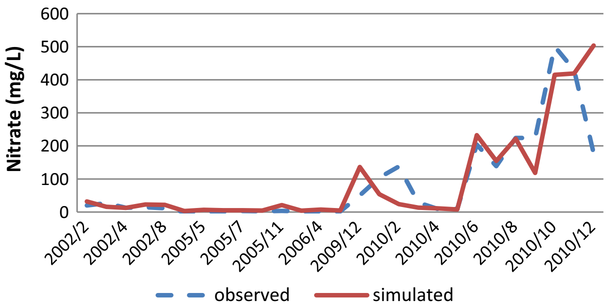


Fig. 2 Calibration results for monthly nitrate loads for Pol Khan Station



gauging station (Khan Bridge) and annual crop yield. These data were gathered by regional water organization, environmental protection agency and Iranian Minister of Jahade-Agriculture (MOJA), respectively.

2.4 Strategies

An effort to improve yield in Iran is keep increasing the use of chemical fertilizer and water inputs. While overuse of fertilizer is making formerly arable land unusable but led to degrading the quality of water. On the other hand, water scarcity is an important issue and amount of water application can effect on nitrogen uptake or losses. So, we can improve water quality and also deal with the water crisis, by the management of water and fertilizer application.

Therefore, in this study, we impose irrigation deficit, fertilizer deficit and the combination of them to investigate the effect of these scenarios in net farm income and water pollution. The implementation of the proposed strategies could increase or decrease the total income and costs. Therefore, for the economic sustainability of agriculture, it is important to consider the impact of scenarios on farmers' revenue, to identify those strategies that enhance farmer profits and surface water quality. However, the greatest environmental improvements do not necessarily result in higher economic profits. For this reason, net farm income of different strategies was estimated and analyzed in this work for wheat, barley, corn and rice. The total number of all considered strategy was 31 scenarios for each crop (Table 1). The scenarios were used to examine the effects of (i) irrigation deficit, (ii) fertilizer deficit, (iii) the combination of these two scenarios, on nitrate leaching and crop yield.

2.5 Trade-off between economic and environmental

To accomplish the economic evaluation of these strategies and recognize tradeoffs between nitrate leaching and net farm income, we first identified the cost of nitrate leaching, as this is the nitrogen fertilizer unused, which was not available for crops (wheat, barley, corn and rice) to uptake. Then we calculated the cost and benefit of crop production in different strategies to investigate the changes of net farm income. Finally, we compared the net farm income (in thousand Rial per ha (1000 Rial = 0.03 USD)) with the nitrate leaching (in kg Nha^{-1}) to identify the ecologically or economically optimal strategy.

3 Results and discussion

3.1 Yield and nitrate leaching simulation

The mean annual nitrate leaching and crop yield were calculated on the basis of the 32-year monthly output of the model runs. We received the output of 10 HRUs from 133 HRUs, that predominate soil type of these HRUs is loam-clay. In Table 4, characteristics of two layer of the soil profile in selected HRUs have been reported.

The management practices (including planting and harvesting date, net water needs and nitrogen application) and results of simulation before imposing strategies (yield and nitrate leaching) for wheat, barley, corn, and rice to current management practices are reported in Table 5.

3.2 Costs and benefit

The total cost of crop cultivation per ha includes the costs of seed, labor, fertilizers, pesticides, land and water. The application of different strategies led to the changes of the total cost. In other words, total production cost changed when we change rate of fertilization application, irrigation application or both of them.

The total production cost was varied from 18,718 to 22,373, 13,644 to 15,479, 40,179 to 49,314 and 42,414 to 57,840 thousand Rial per ha for wheat, barley, corn, and rice, respectively. This means that the application of different strategies could lead to a change in the total cost of 20, 13.5, 22.7 and 36.4 % for wheat, barley, corn, and rice, respectively.

The yield was the lowest in scenario N7 for wheat and S3n7 for barley, corn, and rice. These yield difference led to the differences in the total income.

In Figs. 3, 4, 5, 6, we displayed net farm income and nitrate leaching for different crops in each strategy. The net farm income and nitrate leaching were highest and lowest in scenarios S1 and S3n7 for wheat, N1 and S3n7 for barley, N3 and S1n7 for corn and S2n3 and S3n7 for rice, respectively. These results showed that, by decreasing water application for wheat and rice, we can increase net farm income. Also, we can increase net farm income with a reduction in fertilizer application for barley and corn. So, these results

Table 4 Characteristics of soil profile in selected HRUs

	Depth mm	SOL_BD Mg/m^3	SOL_AWC mm H_2O/mm soil	SOL_K mm/br	SOL_ALB	USLE_K (Metric ton m^2br)/(m^3 metric ton cm)	SOL_EC ds/m	Organic Carbon %	Clay %	Silt %	Sand %
First layer	300	1.5	0.175	2.42	0.154	0.3165	1.37	0.6	32	37	31
Second layer	1000	1.5	0.175	2.49	0.2265	0.3165	1.17	0.4	36	32	31
Hydraulic group: C											

Table 5 Simulated yields and nitrate leaching before impose any strategy

Crop	Planting date	Harvesting date	Net water needs m^3 ha^{-1}	Nitrogen application Kg N ha^{-1}	Real yield Ton ha^{-1}	Simulated yield Ton ha^{-1}	N loss Kg N ha^{-1}	Net farm income 1000 Rial ha^{-1}
Wheat	6 November	22 June	5000	289	6	5.94	48.39	28,112.93
Barley	17 October	5 June	3800	151	4	4.21	11.35	14,485.02
Corn	1 July	17 October	8000	404	9	9.02	101.11	29,193.95
Rice	6 July	22 October	11,400	165	5	5.02	44.52	67,807.31

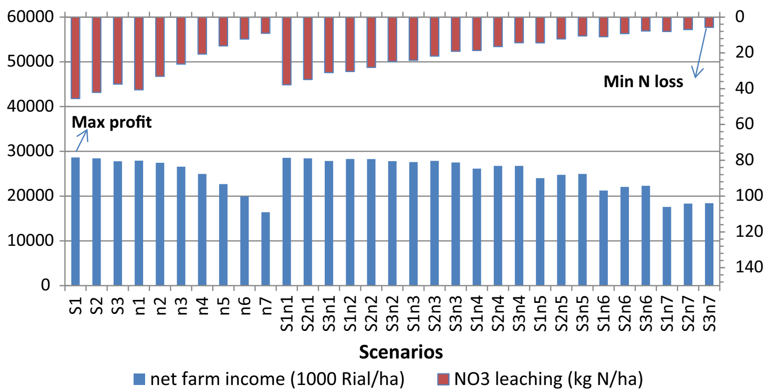


Fig. 3 Comparison net farm income and NO3 leaching in different strategies for wheat crop

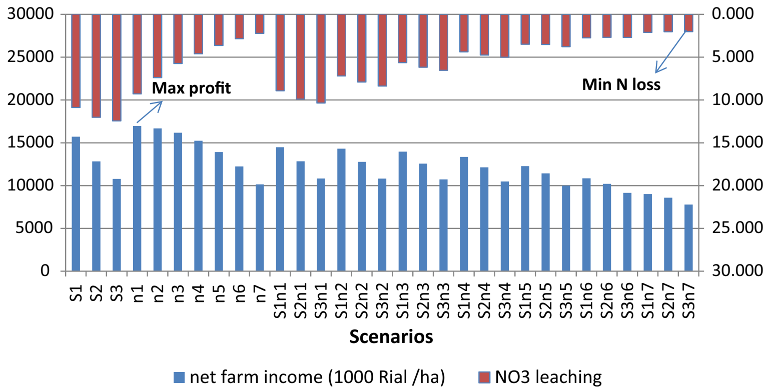


Fig. 4 Comparison net farm income and NO3 leaching in different strategies for barely crop

revealed that farmers in the region of study instead of utilizing modern technology increase their yield through rising application of chemical fertilizers and water inputs. Using too many chemical fertilizers and water leads to financial losses and exacerbated the imbalance of nutrient in soil, leading to environmental damage that will be irreparable.

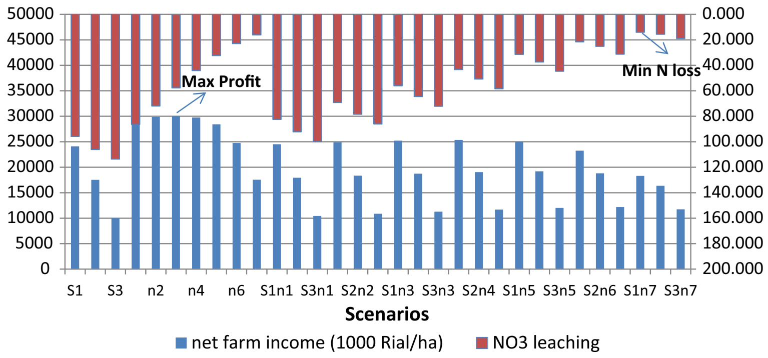


Fig. 5 Comparison net farm income and NO3 leaching in different strategies for corn crop

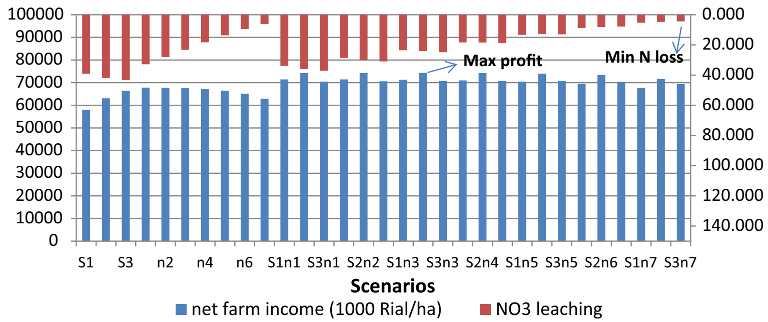


Fig. 6 Comparison net farm income and NO_3 leaching in different strategies for rice crop

In the short-run, change in crop price is not a dominant factor; therefore, change in total revenue results from the change in crop yield. The total production cost changed following the change in water application, chemical fertilizer application or both of them. Therefore, reduction in water or fertilizer application or both of them simultaneously led to decrease in total cost. Also, in some strategies, nitrate leaching increases when water use is reduced that it is due to the reduction of nitrogen uptake by the plant. As a matter of fact, variations in water availability will negatively affect a crop's ability to make effective use of available nitrogen (Conijn and Henstra 2003). Thus in these crops, reduction in water consumption alone cannot be useful to decrease nitrate leaching and have to use reduction in urea fertilizer consumption or mixed strategies. A positive interaction between water and nitrogen management was reported by Aarts et al. (2000). As expected, the simulation results revealed that in general the higher amount of fertilizer and water application, the higher amount of nitrate will be leached.

According to Nie et al. (2008) study, maximum allowable nitrogen loss is 38 kg/ha. Regarding this constraint, among strategies that nitrate leaching is below this threshold, we selected a strategy that has maximum net farm income for each crop. These strategies are reported in Table 6. The effects of strategies in both ecological and economic terms with regard to the quantity of nitrate leaching and net farm income have indicated the tradeoffs.

Since the amount of nitrate leaching for winter barley is less than maximum allowable (less than 38 kg per ha), so it is not require decreasing water or nitrogen fertilizer

Table 6 Optimum strategy regarding to N loss constraint and economic profit

Crop	Strategy	Profit 1000 Rial ha^{-1}	Change profit (%)	N loss Kg N ha^{-1}	Change N loss (%)	Change water applied (%)	Change fertilizer applied (%)
Wheat	S1n1	28,557.64	1.582	37.78	−21.92	−10	−10
Barley	–	–	–	–	–	–	–
Corn	N5	28,424.94	−2.634	32.349	−68.006	0	−50
Rice	S2n3	74,306.46	9.585	24.128	−45.799	−20	−30

consumption. For winter wheat by 10 % reduction in water and fertilizer application, simultaneously, not only net farm income (approximately 1.582 %) will increase, which is beneficial for farmers, but also nitrate leaching will decrease, which is beneficial for the environment. This means that this strategy is in both of ecologically and economically desirable.

In the case of corn, we can reduce nitrate leaching and find maximum net farm income by 50 % reduction in fertilizer application rate. In comparison with the reference scenario, this strategy can reduce the nitrate leaching from 101.11 to 32.349 kg N per ha, while the net farm income simultaneously decreases from 29,193.95 to 28,424.94 thousand Rial per ha. The trade-off between nitrate leaching and net farm income is approximately 11.184 thousand Rial for each unit of nitrate leaching. So this strategy is ecologically desirable but economically unsound.

For rice farms, the best strategy is S2n3 that increase net farm income by 9.585 % and decrease nitrate leaching by 45.799 %. This strategy compared to the current status, in both ecologically and economically, is desirable. In the other words, we can improve farm income by the management of nitrogen and water application.

4 Conclusion

Nitrate pollution continues to influence the environmental, that it is due to increase demand for agricultural products and lack of management of agricultural inputs application (particularly fertilizer and water). Therefore, land use decision makers need information on the possible consequences of agricultural activities on the environment (such as water quality) that can lead to tradeoffs between net farm income and nitrate leaching for sustainable agricultural production. In this study, we investigated impacts of different application levels of irrigation and fertilization inputs on farmers and environmental. Finally, our ecological–economic assessments in a non-point source pollution area of southern Iran (TASHK-BAKHTEGAN basin) comprised several important findings, which are useful for agricultural land use decision making.

The application of different strategies showed clear impacts on the ecological (nitrate leaching) and economic (net farm income) indicators. All considered strategies can reduce the amount of nitrate leaching to water systems, which is beneficial for the environment. However, from an economic perspective, some strategies reduced the net farm income which is not in the interest of farmers. In addition, the combination of adjusted irrigation (irrigation according to crop net irrigation requirement) and reduced nitrogen fertilizer dose are the most appropriate strategies for wheat and rice, because they significantly decrease the nitrate leaching and increase net farm income.

For corn, the highest increase in net farm income was obtained by 50 % reduction in nitrogen fertilizer dose. Also, for barley, the baseline scenario (3800 m^3 ha^{-1} and 250 kg ha^{-1} water and urea fertilizer application) is the best both economically and ecologically, because it has the highest net farm income and allowable nitrogen loss (less than 38 kg per ha).

These findings indicate that without policy interventions, wheat and rice farmers could improve their economic and environmental performance by reducing water, and fertilizer application. This can easily be done if farmers are informed about the ecological and economic effects of these strategies. Also, results showed that except for barley, water and nitrogen fertilizer inputs were used more than plant needs. Thus, we can increase the price of these inputs to manage their application and the environmental damage. This is in agreement with finding from previous studies such as Vagstad et al. (2009), Lam et al. (2011), Nguyen et al. (2014) that surveyed impacts of different BMPs (like fertilization strategies) in the environment. The results of a study such as this can strengthen science-based decision making to guide policy makers in effective water resource and fertilization management and to reduce agricultural pollution.

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