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APPLICATION OF DRAINMOD-N MODEL FOR PREDICTING NITRATE-N IN PADDY RICE FIELDS UNDER CONTROLLED DRAINAGE IN A COSTAL REGION OF IRAN

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ABSTRACT In this study, DRAINMOD-N, a mathematical model for simulation of nitrate-nitrogen (NO3-N) concentration in water outflows (runoff and subsurface drain water) and shallow ground water, has been tested based on the field data collected from paddy rice fields consisting of a controlled drainage (CD) system in north of Iran during 2008 and 2009. The model performance was evaluated first by comparing the observed and simulated water table depth (WTD), that is an essential prerequisite for the model to obtain a proper prediction of NO3-N movement, and then by comparing the observed and simulated NO3-N concentration in shallow groundwater using two statistical indices, lowest root mean square error and the highest correlation coefficient. The lowest root mean square error and the highest correlation coefficient were determined to be 94.4 mm and 0.8 for water table differentiations, and 1.32 (mg/l) and 0.93 for NO3-N concentration, respectively. Therefore, it was found that DRAINMOD-N can be used to simulate soil hydrology and NO3-N concentration in shallow ground water of paddy rice field under controlled drainage CD management practices in north of Iran.

Keywords: Controlled drainage, DRAINMOD-N, Nitrate, Paddy rice.

INTRODUCTION Drained agricultural lands have been recognized as a major source of pollution to both surface and subsurface waters (Randall and Mulla 2001; Stoate et al. 2001; Wang et al. 2006; Salazar et al. 2009). Intensive use of fertilizers and manure to increase food production can enhance the risk of nitrogen (N) contamination of water bodies (Carpenter et al. 1998; Madramootoo et al. 2001; Northcott et al. 2001; Helwig et al. 2002). NO3-N loss to shallow groundwater and surface waters from irrigated and heavily fertilized paddy rice fields in northern Iran, is one of the major environmental concerns, requiring proper water and fertilizer management to improve water quality. Nitrates are water soluble and susceptible to transport via leaching and deep percolation into ground water, which usually increases the concentration of NO_3-N above acceptable water standards. NO_3-N concentration as high as 18-30 mg/l have been observed in the groundwater in North of Iran that received water from agricultural fields (WRPRI, 2001).

Many field studies have been conducted to demonstrate the effect of overusing of fertilizers, irrigation water application and water table management on N pollution in drain waters and ground waters (Singh et al. 2000; Madramootoo et al. 2001; Singh et al. 2001; Cho et al. 2008). However, field experiments are usually site-specific, too expensive, and time consuming. Therefore mathematical models can be used to estimate N in surface and subsurface flows for different environmental conditions and farming practices (Ng et al. 2000; Zhao et al. 2000). Currently, several computer simulation models are available that can simulate the water flow processes and chemical transport through subsurface drained lands. The field hydrological model, DRAINMOD (Skaggs 1978), has been used successfully to simulate surface and subsurface drainage discharges and water table fluctuations for a wide range of soils, crops, weather conditions, and water management practices. Breve et al. (1997a, b) developed DRAINMOD-N, a companion model to DRAINMOD, which simulates nitrogen movement in artificially drained agricultural soils. Drainmod-N simulates NO_3-N leaching, nitrogen transformation, nitrogen uptake, and mineralization in the soil profiles (Zhao et al. 2000). The accumulated amount of NO_3-N in drain outflows and shallow groundwater can be estimated by the model; so that, it can evaluate the effects of irrigation water application, fertilizer use and water table management on N losses from drained cropland. Zhao et al. (2000) applied DRAINMOD-N for simulating nitrogen losses in drainage water in a well-drained clay loam soil in Minnesota. Singh et al. (2001) also successfully simulated nitrate losses using the model for a poorly drained soil in Central Illinois. In the paddy rice fields, it is necessary to look for a model that can accurately simulate NO_3-N movement in shallow groundwater. To the best of our knowledge, DRAINMOD5.1 has not been previously used for simulating the fate and transport of NO_3-N in paddy rice fields. The primary objective of this study was to evaluate DRAINMOD-N for simulating NO_3-N movement in shallow groundwater in paddy rice fields under controlled drainage CD system. The field measurements for the model evaluation were carried out in northern Iran during 2008 and 2009

MATERIALS AND METHODS

Site description and experiment procedure. This study was carried out in Mazandran Province on a site located at the Technology and Development Center of Haraz in Amol in the northern part of Iran. The experimental site is located at 52 º 17´ E longitude and 36º 68´ N latitude with an altitude of 5.5 m. Mazandaran has occupied an important place in agriculture and paddy rice is one of the principal food crops of Iran. The site is characterized by a semi-Mediterranean climate throughout the year. The mean annual maximum and minimum temperatures are 32.7 ^{o}C and 7.8 ^{o}C, respectively. The mean annual rainfall is 882.6 mm of which about 63% occurs from September to December. The period from June to August is relatively dry and hot with small amounts of rain. On average, irrigation water of 900-950 mm is applied to paddy rice fields through 16 irrigation events during the growing season. This irrigation schedule is adopted to keep the rice field under standing water with a depth of 40-50 mm throughout the crop growth period. However, the surface ponding is kept to a minimum at the time of application of basal dose of nitrogen and nearing harvesting date. The experimental field has eight plots contain Subsurface drains. Subsurface drains are corrugated PVC pipes, 100 mm in diameter, with rice husk envelope that have been installed at 0.8 m depth and 10 m spacing. The drain outlet for each subsurface drained plot has a weir for controlling WTD. The weir is operated two times through the growing season. The first operation is done at the middle of growing season to lower water table in order to enhance root growth and the second operation is done for dewatering the soil at the end of season for vehicles entrance to the field for harvesting the crops. The field measurements were carried out in two CD plots (1.1 ha each) during 2008 and 2009. Experimental plots were isolated by buffer plots to prevent lateral water movement between the plots. The cultivated crop in the field was rice in both years. Nitrogen fertilizer was applied twice each year. At planting, the plots were fertilized with ammonium nitrate at a conventional rate of 100 kg-N ha^{-1}. A second dose of N fertilizer was applied approximately 30 days after planting at a rate of 45 kg ha-1. In this study, only the plots receiving the inorganic fertilizer were used to evaluate the model. The soil texture of the experimental field is silty clay and the average values of soil properties are shown in Table 1 and Fig. 1.

Table 1. Average values of soil parameters of the experimental site

Soil properties [a]	Soil depth (mm)		
	0-300	300-600	600-900
Sand (%)	11.7	8.7	9.9
Silt (%)	46.4	47.1	48.1
Clay (%)	41.8	44.2	41.8
Bulk density (g/cm^3)	1.4	1.45	1.45
PH	8.28	8.26	8.26
EC(dS/m)	0.8	0.69	0.64
SSP(%)	66.42	69.95	65.61
NO_3 (mg/l)	7.58	12.2	8.25
$K_{sat\ (m/day)}$	0.48	0.24	0.19

[a] Field data from the experimental site

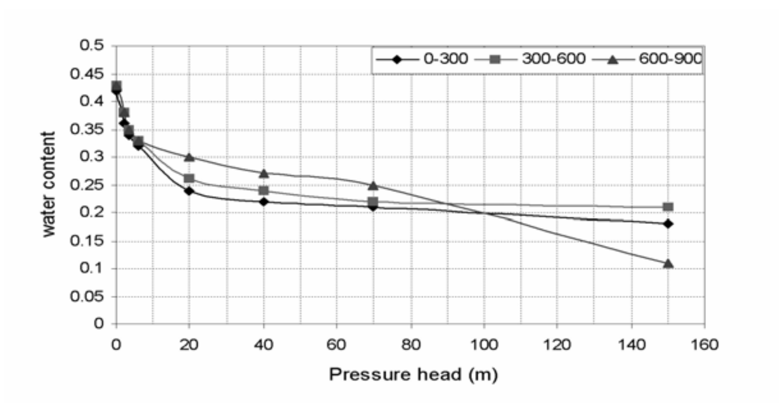

Figure 1. Soil moisture characteristics curve

Undistributed soil cores using steel cylinders (72 mm in diameter, 100 mm in height) were taken at 100 mm depth intervals down to 900 mm, with four replicates at each level. These soil samples were used for determining soil parameters of the experimental site by standard laboratory methods (Andersson 1955). Soil water retention was measured using standard pressure plate method for each horizon of soil. Soil texture was measured using the hydrometery method and saturated hydraulic conductivity K_s was estimated using the auger hole method. The above soil properties were used to generate DRAINMOD's soil inputs. For the two successive years, the WTD and NO_3-N concentration in shallow groundwater was measured during the growing seasons in CD plots. Water table observation wells (perforated, 25-mm in diameter polyethylene pipes with a geotextile sleeve) were installed midway between the subsurface drains to a depth of 1.2 m on the north and south part of each plot. A water sensor was used to monitor the depth of midspan water table for each plot. Water samples for NO_3-N analysis were collected from observation wells on a daily basis after fertilizer application. The samples were stored in refrigerator at 4 ºC and analyzed by spectrophotometer method in the laboratory during two days.

Model inputs In this study, simulations were conducted using data measured from the plots with controlled drainage. DRAINMOD inputs include soil properties, parameters characterizing the crop, drainage system parameters and meteorological data. Nitrogen-related parameters required by DRAINMOD-N include soil, crop management, N transport and transformation and organic matter parameters. Soil inputs were obtained from soil samples taken from experimental site (Table 1). Potential yield and other management and crop production parameters are presented in Table 2.

Table 2. Management and crop production parameters used in DRAINMOD-N

Parameter	Value
Planting date [a]	18 May - 8 June
Number of days from sowing to harvest (day)[a]	100
N-fertilizer input (kg N ha^{-1})[a]	145
Potential yield grain (kg ha^{-1})[a]	7500

[a] Field data from the experimental site

Hydrological parameters The observed daily rainfall values were converted to hourly values using a subroutine in the DRAINMOD5.1 package, assuming that the daily rainfall was uniformly spread over 4 h.

The potential evapotranspiration (PET) was calculated using the FAO Penman-Monteith combination equation (Allen et al., 1998). The infiltration rate was predicted by the DRAINMOD soil preparation program with an approximate equation of Green and Amp (1911). The drain volume and upward flux versus WTD were also estimated by the model, which required inputs of average depth of root zone, depth of each layer, the maximum tension in the root zone when dry and the saturated hydraulic conductivity of each layer. The unsaturated hydraulic conductivity was calculated by the model according to Millington and Quirk (1961) from the soil water retention characteristic and Ks. The drainage parameters were set to be equal to the field trial drainage system design (Table 3).

Table 3. Field trial drainage system design used in DRAINMOD-N

Parameter Drainage system parameters	Value
Drainage system design[a]	controlled
Drainage depth (m)[a]	0.82
Drain spacing (m)[a]	10
Surface storage (m)	0.3
Effective drain radius (mm)[b]	11
Weir depth (m)[a]	0 (first operation) 1.3 (second operation)
Depth to impermeable layer (m)[a]	0.9
Drainage coefficient (mm day^{-1})[b]	3.5

[a] Field data from the experimental site

[b]Estimated according DRAINMOD manual (Skaggs, 1978)

Nitrogen parameters DRAINMOD-N input parameters were obtained from ranges published by Breve et al. (1997b), reported in the literature (Davidson et al. 1978; Johnsson et al. 1987) and field data from the experimental site. A sensitivity analysis performed on DRAINMOD-N by Breve et al. (1997b) showed that NO_3-N loss in the subsurface drains is most sensitive to the rate coefficients for denitrification and mineralization, mildly sensitive to N content in crop, NO_3-N content in rainfall and dispersivity. The rate coefficients for denitrification and mineralization and the value of soil dispersivity were adjusted to improve the agreement between measured and simulated nitrate-N. Main inputs used in the nitrate-N simulations are listed in Table 4.

Table 4. Constant inputs for NO3-N simulation by DRAINMOD-N

Input Parameter	Value
Net mineralization rate (d^{-1})[c]	0.000035
Denitrification rate (d^{-1})[c]	0.4
Dispersivity (cm)[c]	5
NO_3-N concentration of rain (mg l^{-1})[a]	0.8
Tortousity factor[b]	1
Diffusion coefficient[b](cm^2per day)	0.000001
Nitrogen content of plants[a]	1.36%

[a] Field data from the experimental site

[b] Estimated according to DRAINMOD manual (Skaggs, 1978)

[c] Adjusted during model calibration

RESULTS AND DISCUSSION

Hydrological simulation. The simulated and observed WTD were compared during 2008 and 2009. The statistical performance measures for predicting WTD are listed in

Table 5. The statistical comparisons showed good agreement between simulated and measured WTD. The RMSE for 2008 was 94.4 mm, whereas it was 112.3 mm for 2009. Thus the difference between the observed and simulated WTD appeared to be small for both years.

Table 5- Comparison of simulated and observed WTD

Statistical parameter	2008	2009
RMSE(mm)	94.4	112.3
EF	0.53	0.46
r	0.8	0.76

The measured and simulated WTDs during 2008 and 2008 are plotted in Figs. 2 and 3, respectively. The simulated midspan WTDs were generally deeper than the observed values, which could be caused by the assumed deep seepage value of 0.15 mm/h, and also preferred flows through the external side-wall of piezometers which were occurred due to the piezometers installation procedure. Deeper water table simulations were also possible if the actual evapotranspiration rates were lower than the ones calculated with the FAO Penman-Monteith combination equation (Allen et al. 1998). However, this could not be tested because no actual evapotranspiration measurements were made at the site. Although these situations caused some difficulty for DRAINMOD-N to obtain more accurate simulation, reasonably RMSE and r indicated that the model could perform satisfactorily for soil hydrologic simulation, and such a good simulation is essential for proper simulation of nitrate-N losses in shallow groundwater or outflows.

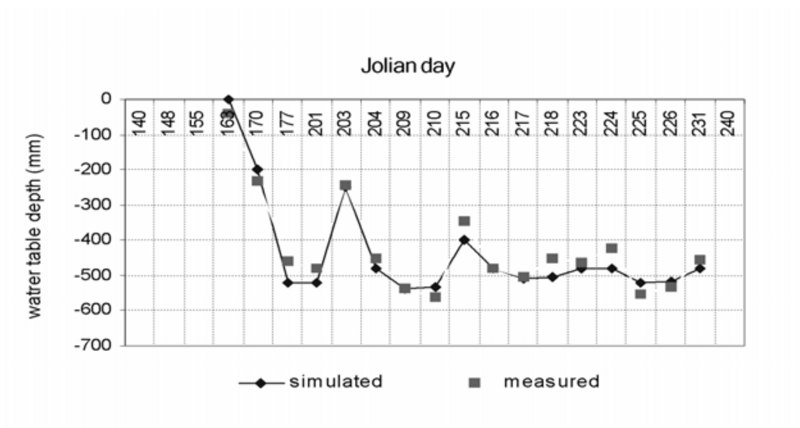

Figure2. Simulated vs. Observed WTD (2008)

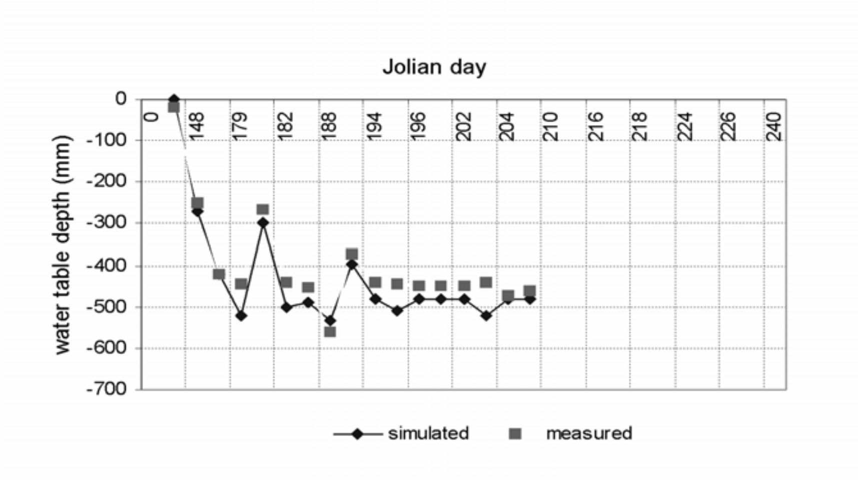

Figure3. Simulated vs. Observed WTD (2009)

Fig. 2 expresses that water table was fairly steady at a depth of 500 mm throughout the growing season in 2008. It also appeared that DRAINMOD-N precisely simulated midspan (WTDs) during 2008. However, in 2009, it tended to overestimate WTD slightly (Fig. 3). Overall, the simulated (WTDs) seemed reasonable for both years. Although the model slightly overestimated (WTDs) during both years, the trend of water table fluctuation was simulated precisely.

Nitrogen simulation A set of N simulations was conducted to calibrate the nitrogen component of the model. The main parameters, denitrification rate, net mineralization rate and dispersivity, were calibrated based on the best agreement between the simulated and observed NO3-N concentrations in shallow ground water on the basis of the statistical parameters. The calibrated values were used as input in the nitrate-N simulations of the experimental controlled drainage plots in both years. The simulated data were compared with the average observed nitrate-N concentration in 2008 and 2009. The statistical analyses for nitrate-N concentration in shallow groundwater under controlled drainage for both years are given in Table 6. High r values, 0.90 and 0.93, showed that DRAINMOD-N could be used successfully in simulating nitrogen-N concentration. The RMSE values, 1.32 and 2.97 mg/l, were relatively low. Therefore the differences between the observed and simulated nitrate-N concentrations in shallow groundwater were found to be small in both years.

Table 6- Comparison of simulated and observed NO_3-N

Statistical parameter	2008	2009
RMSE (mg/l)	1.32	2.97
EF	0.91	0.83
r	0.93	0.9

The results of measured and simulated nitrate.N concentration in shallow ground water in 2008 and 2009 are shown in Figs. 4 and 5 respectively. It appeared from Figs. 4 and 5 that simulation for 2008 and 2009 was satisfactory, and the simulated NO_3-N concentrations were in good agreement with the observed values. The model slightly overestimated the nitrate-N concentration in 2009. In 2008, although the model marginally overestimated, the nitrate-N concentration simulation was better than that in 2009. As described in hydrological simulated results, the measured WTD values were smaller than the simulated values by the model, which caused more saturation condition and denitrification in the soil and therefore lower nitrate-N concentration in shallow groundwater.

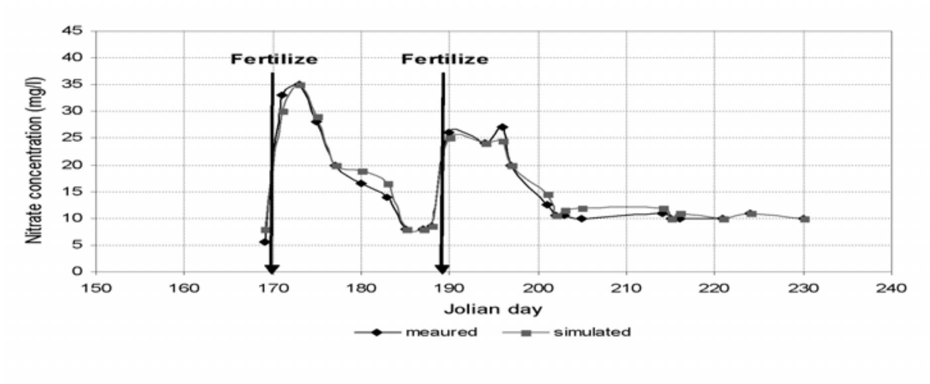

Figure 4. Simulated vs. Observed NO_3-N concentration in shallow ground water (2008)

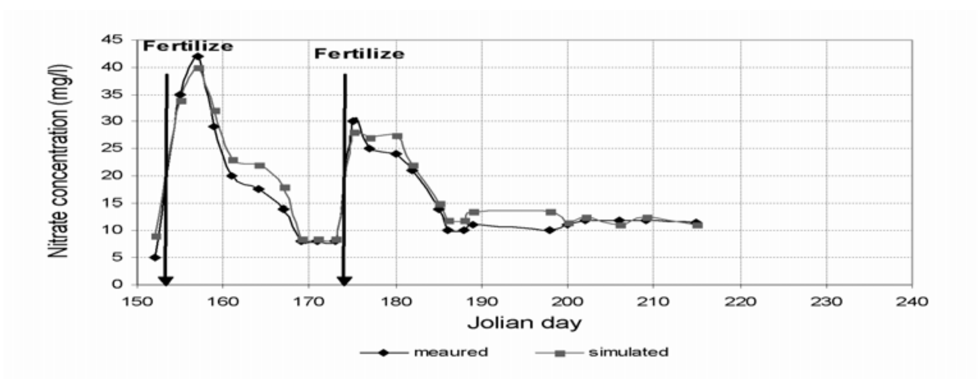

Figure 5. Simulated vs. Observed NO_3-N concentration in shallow ground water (2009)

Although the model slightly overestimated nitrate-N concentration during both years, the variation trend of measured and simulated nitrate-N concentration values was considerably similar. Figs 4 and 5 illustrated that the peak values of measured and simulated nitrate-N concentrations in shallow ground water for both years occurred at the same dates, i.e. 3 days and 1 day after first and second fertilizer application, respectively. While running DRAINMOD-N in the present study, some input parameters which are requisite by the model were not obtainable from direct field measurements in the site. Also at times that the model simulations were not close to the measured values, thus made necessary model calibration. In the present study, the simulated (WTDs) were deeper than the measured values in both years (Figs. 2 and 3); therefore the vertical seepage value at the field site had to be modified. Some parameters for NO_3-N simulations, including the denitrification rate, net mineralization rate and dispersivity cannot be measured easily and thus required some empirical calibration. Calibration and estimation of input parameters in the present study were done on a trial and error basis, because very fewer studies has been reported in similar environment of paddy rice fields yet, especially in north of Iran.

CONCLUSIONS In the present study, DRAINMOD-N has been applied to simulate nitrate-N concentration in shallow groundwater in paddy rice fields under CD system in north of Iran from 2008 to 2009. The RMSE values for predicting WTD were 94.4 mm for 2008 and 112.3 mm for 2009 and the corresponding r values were 0.8 and 0.76, which indicates that the model simulated the soil hydrologic processes satisfactorily. For NO3-N concentration in shallow groundwater, the RMSE values were 1.32 and 2.97 mg/l for 2008 and 2009, respectively. The corresponding r values were 0.93 and 0.9 and the EF values were 0.91 and 0.83. Although the model slightly overestimated NO3-N concentration, the obtained results demonstrate that DRAINMOD-N was able to accurately predict NO3-N concentration in shallow groundwater. Therefore, the model can be applied for simulating NO3-N movement in shallow ground water via CD in paddy rice fields, such as fields in north of Iran, and help in proper management of irrigation and fertilizer which considerably are used on this fields to reduce NO3-N pollution.

REFERENCES

Allen, R.G., Pereira, L.S., Reas, D., Smith, M., 1998. Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements-FAO Irrigation and Drainage Paper 56, FAO Food and Agriculture Organization of the United Nations, Rome, Italy, 293pp.

Andersson, S., 1955. Markfysikaliska undersokningar i odlad jord. VIII. En experimentell method. (Soil physical measurements in arable land. VIII. An experimental method). Grunddforbattringar8, specialnummer 2. (in Swedish).

Breve, M., Skaggs, R..W., Parsons, J. E., Gilliam, J.W., 1997a. DRAINMOD-N, a nitrogen model for artificially drained soils. Trans. ASAE 40(4), 1067-1075.

Breve, M., Skaggs, R..W., Gilliam, J.W., Parsons, J. E., Mohammad, A.T., Chescheir, G.M., Evans, R.O., 1997b. Field evaluation of DRAINMOD-N. Trans. ASAE 40(4), 1077-1085.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., Smith, V.H., 1998. Nonpoint pollution of surface waters with phosphorous and nitrogen. Ecol. Appl. 8(3), 559-568.

Cho, J.Y., Son, J.W., Choi, J.KK., Song, C.H., Chung, B.Y., 2008. Surface and subsurface losses of N and P from salt-affected rice paddy fields of Saemangeum reclaimed land in South Korea. Paddy Water Environment. 6(2), 211-219.

Davidson, J.M., Graetz, D.A., Suresh, P., Rao, C., Selimm, H.M., 1978. Simulation of nitrogen movement, transformations, and uptake in plant root zone. USEPA, EPA-600/3-78-029, Athens, GA.

Helwig, T.G., Madramootoo, C.A., Dodds, G.T., 2002. Modelling nitrate losses in drainage water using DRAINMOD5.0. Agric. Water Manage. 56(2),153-168.

Johnsson, H., Bergstrom, L., Jansson, P.E., 1987. Simulated nitrogen dynamics and losses in a layered agricultural soil. Agric. Environ. 18, 333-356.

Madramootoo, C.A., Helwig, T.G., Dodds, G.T., 2001. Managing water tables to improve drainage water quality in Quebec, Canada. Trans. ASAE 44, 1511-1519.

Ng, H.Y.F., Drury, C.F., Serem, V.K., Ten, C.S., Gaynor, J.D., 2000. Modeling and testing of the effect of tillage, Cropping and water management practices on nitrate leaching in clay loam soil. Agric. Water Manage. 43(1), 111-131.

Northcott, W.J., Cooke, R.A., Walker, S.E., Mitchell, J.K., Hirschi, M.C., 2001. Application of DRAINMOD-N to fields with irregular drainage systems. Trans. ASAE 44(2), 241-249.

Randall, G.W., Mulla, D.J., 2001. Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices. J. Environ. Qual. 30(2), 337-344.

Salazar, O., Westrom, i., Youssef, M. A., Skaggs, R.W., Joel, A., 2009. Evaluation of DRAINMOD-N model for predicting nitrogen losses in loamy sand under cultivation in south-east Sweden. Agric. Water Manage. 96(2), 267-281.

Singh, M., Bhatacharya, A.K., Nair, T.V.R., Singh, A.K., 2001. Ammonium losses through subsurface drainage effluent from rice fields of coastal saline sodic clay soils. Water, Air and Soil Pollution. 127(1-4), 1-14.

Singh, M., 2000. Modelling of salinization and nitrogen losses under subsurface drainage system. Ph.D. thesis (unpublished), Division of Agricultural Engineering, Post Graduate School, Indian Agricultural Research Institute, New Delhi 110012, India.

Skaggs, R.W., 1978. A water management model for shallow water table soils. Technical Report 134. Univ. of North Carolina Water Resources Research Institute, Raleigh, N.C.

Stoate, C., Boatman, N.D., Boralho, R.J., Rio Carvalho, C., Desnoo, G.R., Eden, P., 2001. Ecological impacts of arable intensification in Europe. J. Environ. Manage. 63(4), 337-365.

Wang, S., Prasher, S. O., Patel, R.M., Yang, C. C., Kim, S.H., Madani, A., Macdonald, P. M., Robertson, S. D. 2006. Fate and transport of nitrogen compounds in a cold region soil using DRAINMOD. Computer and Electronics in Agriculture. 53: 113-121.

WRPRI, 2001. General studies of water resource development in Mazandaran. Water Resource Planning Research Institute, Sari, Iran (in Persian).

Zhao, S.L., Huggins, D.R., Moncrief, J.F., 2000. Predicting subsurface drainage, corn yield, and nitrate losses with DRAINMOD-N. J. Environ. Qual. 29(3), 817-825.