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Simulation of No_3-N Concentration under Different Irrigation and Fertilization Regimes: The Definition of a New Scenario

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ABSTRACT

The relationship between the accumulation of nitrate in the soil and its concentration in groundwater and in various plant systems is still not fully understood, but it indicates a high correlation between nitrate leaching and environmental and managerial factors. In this study, nitrate uptake by sugarcanes was simulated by the NLEAP model for different months during the simulation period and a new fertilization scenario was defined. According to the statistical analysis, the NLEAP model provided us with a good estimation in simulations and simulated nitrate volatilization and leaching more accurately. Also, it was revealed that N uptake rate was the highest in the scenario I1N3 due to lower water and higher N and that it was the lowest in the scenario I3N1 due to higher water and lower N.

1. Introduction

The development of agricultural management practices that can reduce the environmental impacts of agricultural production has been concerned by researchers for many years. Today, sustainable agriculture is a vital global concept. Despite sporadic famines in some parts of the world, food supply has already met the needs of the growing population of the world. This success has been partially made possible through the cultivation of new lands. But since the 1950s, the increases in the production of food products have been mainly brought about by the improved production per unit area of agricultural land, partly due to the use of chemical fertilizers. Among the various elements needed by the plants, nitrogen (N) is essential for all plant's living processes. The application of N fertilizer usually enhances plant growth rapidly and clearly, and N fertilization is necessary to increase agricultural return.

N is an essential element for plants and plays a very important role in plant nutrition. Due to the fact that this element is highly absorbed by the plants from the soil, the supply of sufficient available N in the soil is the key for optimal growth (Yasrebi *et al*., 2003).

Simulating models generally consider several components and parameters and simulate the continuous and successive changes of factors resulting from their interactions on a daily or hourly basis (Sackgez, 1999). Modern drainage models are in fact simulating models, and advanced models, in general, address the issue of water level management too. Below is a brief review of some relevant numerical studies.

Roy (2001) used the NLEAP model on corn and tomato fields. After calibration and the use of various management practices, integrated water and fertilizer management in the form of the application of highly efficient irrigation systems, fertilization scheduling and rating, and rainfall forecast was suggested as the best management practice for the control and reduction of nitrate leaching towards ground water tables along with crop maximization.

In a study on citrus, Alva (2006) concluded that about 15 percent of nitrate was transferred to the area under the root zone and that the LEACHM model's estimation of nitrate leaching was very close to the real value.

Tarkalson (2006) assumed 75% of irrigation requirement and full irrigation of corn and showed that the reduction of nitrate leaching under low-irrigation regime depended on soil moisture under the root zone, and this nitrate reduction was found to be significant.

Bahmani *et al*. (2009) examined the rate of nitrate and ammonium accumulation in soil profile under different irrigation and fertilization regimes using the LEACHM model and found that the result of comparing the simulation values of these factors in the soil profile with data derived from the farm was acceptable.

In an in-vitro trial, Nabipour *et al*. (2011) used greenhouse conditions to add various fertilizer treatments including urea, cow manure and urban sewage sludge to the soil column. Then, they measured the post-leaching concentration of nitrates. Their results showed that nitrate concentration was significantly higher in the first irrigation than in next irrigation periods.

Seifi (2013) explored the impact of leaching and nitrate translocation in soil on sugarcanes using the NLEAP model.

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He compared the results of the NLEAP model with those of the LEACHM model. It was reported that the NLEAP model underestimated the concentration of nitrate in most depths and N treatments as compared to the LEACHM model.

A new computer model called NLEAP (Nitrate Leaching and Economic Analysis Package) was developed to implement theories, methods and equations (Follett et al., 1991) that relate to NO3-N leaching (Shaffer *et al*., 1991). Assessment of NLEAP under many climatic, soil, crop and management conditions is needed to test and improve its usefulness. Other assessments of NLEAP, in addition to that reported here, include for data collected in Ohio and lowa (Shaffer, 1990), Minnesota (Khahural and Robert, 1991), Colorado (Shaffer *et al*., 1991) and north Dakota (Follet *et al*., 1994). Such assessments allow model develops to test the model under a range of field conditions, while allowing users to evaluate different management strategies quickly and cheaply. Data sets from experimental plots can provide necessary information to perform such tests while also representing major agricultural areas. (Follet *et al*., 1994).

The present research explores the feasibility of the application of the NLEAP model for simulating nitrate concentration (NO_3-N) under different moisture and fertilizer scenarios in sugarcane farms of Khuzestan Province, Iran. The NLEAP model will be a useful tool for irrigation and fertilization management in the farms if it can accurately simulate the parameters.

2. Materials and Methods

The field trial was carried out in ARC2-14 farm of sugarcane research farms in Amirkabir Agro-Industrial Co. as one of the subsidiaries of Sugarcane Development Plan in 2006-2007 (Bahmani, 1999). To evaluate the NLEAP model, the measured nitrate concentration of the soil profile was compared with the value predicted over the research period and their conformity was statistically examined.

2.1. NLEAP Model

The old version of the software package that was DOS-based was first introduced under the name of *Nitrate Leaching and Economical Analysis* by Schepers *et al*. (1991) from Colorado University. Then, it was revised by Delgado and colleagues in 1998. We used this model to simulate nitrate concentration in soil and define a new fertilization scenario.

2.2. Nitrate-N Available Leaching (NAL)

A mass-balance approach is used by the NLEAP model to calculated kg/ha of No_3-N available for leaching from the crop-root zone, where NAL is calculated as:

$$\mathrm{NAL} = \mathrm{N_{in}} - \mathrm{N_{out}} \quad (1)$$

N_{in} includes inputs of No_3-N from all source, including nitrification of soil NH4-N, fertilizer-N, N in precipitation and irrigation water, biologically fixed N, added N from organic waste and minor inorganic sources. N_{out} includes outputs of all types, including No_3-N uptake by the crop, inorganic No_3-N that is lost with water runoff and soil erosion, No_3-N losses by denitrification and other N losses (Pierde *et al*., 1991; Shaffer *et al*., 1991).

2.3. Nitrification

In the nitrification process, NH4+ by a specific group of oxidized soil bacteria and is converted into equations (2, 3):

$$2NH_2{}^+ + 3O_2 = 2NO_2{}^- + 2HNO_2{}^- + 2H^+ \quad (2)$$

$$2NO_2{}^- + O_2 = 2NO_3{}^- \quad (3)$$

2.4. Urea Fertilizer

Urea fertilizer is the most commonly used fertilizer in agriculture and has 45% nitrogen.

Urea is derived from equation (4):

$$CO(2H_2O)_2 + \text{Urea Enzyme} \rightarrow (NH_{4)} \rightarrow 2NH_3 + CO_2 + H_2O \quad (4)$$

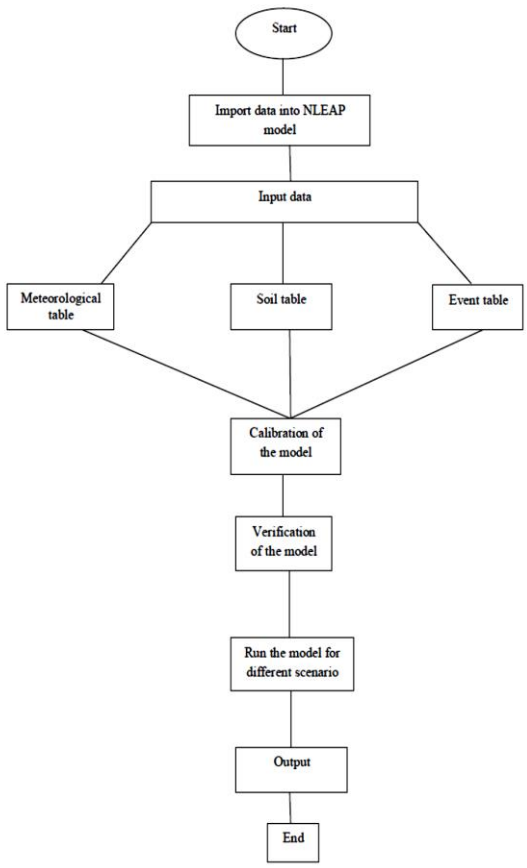

Figure 2. Flowchart of the NLEAP model

When these triple files (Figure 1) of the NLEAP model are specified directly, NLEAP GIS 4.2 can be run which can be reviewed in MS-Excel worksheets under the title of SOIL.SYM-MONTH.

2.5. NLEAP model inputs

There is a database file in MS-Access that includes the following three tables:

1. Meteorology
2. Management codes
3. Soil layer

The data for rainfall were derived from the Meteorological Station of Amirkabir Agro-Industrial Co. for 2007 and the potential evapotranspiration was calculated by evaporation pan using the meteorological data of this station. Then, they were directly entered into the model. Data for soil were selected for three depths of 30-60, 60-90 and 90-120 cm. First, the soil was hammered and screened. Then, its constituents were determined in percentage and were described (Bahmani, 2009).

The first irrigation treatment considered full irrigation. Treatment II applied 85% of treatment I, and treatment III applied 75% of full irrigation. Then, the irrigation dates were added to the table of events.

Urea fertilizer was applied at two steps (May 21 and June 23) at the rates of 50 and 100 kg ha^{-1} in Scenario I, 100 and 150 kg ha^{-1} in Scenario II, and 150 and 200 kg ha^{-1} in Scenario III, respectively.

After all data were entered and the model was run, the values were analyzed in several ways. The outputs included N outputs and water outputs. All outputs of the model that were tabulated in SOLISYMMONTH table have been depicted as graphs.

A study in 2004 in Sugarcane Research Center on nitrate leaching rate in ARC2 farms of Amirkabir Agro-Industrial Co. revealed that 336 kg ha^{-1} nitrate had been added in March-August of 2004 and over the same period, 45.1 kg ha^{-1} nitrate had exited by drainage, showing over 13% nitrate leaching (Bahmani, 2009).

3. Results and Discussion

The input data of the treatments were individually introduced to the model and the values simulated by the model were compared with the field measurements. First, the model was validated by changing the coefficients of denitrification, mineralization and nitrification in the ranges proposed by researchers for the treatment N1 and from the soil surface to the depth of 120 cm. Then, the validated model was validated, evaluated and compared with similar irrigation and fertilization scenarios for this farm.

3.1. Plant Uptake

Figure 3-5 show the values of nitrate uptake by sugarcanes simulated for different months of the simulation period by the NLEAP model.

In the treatment I1, N uptake is expected to be higher due to higher available N in soil.

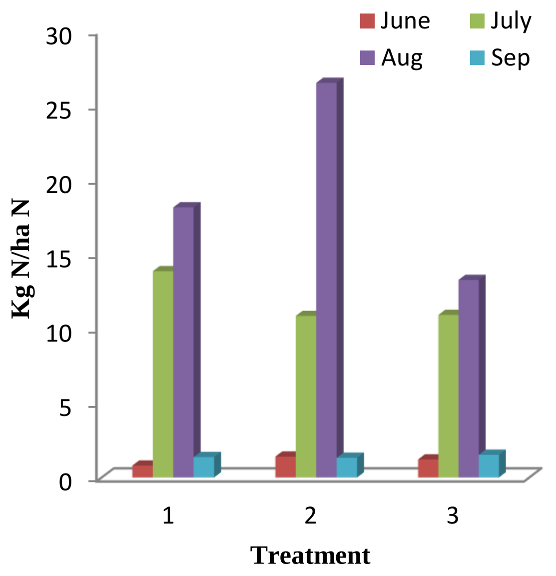

Figure 3. Nitrate uptake rate simulated by NLEAP in the treatment I1

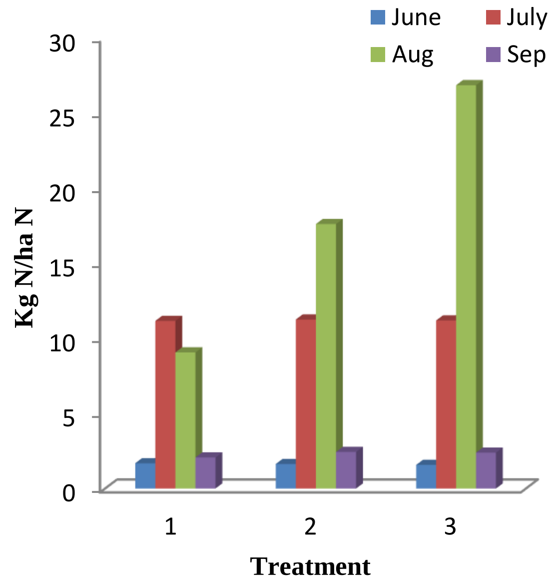

Figure 4. Nitrate uptake rate simulated by NLEAP for the treatment I_2

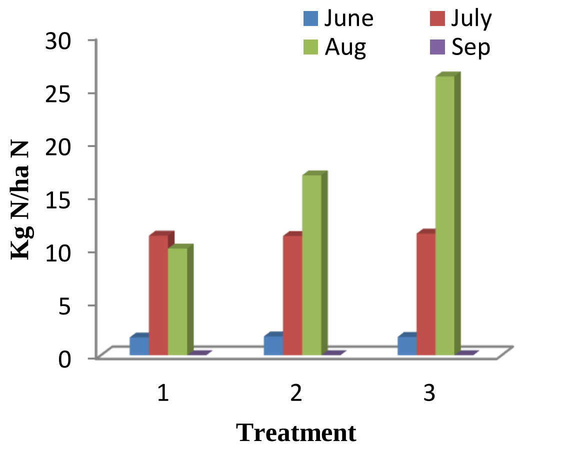

Figure 5. Nitrate uptake rate simulated by NLEPA for the treatment I_3

N uptake was lower in the treatment I_3 than in I_2 due to nitrate leaching and its exit from root zone by full irrigation.

It is evident that over time as root system extends in soil and evolves and as nitrification proceeds to convert ammonium into nitrate, nitrate uptake by plants follows an ascending trend during the growth period so that the highest uptake rate occurs in July-August.

The comparison of different treatments reveals that the rate of N uptake by plants is dependent on soil moisture content. In the treatment I_1, N uptake is expected to be higher due to higher available N in soil, but lower available moisture suppressed N uptake in this treatment, resulting in its only small difference with that of the treatment I_2.

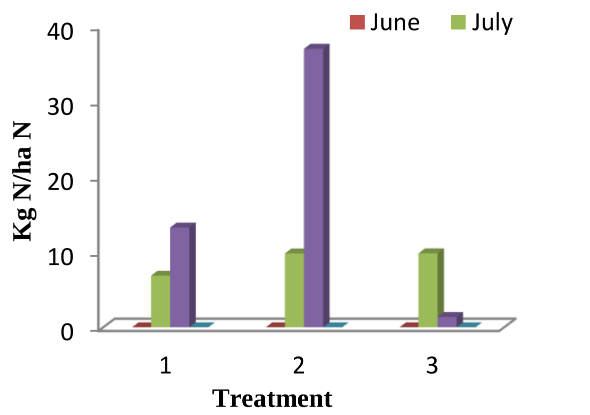

Figure 6. Nitrate leaching rate simulated by NlEPA model in growth months for the treatment I_1

3.2. Leaching Losses

NLEPA model in this research calibrate the Nitrate data in the soil. Due to the model is calibrated, the Nitrate amount is predicted with acceptable accuracy, therefore, from estimated Nitrate leaching losses rate by this model, during the growing months after fertilization, from June to September, Nitrate leaching was used in different treatments and the results are shown in following figures.

In treatment I_1, leaching rate for fertilizer application from N_1 to N_3 increases ascending.

In treatment I_2, leaching rate for fertilizer application from N_1 to N_3 increases ascending and the highest level of leaching related to scenario I1N3 in August. Also, the least amount of leaching is related to scenario I2N1.

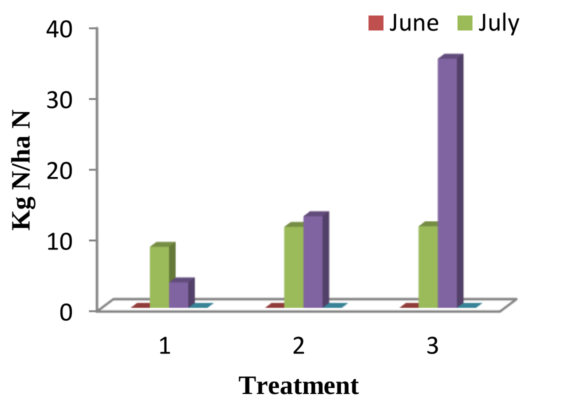

Figure 7. Nitrate leaching rate simulated by NlEPA model in growth months for the treatment I_2

In treatment I3, as both I1 and I2 treatments, the leaching rate increased from N1 to N3. In August, scenario I3N3 has the highest values and the least is also the I3N1 scenario.

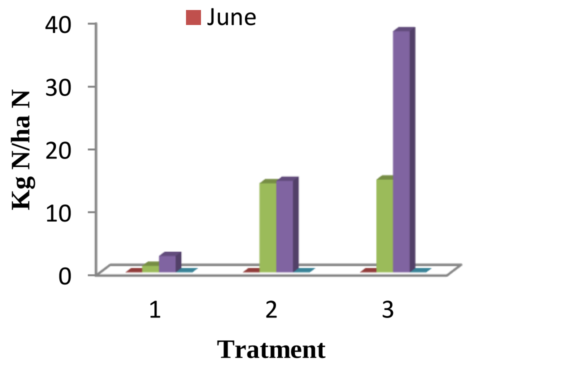

Figure 8. Nitrate leaching rate simulated by NlEPA model in growth months for the treatment I_3

As seen in the above figures, in all treatments, nitrate leaching increase until August and most nitrate leaching occurred this month then, it decreased in September. Comparison of different treatment indicates that the application water level is reduced and nitrate leaching rate from the root zone is significantly reduced and, due to increased fertilization level, the leaching rate has increased.

Application rates for urea (150 Kg/ha, 250 Kg/ha and 350 Kg/ha) were presented for each irrigation treatment (completed treatment, 85% complete treatment and 70% complete treatment). The X-axis represented the different months of June, July, August and September and the Y-axis shows nitrate leaching from the root zone in Kg/ha.

Comparison three treatments I_1, I_2 and I_3, is inferred that the leaching rate for fertilizer application from N_1 to N_3 is increasing each month. The highest leaching rate is predicted in the I3N3 scenario and the lowest in I1N1 scenario.

3.3. N Uptake, Nitrate Leaching and Volatilization

The statistical analysis indicated good simulated estimations by the model, but its estimations were more accurate for nitrate volatilization and leaching. According to AE index, the model underestimated all the values.

Table1. Comparison of observed values and the simulated values for whole soil and among the treatments

	RMSE	R^2	AE
N uptake	72	0.67	-7.1
Nitrate leaching	16.7	0.87	-7.9
Volatilization	11.5	0.88	-3.9

3.3.1. Simulation of Nitrate Concentration in Soil by Defining a New Fertilization Scenario Using the NLEAP Model

Results for the simulation of nitrate concentrations at different soil depths and various irrigation and fertilization rates by the NLEAP model indicate the good accuracy of the model in predicting the rate of this ion in soil. Thus, the model was used to simulate nitrate concentrations from soil surface to the depth of 120 cm at 30 cm intervals by defining a new fertilization scenario (F) in which 450 kg ha^{-1} urea was applied and irrigation was carried out at three levels.

The simulation of nitrate concentrations at different soil depths for the case of applying 450 kg ha^{-1} urea exhibited a trend similar to its variations in the treatments mentioned in previous section. So, we ignored its repetition. An overall comparison indicates that when 450 kg ha^{-1} urea is applied, higher amounts of nitrate accumulate at all soil depths as compared to lower rates of urea.

In a study on the effect of phreatic zone control on the flow rate and N and P outflow from underground drains in arid regions and sugarcane farms of Shoeybah region of Khuzestan, Sadeghi Lari (2012) reported that total nitrate loss by drainage water was 179.35 kg ha^{-1} under free draining, full irrigation and the application of 450 kg ha^{-1} urea and that total ammonia N loss was 57.78 kg ha^{-1} through outflow of drainage, whereas the nitrate leaching rate simulated by the NLEAP model for the treatment I_3N_3 was estimated at about 450 kg ha^{-1}. The comparison of the nitrate rate shows that the application of 450 kg ha^{-1} urea increased the nitrate loss through drainage significantly.

3.3.2. Leaching Wastage in New Scenario F (450 kg ha^{-1} urea)

As can be seen in Figure 6, this scenario experienced rising rate of nitrate leaching up to July-August during which it reached its peak. Then, it started to decline in August-September. The comparison of the treatments I_1, I_2 and I_3 indicated that as more water was applied, more nitrate was leached from the root zone. In this case too, the highest leaching was related to July-August in the scenario I_3F.

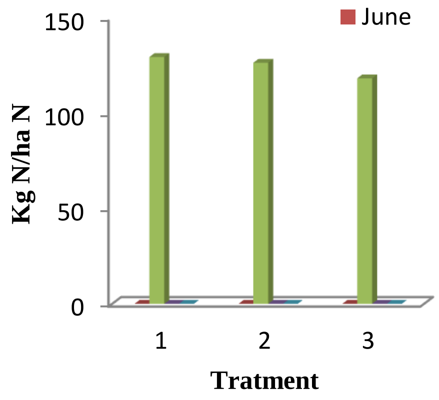

Figure9. Nitrate concentration simulation as per the application of 450 kg ha^{-1} urea

3.3.3. Denitrification Wastage in New Scenario (450 kg ha^{-1} urea)

Figure 10 shows volatilization loss simulated by the NLEAP model for the treatment F during simulation period over May-September. As can be observed, N volatilization due to denitrification showed an increasing rate over time, culminating in July-August.

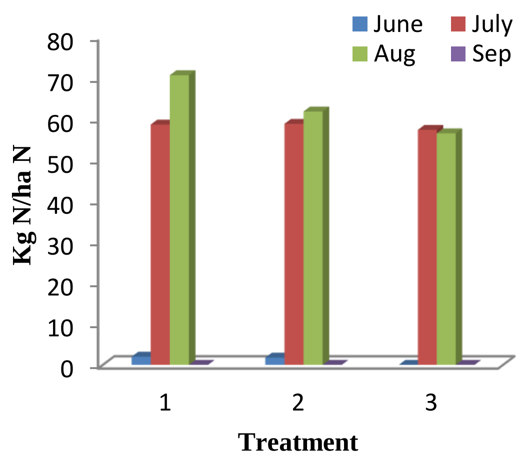

Figure10. Nitrate leaching simulation as per the application of 450 kg ha^{-1} urea

3.3.4. N Uptake by Plants in New Scenario (450 kg ha^{-1} urea)

Figure 11 depicts the simulated values of N uptake by sugarcanes over May-September using the NLEAP model to define the new scenario F.

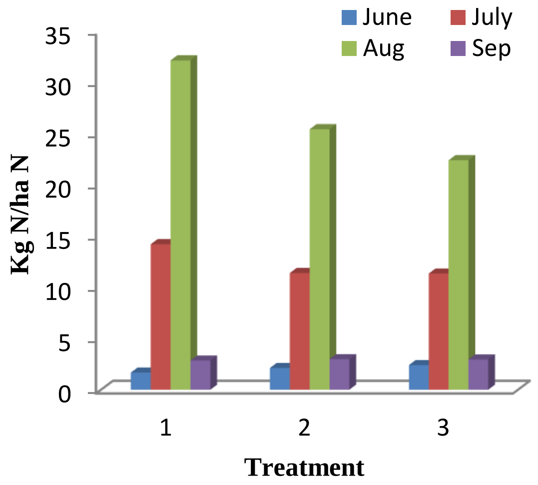

Figure 11. Nitrate volatilization simulation as per the application of 450 kg ha^{-1} urea

It is evident that as root system developed and evolved in soil and denitrification happened, nitrate uptake by plants followed an ascending trend, culminating in July-August. According to the comparison, N uptake by plants depends on soil moisture content. More N was available to plants in the treatment I_1 than in the treatments I_2 and I_3 due to lower water content and so, lower leaching. Thus, the treatment I_1 showed higher N uptake rate. Similarly, N uptake was higher in the treatment I_2 than in the treatment I_3 owing to its lower relative moisture content.

N uptake rate was the highest in the scenario I_1N_3 which can be related to its lower water and higher N. Likewise, it was the lowest in the scenario I_3N_1 due to higher water and lower N.

3.4. Offers

Considering that the use of mathematical software has been recently increasing in the study of water, soil and plant relationships, therefore, it is suggested that in a country like Iran which is faced with a scarcity of information and research costs, use software that accepts available parameters as input.

4. Conclusions

This research addressed the simulation of NO_3-N concentration at various irrigation and fertilization levels in order to define new scenarios. It was revealed that the highest and lowest leaching was predicted for the treatments I_3N_3 and I_1N_1, respectively, implying that this parameter is a function of soil moisture content and fertilization rate. The highest denitrification waste was predicted for the treatment I_1N_3 and the lowest one for the treatment I_3N_1. This means that this parameter depends on soil moisture content and fertilizer rate, too. The highest and lowest N uptake rates were observed in the treatments I_2N_3 and I_3N_3, respectively. It means that this parameter was also a function of soil moisture content and fertilization rate.

Results of this study show that the NLEAP model is adaptable to data collected for non-irrigated and irrigation conditions on sandy soil for a wide range of Urea fertilizer rates. Also, use of the NLEAP model can help evaluate possible climatic and management on N leaching.

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