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Numerical Modeling of Soil Water Flow and Nitrogen Dynamics in a Tomato Field Irrigated with Municipal Wastewater

Ali Erfani Agah

Abstract

Because of water scarcity, reduction of annual rainfall and the use of wastewater in agriculture, there is a need for research to evaluate the potential impacts of using such sources on hydraulic soil properties and groundwater quality. Nitrate loss from the area under cultivation and regular use of fertilizer and wastewater is a major reason for non-point source contamination on agricultural lands. Numerical model, Hydrus-1D used to simulate soil nitrate in soil cultivated with tomato-crop during the growing period, in North-East Iran. A randomized completely blocked design with five irrigation treatments with different sources of nitrogen was applied. Comparison between simulated and measured soil moisture content shows that the model can follow the temporal variation of soil water content. However, some over estimation of the measured data was observed during the simulation period. To evaluate the Hydrus model performance with respect to nitrogen transport and transformations, the simulated nitrogen concentrations ($\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$) are compared for different treatments at different depths of soil profile, (7.5, 22.5, 37.5, 52.5 and 120 cm from soil surface). It takes about 4 days to convert 90% of urea into ammonium and it takes about 70 days to convert 90% of ammonium into nitrate. However, urea concentrations decreased with time between irrigations as a result of hydrolysis. As expected, at 3.73 days, the urea was concentrated near the surface, immediately after fertigation. Ammonium remained concentrated in the immediate in the top soil at all times for all treatments. There was only slight movement, because of soil adsorption and subsequent fast nitrification and/or root uptake. In contrast to ammonium, nitrate moved continuously downwards during the 28-day simulation period, as nitrate is not adsorbed, whereas denitrification was assumed negligible. Leaching percentages were smaller for nitrate wastewater compared to nitrate- fertilizer, and manure. Base on simulation results treated municipal wastewater by an aerated lagoon can be used as a valuable source of irrigation without causing contamination of groundwater.

Keywords: Irrigation, Wastewater, Tomato, Nitrate leaching, Hydrus-1D

1. Introduction

Irrigation with wastewater is one of the best options to reduce the stress on limited fresh water available today and to meet the nutrient requirement of crops.

There is potential for these nutrients present in recycled water to be used as a fertilizer source when the water is recycled as an irrigation source for agriculture [1]. Nitrogen is a valuable nutrient contained in wastewater [2]. Various studies confirm that municipal wastewater can be useful as an additional water resource for irrigation [3–7]. Some researchers have shown that the best way to use wastewater after treatment is in agriculture [8].

Understanding the behavior of nitrogen in the soil system helps to maximize crop production while reducing the impacts of N fertilization on the environment. Nitrogen applied as fertilizer or wastewater may be: utilized and stored in the plant; stored as organic nitrogen in the soil; volatilized as ammonia, nitrogen gas or nitrous oxide; lost in runoff; or leached to the groundwater as nitrate [9, 10]. The main processes response for nitrogen transport and transformations in the soil are mass transport of inorganic nitrogen forms, commonly described by the general convection–dispersion equations and both chemical and biological reactions [11].

Nitrate is one of the nitrogen compounds most susceptible to leaching. Three kinds of soil transformation of the N contained in wastewater are important. The first of these is mineralization:

Mineralization occurs in soil as microorganisms, both aerobic and anaerobic convert organic nitrogen to inorganic forms. After wastewater application to soil, organic N quickly converts to ammonium nitrogen and then to nitrate nitrogen [12]. The sequel to mineralization is nitrification:

Microbial activity is also responsible for the two steps of nitrification. Nitrosomonas convert ammonium to nitrite. The second step of nitrification occurs through Nitrobacter species, which convert nitrite to nitrate. This step rapidly follows ammonium conversion to nitrite, and consequently, nitrite concentrations are normally low in soils.

Another important nitrogen transformation in soils is denitrification.

Nitrate, which is the end product of the nitrification process in aerobic soils, it can undergo reduction to NO_2 and finally to N_2 when the soil oxygen content is low and decomposable organic materials are present to furnish energy for the process. The sequence of products is:

This process, which is done by a group of bacteria, is called desalination or denitrification. Denitrification occurs under oxygen-limiting conditions when anaerobic bacteria use nitrate in respiration in the presence of carbon sources such as organic matter. NO_2 and N_2 are both gaseous and emitted from the soil. Factors influencing denitrification control include oxygen restriction and the presence of organic matter. In the case of wastewater irrigation, only wastewater with a high BOD can be a source of organic matter for denitrification [12].

The amount of soil nitrogen losses through denitrification depends on the type of soil and irrigation management applied in the field and may vary between zero and 90% of applied nitrogen [12].

Mineralization and nitrification processes convert the organic N and NH_4^+ into NH_4^+ and NO_3^{2-} respectively, which are absorbed and utilized by crops and termed as available nitrogen [13–15]. Nitrate is highly mobile and leachable. It has been established that excessive application of nitrogen leads to nitrate pollution of groundwater and surface water [16, 17]. Leaching of NO_3^{2-} below the root zone can be affected by a range of factors, including fertilizer application rates and the timing of applications [18].

Computer models are tools used in science to approximate natural phenomena. Therefore, models that predict flow and transport processes in soils are increasingly being applied to address practical problems. The use of simulation models allows extrapolation, in time and space, of data from leaching experiments and monitoring studies. More recently, computer simulation tools have been applied to predict the fate and transport of contaminants for risk evaluation [19].

In this study we present results of field experimentation and numerical simulations on a loamy soil cultivated with tomato plants, which were used to evaluate the performance of the different component of water and nitrogen dynamic in the soil. Model parameters were either solely derived from laboratory measurements or optimized by the inverse simulation method. The objective of this study was to determine the difference in concentration of nitrate in soil water below the root zone (about 1.5(m) for plots treated with (1) municipal wastewater (2) manure and (3) commercial chemical fertilizers, using HYDRUS-1D model, [31] at the research station of Mashhad in north-east of Iran. Field data, collected on a loamy soil cultivated with tomato plants, were used to evaluate the performance of the different component of water and nitrogen dynamic in the soil.

2. Material and methods

2.1 Site description and measurements

The weather data (daily maximum and minimum temperature, wind speed, humidity, sunshine hour and rainfall data) was collected from metrological station installed 2006 and 2007 at the Mashhad research station site, (36° 13' latitude, 59°38' longitude) in Northern east Iran. A soil profile pit was excavated to 120 cm depth and soil samples at different soil texture layers were sampled on 20 March 2009 before tomato sowing and basic properties, including soil water retention and saturated hydraulic conductivity were measured. The soil consists of heterogeneous layers with a deep groundwater ground water table (far below 80 m) and is characterized as sandy loam top soil (0–40 cm) over sandy clay loam (40–65) over sandy clay (65–120 cm). From the rooting depth (120 cm) of tomato crop 100 soil samples were collected and analyzed for various physical and chemical parameters before starting the experiment (**Table 1**).

TDR probes and ceramic cup tensiometers were installed at 0–20, 20–40, 40–60 and 60–100 cm soil layers in the investigated area. Water content measurements were taken daily starting in January 2009 and concluded in October 2010. TDR data will be used to assess estimate of shallow soil water content at soil profile. The irrigation scheduling was based on the soil moisture deficit in the root zone at each irrigation event (difference between root zone soil water at field capacity and at irrigation time) with intervals of 10 days. The characteristics of water and wastewater are summarized in **Table 2**. Total irrigation depth during this period was 23.9 cm.

Physical properties of soil			
Parameters	Soil layers, cm		
	0–40	40–65	65–120
Clay %	11.1	19.4	34.9
Silt %	39.4	35.9	23.8
Sand %	50.5	44.7	42.3
Textural class	Sandy loam	sandy clay loam	sandy clay
Bulk density, g/cm ³	1.55	1.43	1.35
FC, (vol. %)	21.34	27.61	28.22
PWP, (vol. %)	7.18	9.87	11.18
Chemical properties of soil			
pH	7.54	7.54	7.54
EC (ds/m)	1.53	1.53	1.50
Organic carbon (%)	1.82	1.79	1.71
Organic matter, g/100 g soil	1.19	0.67	0.63
Total nitrogen, g/100 g soil	0.059	0.060	0.054
Available P (mg/kg)	54.2	54.2	48

Table 1.
Physical and chemical properties of soil at initial condition.

Parameter	Unit	Well Water	Wastewater	Standard value
PH	—	7.9	7.9	6–8.5
EC	dS/m	0.58	1.1	—
Na ⁺	mg/l	63.7	85.8	—
K ⁺	mg/l	2.3	24.6	—
Ca ²⁺	mg/l	24	36.5	—
Mg ²⁺	mg/l	15	18.2	100
NH ₃ -N	mg/l	—	32	—
NO ₃ -N	mg/l	—	0	—
Org – N	mg/l	—	14	—
P	mg/l	0.18	2.8	—
Cl	mg/l	12.4	118	600
SAR	mg/l	2.45	2.87	—
B	mg/l	0.86	0.9	1
Alkanity	—	—	670	—
Hardness	—	—	189	—
Total N of Coliform	—	—	1000	—
BOD ₅	mg/l	—	115	100
COD	mg/l	—	145	200

Table 2.
Physico-chemical characteristics of water and treated wastewater.

The rainfall at the same period was 11.48 cm and reached 42.84 cm for the whole simulation period of one year.

2.2 Experimental design

Plots were irrigated with either well water or wastewater in a random complete block design (RCBD), with four replications according to the following treatments:

T1 - Irrigation by treated wastewater during all growing season, (%100 wastewater).

T2 - Alternate irrigation by treated wastewater and well water.

1. Alternate irrigation of tomato with wastewater and well water during the growing season, (%75 wastewater +%25 well water).

2. Alternate irrigation of tomato with wastewater and well water during the growing season, (%50 wastewater +%50 well water).

3. Alternate irrigation of tomato with wastewater and well water during the growing season, (%25 wastewater +%75 well water).

T3 -Irrigation with well water plus application animal manure.

T4 - Irrigation with well water plus application of fertilizer.

T5 - Irrigation with well water only.

To obtain these ratios were used in the operation of the irrigation turn. (Table 3).

The experiments were carried out on 20 plots, and each experiment included five irrigated furrows 4 m in width and 4.2 m in length (along the crop rows). Each plot consisted of 5 crop rows with a plant row spacing of 75 cm. The plots (T3) were grazing prior sowing with 3000 kg ha⁻¹ or (3 kg m⁻²) animal manure. The chemical analysis of animal manure has been showed in Table 4.

The plots (T4) were fertilized based on soil sample tests with 300 kg ha⁻¹ or (30 gr m⁻²) of triple super phosphate, broadcast at seedbed preparation, and 110 kg ha⁻¹ of net nitrogen or (200 kg ha⁻¹) of urea at tillage time (at two equal section) and 6 weeks after panting. In this study, the total manure was applied prior sowing and

Irrigation turns	Mixing ratios of wastewater				
	1%	2%	3%	4%	5%
	100s	75	50	25	0
First	Wastewater	Well water	Well water	Well water	Well water
Second	Wastewater	Wastewater	Wastewater	Well water	Well water
Third	Wastewater	Wastewater	Well water	Well water	Well water
Fourth	Wastewater	Wastewater	Wastewater	Wastewater	Well water
Fifth	Wastewater	Well water	Well water	Well water	Well water
Sixth	Wastewater	Wastewater	Wastewater	Well water	Well water
Seventh	Wastewater	Wastewater	Well water	Well water	Well water
Eighth	Wastewater	Wastewater	Wastewater	Wastewater	Well water
Ninth	Wastewater	Wastewater	Wastewater	Well water	Well water
Tenth	Wastewater	Well water	Well water	Wastewater	Well water

Table 3.
The proportions of water and wastewater.

pH	EC	N	P	K	OC	C:N	Fe	Mn	Cu	Zn
—	ds/m ⁻¹		%			—		Mgkg ⁻¹		
7.73	13.6	2.4	1.02	0.81	61	25.4	1611	72	4	54

Table 4.
Chemical analyses of animal manure.

for chemical fertilizer, 50% N and total P fertilizers were applied to the sowing seeds. Tomato was seeded on first week of May of each year in the plots at a plant spacing of 75 cm; Weed, diseases and insect control were uniformly managed during the growing season. After planting, irrigation was applied as required with well water until green stage and then treatments and irrigation applied as required during the growing season.

2.3 Model selection: HYDRUS 1D

The HYDRUS-1D software package uses numerical methods to solve the Richards’ equation for saturated–unsaturated water flow and the convection–dispersion equation for solute transport [20]. In this study, we used HYDRUS-1D to analyze water flow and nitrogen transport through tomato field irrigated with wastewater and soil surface management strategies. The measured data used are taken from completed research projects in field study. The data measurements were realized by [3, 21, 22] and were combined with additional measurements. Before simulation, the model was calibrated with field data.

2.4 Boundary conditions

As the all the plots were at field capacity during the transplantation, therefore, the initial condition for volumetric soil water content was between 0.2–0.3 cm³ cm⁻³ for all simulations. The upper boundary soil condition was the atmospheric boundary with a surface layer at which rainfall and evaporation occurred. The upper and lower soil boundary conditions (BC) for solute transport were considered as flux BC and zero concentration gradient.

2.5 Soil hydraulic properties

In this model, soil hydraulic properties, concerning soil moisture retention characteristics, $\theta(h)$, and saturated hydraulic conductivity, K_{sat} , were measured in the field. The parameters of the [23] model were evaluated by fitting on $\theta(h)$ data using the Curve RETC code. The average values of Van Genuchten parameters for study at different soil depths are given in **Table 5**.

2.6 Parameter values

Initial soil water contents for tomato in different soil depths were 0.20–0.30 cm³ cm⁻³ (giving a mean value of 0.27 cm³ cm⁻³). Transport parameters were the model inputs. They were modified to calibrate the model. The modified longitudinal dispersivity and molecular diffusion coefficients of NO₃–N in free water (Do) were used as/set at 1.0 cm and 1.65 cm² d⁻¹), respectively. Urea and NO₃⁻ were assumed to be present only in the dissolved phase (i.e., $K_d = 0$ cm³ g⁻¹) soil. The first-order decay coefficient, μ , for urea, representing hydrolysis, was set at 0.38 day⁻¹. Again, similar values were used in the literature, for example by [24] and

Depth	θ_r	θ_s	a	n	m	K_{sat}
(cm)	($\text{cm}^3 \text{ cm}^{-3}$)	($\text{cm}^3 \text{ cm}^{-3}$)	cm^{-1}	—	—	cm hr^{-1}
25	0.067	0.412	0.0073	1.86	0.414	3.896
60	0.095	0.375	0.0075	1.317	0.5310	2.160
85	0.185	0.421	0.0068	1.657	0.3916	0.131
110	0.048	0.473	0.0298	1.751	0.4259	18.922

Note: Van Genuchten model: $\theta(h) = \theta_r + (\theta_s - \theta_r) / \left[1 + (a|h|)^n \right]^{1/m}$, $m = 1 - 1/n$.
 $K(h) = K_{sat} Se^{1/2} [1 - (1 - Se^{1/m})^m]^2$ with $Se = (\theta - \theta_r) / (\theta_s - \theta_r)$, θ_s and θ_r are saturated and residual water content, respectively, K_{sat} is saturated hydraulic conductivity, a and n empirical parameters.

Table 5.
Parameters of Van Genuchten equation for the soil moisture retention characteristics and the hydraulic conductivity function.

by [25] who all considered hydrolysis to be in the range of 0.36 or 0.38 to 0.56 day⁻¹. Nitrification from NO₄⁺ to NO₃⁻ was modeled using the rate coefficient of 0.2 day⁻¹, which represents the center of the range of values reported in the literature, e.g., 0.2 day⁻¹ ([24, 26], 0.02–0.5 day⁻¹ [27], 0.226–0.432 day⁻¹ [28], 0.15–0.25 day⁻¹ [25], and 0.24–0.72 day⁻¹ [29]. It is further assumed that the maximum rooting depth increases logarithmically with time (increases from 2 cm at germination at 60 cm at harvest), and that there is an exponential root distribution with depth. Uptake of nitrate and ammonium is by passive uptake only. That means that, e.g. NO₃-N uptake at a given time and depth is equal to the water uptake multiply nitrate concentration in neglected. But assume that the maximum allowed concentration for solute is (50 ppm N 550 mgN/L). Assume the soil profile is initially solute free.

2.7 Model testing

The model was evaluated by comparing measured and simulated values over time and depth using both qualitative and quantitative procedures. The qualitative procedures consisted of visually comparison between measured and simulated values over time and depth. For quantitative procedures, statistical analysis were used to calculate the average error (AE), the root mean square error (RMSE), the coefficient of residual mass (CRM), and the modeling efficiency (EF) between the measured and simulated values of water content in the soil during the study period [30–32].

The (AE) is the average difference between the simulated and the measured values. The AE with a positive or negative sign indicates whether the model tends to overestimate or underestimate the measured values. The RMSE statistical index shows the mean difference between simulated and observational data. The RMSE coefficient is equal to the variance of the remaining error and the lower the value, the higher the accuracy of the model. In the Nash-Sutcliffe criterion (EF), the numerical value of one indicates the complete conformity of the simulated and observational data. The CRM also shows the difference between experimental and estimated values. Positive CRM values indicate that the proposed model estimates the values less than its actual value, and vice versa. In the most optimal case, the RMSE and CRM values are equal to zero, in which case the proposed model estimates the values with the highest possible accuracy. Willmott agreement statistical index (d) with a value it is between zero and one that the value of one indicates the best fit. The value of Willmott’s index (*d*) reflects the degree of agreement, and *d* = 1 indicates perfect agreement between the measured and simulated values.

The closer the calculated values are to zero, the better the approximation of the simulated data to the field data [33]. The optimum values of AE, RMSE, EF and

CRM criteria are 0, 0, 1, and 0, respectively. Positive values of CRM indicate that the model underestimates the measurements and negative values for CRM indicate a tendency to overestimate them. If EF is less than zero, the models' predicted values are worse than simply using the observed mean. The average error and root mean square error are calculated as outlined in [33]:

The average error is defined as:

$$\text{Average error (AE)} = \frac{\left(\sum_{i=1}^n S_i - Q_i\right)}{n} \quad (5)$$

The Root Mean Square Error is defined as:

$$\text{Root mean square error (RMSE)} = \sqrt{\frac{\left(\sum_{i=1}^n S_i - Q_i\right)^2}{n}} \quad (6)$$

The Nash-Sutcliffe Efficiency is defined as:

$$EF = \left[1 - \frac{\sum_{i=1}^n (S_i - O_i)^2}{\sum_{i=1}^n (O_i - \bar{O}_i)^2} \right] \quad (7)$$

The coefficient of residual mass (CRM) is defined as:

$$CRM = \left[\frac{\sum_{i=1}^n (Q_i - S_i)}{\sum_{i=1}^n (O_i)} \right] \quad (8)$$

Where n is the number of observations, $\bar{O}_i$ is the average of the observed values and S_i and O_i are the simulated and measured values, respectively [34].

3. Results and discussion

3.1 Water flow simulation

Simulated soil water content in the soil profile are shown in **Figure 1**. However, the results in this section are presented to have an idea about the water regime in the soil profile with respect to the day of planting and harvesting the tomato. There were several rainfall events during the simulation period; however, more rainfall events were registered in the first part of the simulation period. As a result, the soil water content showed at all depths fluctuated more frequently in the first part of the simulation compared to the second and third part.

HYDRUS 1-D was also compared to the water content from field data collected from each treatment (by TDR) and simulated data for the soil profile over the growing season. The following observations are based on visual assessment of model fit compared with observed values of moisture contents of soil. The simulated and measured water contents at 20, 40, 60 and 100 cm are shown in **Figure 2A and B**, **Figure 3C and Figure 4D**, respectively. The predicted water

Figure 1.
 Simulated soil water content at different times of the experiment in the soil profile. With ($T_0=50$ days, $T_1=150$ days, $T_2=200$ days, $T_3=240$ days, $T_4=300$ days and $T_5=339$ days)..

contents at 20 cm depth agree well with the measured values during growing season. The simulation closely match the measured moisture dynamics, except in the (wet) spring and winter of 2010 when the model at times underestimates the soil water content in the top soil. The simulated water contents did not agree well with the measured data at 40, 60 and 100 cm depths, the response of the model was lower than measured, especially deeper in the soil profile. At all depths, a close agreement between the measured and simulated data was registered during (wet) winter period. The difference between simulated and measured water contents varied with depth from -0.045 to $0.152 \text{ cm}^3 \text{ cm}^{-3}$. For the deeper positions (40, 60 and 100 cm), the model systematically underestimates the measured water content by 0.04 to $0.110 \text{ cm}^3/\text{cm}^3$ over the entire growing season at deeper depths, potentially due to under-estimation in the amount of free drainage and an over-estimation of the soil porosity, although the dynamics (water depletion in summer, replenishment in winter) is well simulated. Given that the underestimation is not just limited to the growing season, but is also evident in winter periods when there is little evapotranspiration and the entire soil profile is draining suggests that the problem is not with the crop parameters or evapotranspiration, but rather with the soil hydraulic properties of the deeper soil horizons: the parameters of the van Genuchten-Mualem $K-h-\theta$ relationship control the equilibrium water contents in winter ('field capacity').

The statistical criteria of quantitative model evaluation between simulated and measured soil water content are summarized in **Table 6**. Overall, the values calculated demonstrate a good correlation of the model to field data. The results of the simulations may be affected by the value of the saturated hydraulic conductivity (K_s). Therefore, optimizing this parameter for all the three layers using inverse modeling of the Hydrus-1D, would slightly improve the simulation results. So the predicted water contents at -40 , -60 and -100 cm are indeed much closer to the measured value, and this parameter change does not affect the (good) match observed for -20 cm. For further improvement, other hydraulic parameters (e.g. θ_s and α) also should be optimized. In addition, changing the matric pressure head may lead to good results.

Figure 2. Daily rainfall (solid bars, A) [cm], and measured (circles) and simulated (lines) soil water contents at 20 cm (A), 40 cm (B), 60 cm (C) and 100 cm (D) depths.

Figure 3. Variation of concentration Urea, Ammonium and Nitrate in different observational nodes of experiment in the soil profile. With (N1=20cm , N2=40cm, N3=60cm, N4=100cm and N5=120cm).

Figure 4.
Variation of concentration urea, ammonium and Nitrate with depths for different times and depths of experiment for different treatment. With (T₀=50 days, T₁=150 days, T₂=200 days, T₃= 240 days , T₄=300 days and T₅=339 days).

3.2 Fate of nitrogen sources

We determined the effects of different sources of nitrogen on the soil distribution of urea, ammonium, and nitrate during of growing season tomato field.

Depth		Statistical criteria			
(cm)	n	AE (cm ³ cm ⁻³)	RMSE (%)	EF	CRM
20	365	-0.078	0.115	0.953	0.277
40	365	-0.094	0.115	0.958	0.303
60	365	-0.085	0.106	0.964	0.274
100	365	-0.032	0.058	0.989	0.098

Note: n = number of measurements, AE = average error, RMSE = relative root mean square error, EF = modeling efficient and CRM= coefficient of residual mass.

Table 6.
Statistical criteria for the simulated and measured soil water content.

N balance components Applied – Inflow kg N ha ⁻¹	Losses – Outflow kg N ha ⁻¹			Corn grain yield kg ha ⁻¹
	Crop uptake		Leaching	
N applied by wastewater	Ammonium-N	Nitrate-N	Nitrate-N	
T1 = 100	5.3	47	-	82510
T2 = 75	5.2	47		81830
T2 = 50	4.1	39		7812
T2 = 25	1.7	23		63253
T3 = N-manure =100	4.2	43	21	78956
T4 = N-fertilizer =90	5.8	44	25	77582
T4 = split application	4.9	43	23	78962
T5 = well water = 0	—	—	—	51254

Table 7.
Components of nitrogen balance at the end of simulation period in kg N ha⁻¹ for a soil depth of 150 cm.

To evaluate the Hydrus model performance with respect to nitrogen transport and transformations, the simulated nitrogen concentrations (NH₄-N and NO₃-N) are compared for different treatments at different depths of soil profile, (7.5, 22.5, 37.5, 52.5 and 120 cm from soil surface). **Figure 3 (A–C)** gives the daily variations in the simulated Urea-N, NH₄-N and NO₃-N concentrations respectively. It takes about 4 days to convert 90% of urea into ammonium and it takes about 70 days to convert 90% of ammonium into nitrate. Urea fertilizer is easily dissolved in water and transferred to the soil. After fertilization, urea is hydrolysed in the soil a urea concentration decreased over time between irrigations and ammonium is formed and then, during the nitrification process by bacteria in the soil, convert ammonium to nitrite and then to nitrate. Immediately after fertigation, at 3.73 days, the urea was concentrated near the soil surface.

For all treatments ammonium accumulated in the topsoil immediately (**Figure 4**). Because of soil adsorption and subsequent fast nitrification and/or root uptake, there was only a slight movement of ammonium in the soil profile. The results obtained in this study indicated that nitrate moved continuously downwards during the 28-day of growing season simulation. Also, nitrate is easily exposed to leaching due to its high mobility and is not adsorbed to the soil, therefore denitrification was assumed negligible.

Nitrogen is applied to the soil solution by fertilizer application, treated wastewater irrigation and animal manure.

Ammonium is usually ionically exchanged and stabilized in the surface of clay minerals. It is found in small amounts in soil solution and can be retained by the negative charges of clay mineral particles and organic particles. Therefore, the mobility of ammonium ions is lower than that of nitrate ions. The $\text{NH}_4\text{-N}$ then transformed to nitrate by the nitrification process, which is the most soluble form of nitrogen in the soil for uptake by crops.

Table 7 shows the different components of nitrogen balance during the simulation period. Slightly smaller leaching percentages were computed for the urea–ammonium–nitrate wastewater compared to the nitrate- fertilizer and manure. Fertilizer use efficiency ranged from 54% (treatment T4) to 84.9% (treatment T1). The results reported from nitrogen balance components show that nitrate leaching losses (0%, 23% and 25%) in treatments T1, T3, T4 respectively, and mainly occurred during the winter period. The reduced level of leaching is explained by low amount of drainage water, low nitrogen concentration of irrigation wastewater and excessive nitrogen uptake by the crop. Since the nitrate transport through the soil profile and out into field drains or deep groundwater, is usually controlled by water movement. The effect of irrigating different on the grain yield of tomato was also significant ($P < 5\%$) (**Table 7**). The results showed an increase in the mean of fresh and dry forage yield (8.25% fresh forage and 23.14% of dry forage) (**Table 7**). Because treated wastewater is an important source of plant nutrients and can be reused for irrigation to increase forage crop production.

4. Conclusions

The HYDRUS-1D software was performed to simulated water flow and nitrogen transport in tomato crop soil for wastewater irrigation and fertilization. Based on the study carried out in the field, the ability of the model to predict the moisture in the soil at various depths is accurate. This can be due to an acceptable method in the simulation model.

The results reported from nitrogen balance components show that nitrate leaching losses (0%, 23% and 25%) in treatments T1, T3, T4 respectively and mainly occurred during the winter period. The reduced level of leaching is explained by low amount of drainage water, and excessive nitrogen uptake by the crop. Since the nitrate transport through the soil profile and out into field drains or deep groundwater, is usually controlled by water movement. It was found that the slightly smaller leaching percentages for the urea–ammonium–nitrate wastewater compared to the nitrate- fertilizer and manure. Fertilizer use efficiency ranged from 54% (treatment T4) to 84.9% (treatment T1). Based on these results we conclude that nitrogen from wastewater has smaller nitrate leaching compared to nitrogen from animal manure and commonly fertilizer. Nevertheless, our simulation results provide guidance on the appropriate fertigation strategy for use of waste water in irrigation.

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