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SIMULATION OF NITROGEN BALANCE UNDER SUB-SURFACE DRAINAGE CONDITIONS AT THEHRI MUKTSAR PUNJAB, USING THE DNDC MODEL V. 9.5

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ABSTRACT

Aim of the study
The aim of the study is DNDC model simulation for nitrogen balance in rice-wheat cropping system.

Material and methods
The DeNitrification-DeComposition (DNDC) model is a computer simulation model for the biogeochemistry of carbon and nitrogen in agro ecosystems that takes a process-oriented approach. The DNDC model version 9.5 (http:// www.dndc.sr.unh.edu) was selected for estimating nitrogen balance. The model consists of two modules. The first component simulates moisture, soil temperature, pH, and substrate concentration, which are determined by ecological parameters such as soil, climate, anthropogenic activities, and vegetation. It consists of sub-models for plant growth, decomposition, and soil climate. The second module predicts the emission of gasses from plant-soil systems such as methane (CH_4), nitrous oxide (N_2O), nitrogen oxide (NO), dinitrogen (N_2), ammonia (NH_3), and carbon dioxide (CO_2). The model includes empirical equations developed from laboratory studies and is based on the classical laws of chemistry, physics, and biology. The empirical equations included parameterizing specific biochemical or geochemical reactions. The entire model bridges the primary ecological drivers with the biogeochemical cycles of C and N (see: Figures 1 and 2).

Results and conclusions
This study used the DNDC model to estimate nitrogen balance in the studied area. A calibrated and validated DNDC model was used to simulate NO_3-N loss in runoff and leachate from rice–wheat cropping system between 2018 and 2020. The total nitrogen balance in the study area, estimated using the DNDC model, was negative (–99.44 kg N ha^{-1} yr^{-1}) and positive (69.1 kg N ha^{-1} yr^{-1}) for rice and wheat cropping systems, respectively.

Keywords: nitrogen balance, rice-wheat system, DNDC model, subsurface drainage system

ABBREVIATIONS

DNDC	Denitrification and Decomposition
APSIM	Agricultural Production Systems Simulator
DRAINMOD	Drainage model
ADAPT	Crop model
N_2	Nitrogen
NO_3	Nitrate
N_2O	Nitrous oxide
ECe	Electrical Conductivity
CH_4	Methane
NH_3	Ammonia

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CO_2	Carbon Dioxide
RMSE	Root Mean Square Error
NSE	Nash Sutcliffe Model Efficiency

INTRODUCTION

The large spatial and temporal variability of nitrogen processes makes quantifying soil nitrogen and its losses difficult. Close interactions between runoff and soil N status increase the complexity of quantifying N processes and losses. Using computer simulation models is an effective tool or alternative to measuring or estimating water and N fluxes because these models can simulate complex interactions, processes, and variables that are difficult to calculate at the agroecosystem level. These models are important research tools for understanding the relationships between the various components of water and nitrogen cycles, their interactions, and studying the agronomic and ecological impacts of crop management. Pathak et al. (2006) used the DeNitrification- DeComposition model (DNDC) to simulate nitrogen dynamics and balance in rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) cropping systems in the Indo-Gangetic Plains with different nitrogen and water management practices. There was good agreement between the observed and the simulated parameters. In rice–wheat systems, the current annual N inputs from fertilizer, manure, biological fixation, atmospheric deposition, and irrigation were 98, 37, 17, 8, and 7 kg N ha^{-1}, respectively, while the outputs from uptake, volatilization, leaching, and denitrification were 175, 14, 12, and 4 kg N ha^{-1}, respectively. Vogeler et al. (2013) used two process-based models, the Agricultural Production Systems Simulator (APSIM) and DeNitrification DeComposition (DNDC), to simulate nitrification, denitrification, and nitrous oxide (N_2O) emissions from soils following N inputs from fertilizer or excreta. The effects of environmental conditions on N transformations simulated by the two models were compared. The results showed that temperature had a greater effect on nitrification in APSIM. At the same time, water content produced a stronger response in DNDC. Li et al. (2014) applied the DeNitrification–DeComposition model or DNDC to quantify nitrate leaching in an intensively farmed region in northern China. The regional simulation results showed that the total potential nitrate leaching from the simulated 16.31 million ha of cropland (sown area) ranged from 1.5 to 2.15 Tg N per year, with an average of 1.8 Tg N, which was 26.1% the total N fertilizer applied in the region in 2009. The modeled results showed clear spatial patterns of nitrate leaching rates in the region due to spatially differentiated fertilizer application rates and soil water regimes.

Nitrate losses from subsurface drainage are not significantly affected by changes in tile spacing when the amount of nitrogen applied is reduced. This hypothesis was made in recent modeling studies by Davis et al. (2000) after conducting long-term (80-year) simulations using the ADAPT model and by Zhao et al. (2000) who applied the DRAINMOD-N model to a 24-year period. Further research is needed in order to confirm the effects of agronomic and environmental factors on tile spacing in subsurface drainage systems. (Gilliam et al., 1999) suggested controlled drainage as a management technique to control water elevation within an underground drainage system.

In the Muktsar Thehri region of Punjab, more nitrogen fertilizers than recommended are added to the rice and wheat crops grown there because of the less fertile or saline soils and the underground drainage system. Subsurface drainage technology regenerates moderately to severely saline soils into alluvial and black soil within 2–5 years (5 years in Thehri) with effective pumping and maintenance (Dar et al., 2020). Soil salinity (ECe) decreases from 10–52 to 2–5 dS/m (4–6 dS/m in Thehri) within 2–3 years (Bundela et al., 2016). The installed subsurface drainage system at Thehri will drastically improve soil salinity after a few more years. However, the nitrogen fertilizers of concern, as nitrate, would be discharged from the field, which can then be reused for agricultural purposes due to its low electrical conductivity. The area selected for the study is under the subsurface drainage system, which had been installed by the Punjab Drainage Authority and has been in operation since 2016. Farmers are satisfied with the existing system, but due to excessive use of fertilizers, nitrogen gets leached out as nitrate and carried to the nearby water bodies. Therefore, it was necessary to quantify the amount of nitrogen leached and to estimate the total nitrogen balance through this study, in order to minimize the loss of nitrogen for the benefit of the farmers in the studied area. The following objectives were addressed in studying the nitrogen balance: (1) Assessment of nitrogen inputs from various sources into the study area; (2) Impact of the subsurface drainage system on the nitrogen losses from the study area; and (3) Simulation of nitrogen balance using DNDC model in order to quantify the losses of nitrogen through various outputs.

MATERIALS AND METHODS

Description of the study area

The study area we have chosen is Thehri Muktsar in Punjab, India. The area is equipped with a subsurface drainage system at a depth of 1.98 m and a spacing of 30.48 m between the laterals. Since the area does not have any gravity outlet, a sump of 2.5 m in diameter and 5.5 m in depth was constructed, with a reinforced side and sealed bottom (see: Figure 1). The water thus collected is regularly drained out with the help of a 2.2/3.0 (Kw/HP) pump motor assembly, and the drained water is released into the nearby drainage channel. In order to observe water table fluctuations, a series of observation wells were fitted in the study area. The area is surrounded by residential settlements, roads, and fields – these have salinity and waterlogging problems, yet there is no subsurface drainage system installed; also, the field is located just 2–3 km from the Indira Gandhi Canal (Rajasthan feeder), which is the major cause of waterlogging in the area. The drainage channel is just adjacent to the field, disposing of the drainage water pumped out from the fields, but not properly maintained. There is a problem of excessive water seepage into the field, as well as the water being drained out, possibly re-entering the field, due to its improper maintenance. These factors affect the net drain outflows by the pumps, irrespective of the precipitation and irrigation. The experimentation was started in the year 2018 and lasted until 2020 for paddy-wheat crop rotation. The study was designed in order to quantify the amount of nitrogen losses through various processes and an overall nitrogen balance to be estimated for this area, for the benefit of the farmers, to enable a more efficient use of nitrogen fertilizers in their fields.

Fig. 1. Drainage sump and observation well in the study field (source: Dar et al., 2022, p. 7)

Description of the DNDC Model

The DeNitrification-DeComposition (DNDC) model is a computer simulation model for the biogeochemistry of carbon and nitrogen in agroecosystems that takes a process-oriented approach. The DNDC model version 9.5 (http://www.dndc.sr.unh.edu) was selected for estimating nitrogen balance. The model consists of two modules. The first component simulates moisture, soil temperature, pH, and substrate concentration, which are determined by ecological parameters such as soil, climate, anthropogenic activities, and vegetation. It consists of sub-models for plant growth, decomposition, and soil climate. The second module predicts the emission of gasses from plant-soil systems such as methane (CH4), nitrous oxide (N2O), nitrogen oxide (NO), dinitrogen (N2), ammonia (NH3), and carbon dioxide (CO2). The model includes empirical equations developed from laboratory studies, and is based on the classical laws of chemistry, physics, and biology. The empirical equations included parameterizing the specific biochemical or geochemical reactions. The entire model bridges the primary ecological drivers and the biogeochemical cycles of C and N (see: Figure 2 and 3).

Input parameters to DNDC model

The various parameters required for the proper functioning of the DNDC model are listed in Table 1. The various input parameters include climate parameters, crop yield parameters, soil parameters, and irrigation data.

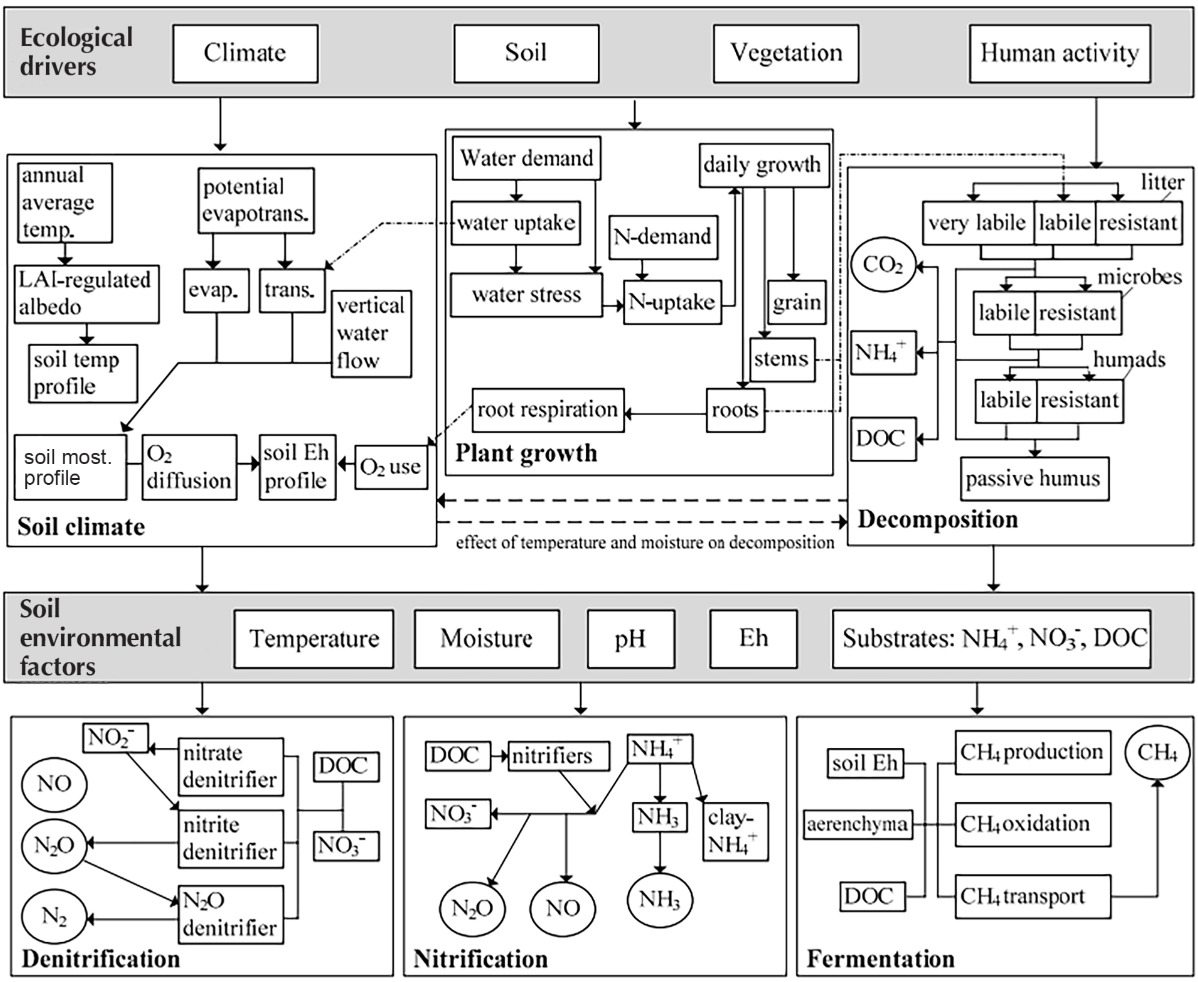

Fig. 2. Structure of the DNDC model (X. Li, 2012)

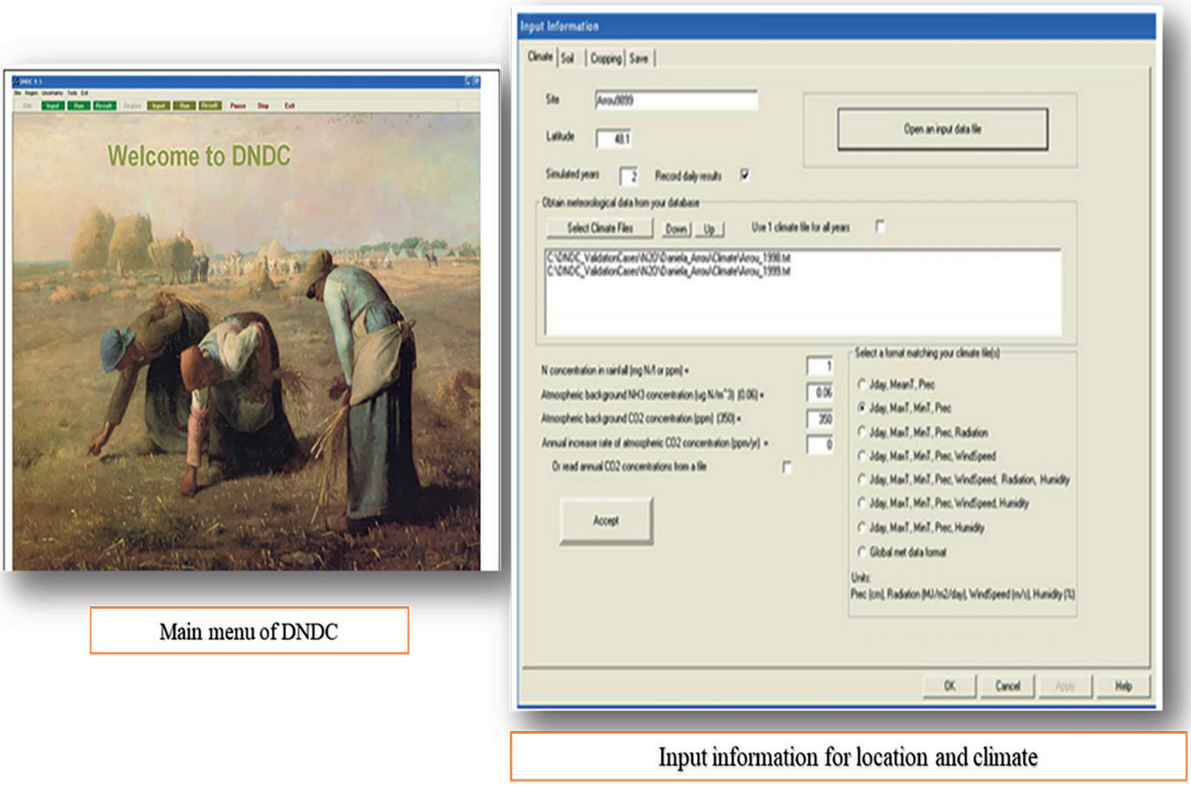

Fig. 3. DNDC model interface (X. Li, 2012)

Table 1. Input parameters for the DNDC model (source: own elaboration)

Input parameter	Value and units	Source
Max potential yield Rice Wheat	 8000 (kg ha^{-1}) 5500 (kg ha^{-1})	 Field observed
Climate data (rainfall, maximum, and minimum temperature)	Daily variations in (cm and °C)	Bathinda weather station
Organic carbon at the surface	0.013 (kg C kg^{-1})	
Initial Amnonical and nitrate N at the surface	0.5, 0.05 (mg N/kg)	Lab experimentation
Microbial index	1	Default
Clay content	0.078	Lab experimentation
Hydraulic conductivity	0.018 (m/h)	Field measurement
Soil pH	8.7	Lab experimentation
Bulk Density	1.796 (g/cm^3)	Lab experimentation
Biomass fraction (grain, leaf, stem, and root) Rice Wheat	 0.41, 0.23, 0.24, 0.12 0.41, 0.21, 0.21, 0.17	Default

Table 1. cont.

Input parameter	Value and units	Source
C/N ratio (grain, leaf, stem, and root) Rice Wheat	45, 85, 85, 85 40, 90, 95, 95	Default
Thermal degree days for maturity Rice Wheat	2000 1300	Default
Tillage (date and depth)	Variable according to crop	Field experimentation (Farmer's field)
Fertilization (date, dose and form of application)	Variable according to crop (mostly urea)	Field experimentation (Farmer's field)
Irrigation (date, depth and method)	Variable according to crop	Field experimentation (Farmer's field)

Sensitivity analysis

The model's sensitivity to variations in source and amount of N fertilizer, N dynamics, and irrigation for yield was analyzed using baseline data for location, soil, variety, weather, and other inputs, for crop years 2018–2020 in Thehri Muktsar (Pathak et al., 2006, Singh et al., 2018). The detailed results of that analysis are presented in Table 2 and Table 3.

Calibration and validation of the DNDC model

The DNDC model was calibrated with the data (weather, soil, management, site, and other data) obtained during the field trials in 2018 and 2019 in Thehri Muktsar. Model parameters were derived from experimental observations and literature; some were retained as default values (see: Table 4). The model's performance was validated using independent data sets of 2019–2020 from the same location, for crop yield and nitrogen uptake, in order to estimate the nitrogen balance for the study area. The detailed results of the process are explained in Table 4.

Performance evaluation measures

The differences between the observed and the predicted state variables and the model's performance can be evaluated by statistical measures. The following statistical measures were applied to ensure the quality and reliability of the DNDC and DRAINMOD-NII model predictions for g and estimation of the nitrogen the balance in the study area.

Root mean square error (RMSE)

The first statistical parameter is the Root Mean Square Error (RMSE) (Hashemi et al., 2020), which is defined as:

$$RMSE = \sqrt{\left(\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)\right)^2} \qquad (1)$$

where P_i is the predicted value, O_i is the observed value; N is the number of cases. The RMSE is an index of actual error produced by the model.

Correlation coefficient

The second statistical parameter is the Coefficient of Determination (R^2) (Shedekar et al., 2021), which varies from 0 to 1 and describes the degree of association between the observed and the predicted values.

$$R^2 = \frac{\left\{\sum_{i=1}^{N}(O_i - O)(P_i - P)\right\}^2}{\sum_{i=1}^{N}(O_i - O)^2 \sum_{i=1}^{N}(P_i - P)^2} \qquad (2)$$

where P and O are the predicted and observed means, respectively.

Model efficiency

The third statistical parameter is the Nash-Sutcliffe coefficient or the model efficiency (ME), described by (Nash and Sutcliffe, 1970).

$$NSE = 1 - \left[\frac{\sum_{i=1}^{i=n} \left(O_i - P_i \right)^2}{\sum_{i=1}^{i-n} \left(O_i - \bar{O} \right)^2} \right] \tag{3}$$

where P_i and O_i are the predicted and observed values, respectively, with Obar as the observed mean**.**

RESULTS AND DISCUSSION

DNDC Model for Nitrogen Balance Estimation and Sensitivity Analysis

The denitrification and decomposition model (DNDC) was evaluated for its ability to simulate nitrogen dynamics and balance in rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) cropping systems in Thehri village of Muktsar, Punjab, between 2018 and 2020. The required input data were generated based on weather, soil, and crop management parameters. The DNDC model predicts C and N biogeochemistry in agricultural ecosystems at the site or regional level. The period simulated by DNDC ranges from one year to centuries, and it is site-specific. The model was tested for sensitivity (see: Table 2 and Table 3) to input parameters of fertilizer and water management practices on crop yield, N uptake, and N losses before being calibrated and validated.

Calibration and validation of the DNDC model

The model's sensitivity was analyzed for the effects of different nitrogen and water management practices on crop yield, nitrogen uptake, and nitrogen losses in rice and wheat cultivation in Thehri village, Muktsar district. Crop yield and N uptake in rice increased with an increase in nitrogen application up to 300 kg ha^{-1} (range 0–350 kg ha^{-1}). However, crop yield and N uptake also increased with an increase in nitrogen application up to 240 kg ha^{-1} (see: Table 2). Nitrogen volatilization, denitrification, and leaching progressed continuously with increasing N fertilization. High soil pH (8.7) and temperature are responsible for this high loss of N through volatilization and denitrification (Pathak et al., 2006, Singh et al., 2018). Nitrogen leaching and denitrification had no effect and remained almost the same for all N application rates. The soil remained flooded, and anaerobic conditions prevailed throughout the rice-cropping period, resulting in lower nitrification rates, as aerobic conditions are required for NO_3 formation. Loss of N by leaching and denitrification was lower during the rice-growing season due to the lower formation of NO_3. Crop yield and N uptake in wheat increased with increasing nitrogen application up to 300 kg ha^{-1} (range 0–350 kg ha^{-1}). However, the higher the nitrogen application was, the smaller the increase (see: Table 3). Nitrogen losses by denitrification remained almost the same with increased nitrogen application. On the other hand, nitrogen losses by leaching and volatilization increased steadily with increased N

Table 2. Sensitivity analysis of the DNDC model with different nitrogen application rates and water regimes for rice crop (source: own elaboration)

Urea N (kg N ha^{-1}) (Input)	Water regime (Input)	Grain yield (kg ha^{-1})	Uptake (kg N ha^{-1}) (Output)	Volatilization (kg N ha^{-1}) (Output)	Denitrification (kg N ha^{-1}) (Output)	Leaching (kg N ha^{-1}) (Output)
0	Continuous Flooding	1558	96.6	15.8	4.4	9.6
50	Continuous Flooding	2204	140.2	19.7	4.8	10.2
120	Continuous Flooding	3293	191.9	32.6	5.3	10.8
180	Continuous Flooding	5225	235.1	46.3	5.6	10.8
240	Continuous Flooding	6724	268.7	70.3	6.4	10.7
280	Continuous Flooding	7043	275.8	95.4	7.4	10.8
300	Continuous Flooding	7043	275.8	106.4	7.7	11.7

application (see: Table 3). In contrast to rice, nitrogen losses due to volatilization and denitrification in wheat were significant at all levels of nitrogen application.

Simulated and observed rice and wheat yields were closely matched and corresponded well during the calibration and validation period (see: Figure 4 and 5). The values of RMSE, NSE, and Coefficient of Determination (R^2) were 8.5, 0.84, and 0.90 for grain yield and 7.5, 0.82, and 0.84 for total N uptake, respectively, during the calibration period (2018–2019) at Thehri village in Muktsar district (see: Table 4 and Table 5). The values of statistical parameters RMSE, NSE, and R^2 were calculated as 6.8, 0.88, and 0.88 for yield and 7.8, 0.78, and 0.85 for N uptake, respectively, during the validation period (2019–2020), indicating that the model successfully simulated the yield and N uptake in the rice crop system in Thehri, with the view to more successful prediction of nitrogen balance parameters (see: Table 5).

Table 3. Sensitivity analysis of the DNDC model with different nitrogen application rates for wheat crop (source: own elaboration)

Cropping season/parameter	Grain	Leaf	Stem	Root	Simulated yield (kg C ha$^{-1)}$	Observed yield (kg C ha^{-1})
Paddy Rice 2018						
Maximum biomass production (kg C ha^{-1} y^{-1}	8000	4487	4682	2341	7468	8000
Biomass fraction	0.41					
Biomass C/N ratio	45	0.23	0.24	0.12		
Thermal degree days	2000	85	85	85		
Water demand (g water/g DM)	508					
Optimum temperature (ºC)	35					
Winter Wheat 2018-2019						
Maximum biomass production (kg C ha^{-1} y^{-1}	5500	2817	2817	2280	5457	5500
Biomass fraction	0.41					
Biomass C/N ratio	40	0.21	0.21	0.17		
Thermal degree days	1300	95	95	95		
Water demand (g water/g DM)	200					
Optimum temperature (ºC)	22					

Table 4. Crop parameters and grain yield for the calibration period (2018–2019) (source: own elaboration)

Urea N (kg N ha^{-1}) (Input)	Grain yield (kg ha^{-1}) (Output)	Uptake (kg N ha^{-1}) (Output)	Volatilization (kg N ha^{-1}) (Output)	Denitrification (kg N ha^{-1}) (Output)	Leaching (kg N ha^{-1}) (Output)
0	4828	25.6	18.9	1.2	25.8
50	4829	25.6	55.7	1.2	38.6
120	4829	25.6	107.8	1.3	56.2
180	4828	25.6	156.0	1.4	68.6
240	4835	25.6	203.8	1.5	81.3
280	4832	25.6	234.4	1.5	90.3
300	4833	25.6	252.6	1.6	92.9

Table 5. Statistical validation of the DNDC model (source: own elaboration)

Statistical Indicator	Calibration (2018–2019)		Validation (2019–2020)	
	Yield	N uptake	Yield	N uptake
Root Mean Square Error (RMSE)	8.5	7.5	6.8	7.8
Nash-Sutcliffe modeling efficiency (NSE)	0.84	0.82	0.88	0.78
Coefficient of determination (R^2)	0.90	0.84	0.88	0.85

Simulation of nitrogen balance using the DNDC model

The nitrogen balance input and output parameters were simulated using the DNDC model. Urea fertilizer was the major nitrogen input for rice and wheat cultivation in the studied area. The application of nitrogen by urea for rice and wheat cultivation ranged from 323.2 to 479.7 kg N ha^{-1}, with an average of 401.4 kg N ha^{-1} (see: Table 6). Average inputs of nitrogen from manure, fertilizer, atmospheric deposition, biological fixation, and irrigation were 287.5, 0, 1.1, 6.9, and 0.6 kg N ha^{-1} for rice cultivation and 337.5, 0, 8.5, 89.6, and 0.3 kg N ha^{-1} for wheat cultivation (see: Table 6), respectively, during the validation period. The simulated total nitrogen output for the rice-wheat cropping system ranged from 410.6 to 422.6 kg N ha^{-1}. Significant outputs included nitrogen uptake by crops, nitrogen volatilization and leaching, with NH_3 volatilization being the major N sink. The rice crop showed higher nitrogen uptake due to higher N use than the wheat crop. Simulated N losses were 103.7 to 283.2, 35 to 100.2, and 1.6 to 8.1 kg N ha^{-1} due to NH_3 volatilization, leaching, and denitrification, respectively, for rice–wheat cropping systems (see: Table 6). Somewhat similar results were reported by Jalota et al. (2013, 2014) and Singh et al. (2018) for Punjab conditions.

Loss of nitrogen by volatilization was greater in both crops because more nitrogen was used as a fertilizer. A greater amount of NO_3-N leaching was simulated for wheat because more nitrogen was available in the soil layers from the previous rice crop, above the drainage system due to better rainfall and drainage conditions. Rainfall during the rice-growing season was 36.41 cm, less than the rainfall during the wheat-growing season (77.72 cm). The average N losses were 29.36 kg N ha^{-1} yr^{-1} and 77 kg N ha^{-1} yr^{-1}, with the highest fertilizer application of 287.5 and 337.5 kg N ha^{-1} for rice and wheat crops, respectively. Nitrogen losses were 10.2% and 22.8% of fertilizer-applied nitrogen for rice and wheat, respectively (see: Table 6). The simulated nitrogen balance was negative for rice and positive for wheat throughout the study period. This could be because more fertilizer was applied during the wheat crop, resulting in low yield. The nitrogen remaining in the soil was responsible for the negative nitrogen balance in the following rice crop. In most long–term rice and wheat trials in the Indo Gangetic Plains (IGP), soil organic matter content decreased over time. Rice and wheat yields decreased accordingly under recommended NPK treatments (Duxbury et al., 2000, Yadav et al., 2000). The average nitrogen loss in the present simulation study was 29.36 kg N ha^{-1} for rice and 77 kg N ha^{-1} for wheat (see: Table 6). Significant differences in N losses were observed between the rice and wheat seasons. The wheat season contributed 69% of N losses due to denitrification and volatilization compared to the rice season. More N was applied in the wheat season, which was 14.8% more than in the rice season (see: Table 6). These results are consistent with the findings of X. Zhao et al. (2009). NH_3 volatilization was the main nitrogen loss pathway in the study area, with 103.7 kg N ha^{-1} for rice cultivation and 283.2 kg N ha^{-1} for wheat cultivation. Due to the flat landscape, high water table, clayey-sandy to loamy parent material of lacustrine deposits and loess

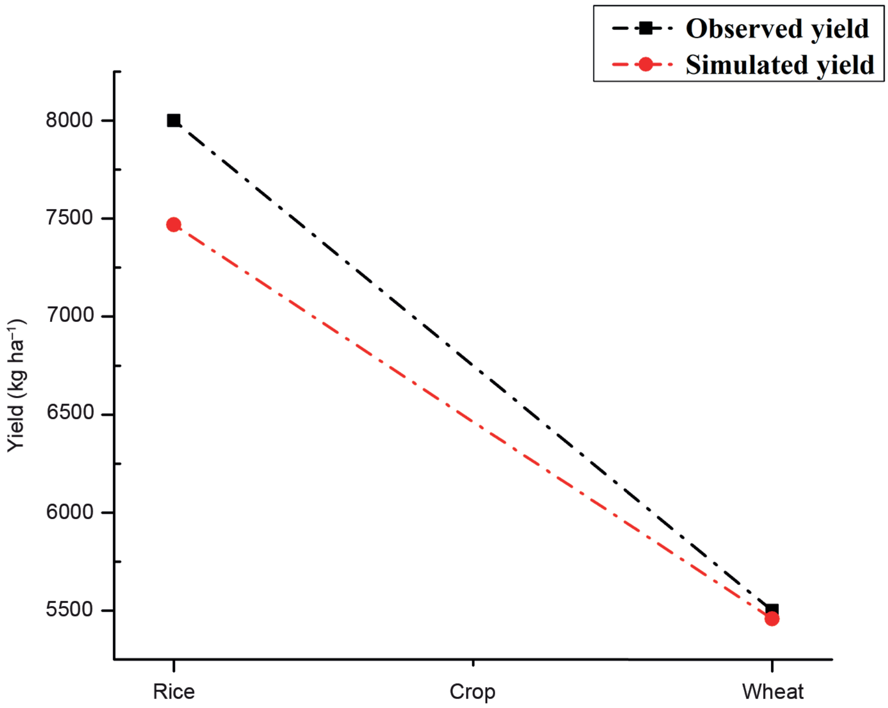

Fig. 4. DNDC calibrated yield in rice and wheat (source: own elaboration)

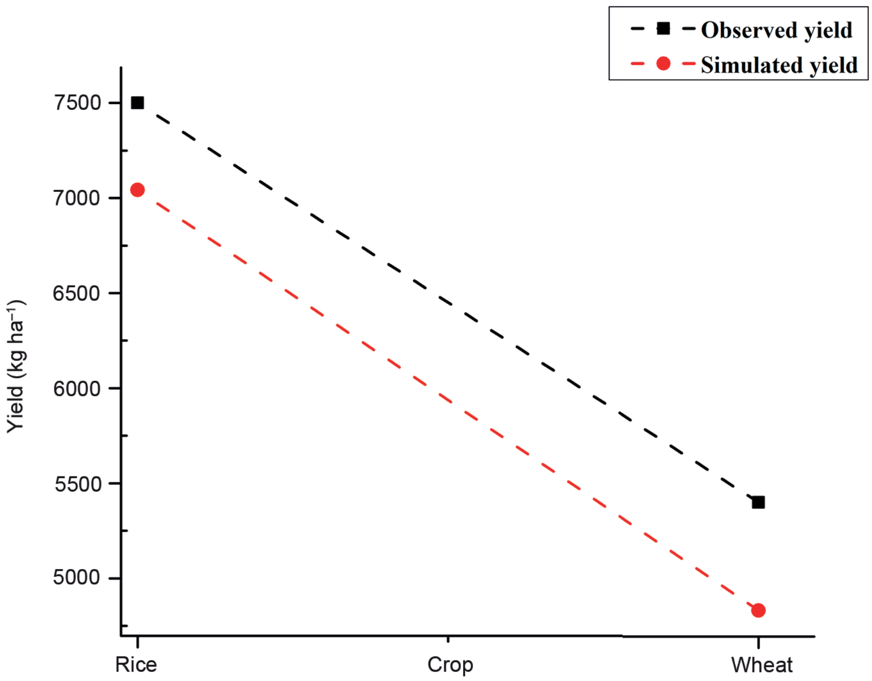

Fig. 5. DNDC validated yield in rice and wheat (source: own elaboration)

Table 6. Simulated annual inputs, outputs, and balances of N in the rice–wheat cropping system in Thehri Muktsar using the current farmers' practices (source: own elaboration)

Nitrogen Balance Parameters	Rice (kg N ha^{-1} yr^{-1})		Wheat (kg N ha^{-1} yr^{-1})	
Inputs	Calibrated (2018–2019)	Validated (2019–2020)	Calibrated (2018–2019)	Validated (2019–2020)
Fertilizer N Input	287.5 (urea)	287.5 (urea)	337.5 (urea)	337.5 (urea)
Manure Nitrogen Input	0	0	0	0
Crop Stub N Input	28	27.1	44.1	43.8
Crop Root N Input	0	0	0	0
Atmospheric N deposition	0.3	1.1	13.4	8.5
Biological N fixation	8	6.9	93.8	89.6
Irrigation N Input	0.5	0.6	0.2	0.3
Total Input	**324.3**	**323.2**	**489**	**479.7**
N uptake by crop	287.5	275.8	26.8	25.6
NH_3 Volatilization	95.5	103.7	267.5	283.2
N Leaching	30	35	95.5	100.2
N Runoff	0	0	0	0
N_2O Flux	1	1.3	1.6	1
NO Flux	0.5	0.9	0.4	0.4
N_2 Flux	6.1	5.9	0.3	0.2
Total Output	**420.6**	**422.6**	**392.1**	**410.6**
Change in Soil Nitrogen Storage (Input-Output = ΔS)	–96.3	–99.44	96.9	69.1

eluvium, as well as the long cultivation history under a unique water regime, rice fields can form a special soil profile with the existence of oxidized and reduced layers in the waterlogged plow layer during the rice season and a subsurface saturated soil layer in both seasons (Zhu et al., 1997, Xing et al., 2002). These unique conditions in flooded rice fields favor significant denitrification losses, 1.6 kg N ha^{-1} for rice in the present study. Due to excessive rainfall and the high availability of C sources to promote microbial activity in rice soil, denitrification loss is also evident during the wheat season: this loss amounted to 8.1 kg N ha^{-1} in the present study. In addition, flooding during the rice season under strong sunlight and high temperatures usually promoted significant NH^3 volatilization (103.7 kg N ha^{-1}) as suggested by Cai et al. (1988). Water management practices with frequent artificial drainage during the rice and wheat rainy seasons inevitably resulted in significant N runoff losses from the rice soil. DNDC model has been mainly developed for simulating GHG emissions from crop fields and has been widely used all over the world (C.S. Li, 2000, Zhao et al., 2020). In our study, the rate of volatilization was comparable with the results found by Liu et al. (2015) and Shang et al. (2014). The model captures all the biogeochemical processes of nitrogen dynamics and satisfactorily describes nitrogen volatilization. Though we lacked measurements of NH_3 volatilization, which was the main source of N loss, our modeled values agreed well with the literature values for equivalent systems. Thus the DNDC model is suitable for exploring N management as put forward by Castillo et al. (2023).

CONCLUSIONS

This study used the DNDC model to estimate nitrogen balance in the study area. A calibrated and validated DNDC model was used to simulate NO_3-N loss in runoff and leachate from rice–wheat cropping system from 2018 to 2020. The total nitrogen balance in the studied area, estimated using the DNDC model was negative (–99.44 kg N ha^{-1} yr^{-1}) and positive (69.1 kg N ha^{-1} yr^{-1}) for rice and wheat cropping systems, respectively. Fertilization and precipitation were the two most important factors affecting NO_3-N loss in rice and wheat crops. The distinct pattern of N balance predicted by the DNDC model suggests that special attention should be paid to rice croplands that are alternately flooded and drained, as this can significantly affect the N balance and its environmental consequences. It is particularly important when exploring strategies for Punjab's agronomic infrastructure and improving N management. Therefore, optimizing N application rates in rice-wheat crop rotations to significant is crucial. To conclude, the DNDC model, which is a biogeochemical model, is a robust tool in simulating the various processes of soil interactions, nitrogen dynamics etc., and it can aid in designing various policies as far as the nutrient management is concerned for different agro ecosystems of Punjab state.

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Declaration of Funding

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Conflicts of Interest

The authors declare no conflict of interest.

Data Availability

The data used to generate the results in this paper will be made available upon request by the reader.

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SYMULACJA BILANSU AZOTU W WARUNKACH DRENAŻU PODPOWIERZCHNIOWEGO W REGIONIE THEHRI MUKTSAR W STANIE PENDŻAB PRZY UŻYCIU MODELU DNDC V. 9.5

ABSTRAKT

Cel badań
Celem badań jest symulacja bilansu azotu w systemie upraw pszenicy i ryżu przy użyciu modelu DNDC.

Materiał i metody
DeNitrification-DeComposition (DNDC) to komputerowy model symulacyjny opisujący biogeochemię węgla i azotu w ekosystemach rolniczych, który przyjmuje podejście zorientowane na proces. Do oszacowania bilansu azotowego wybrano model DNDC w wersji 9.5 (http://www.dndc.sr.unh.edu), składający się z dwóch modułów. Pierwszy moduł generuje symulację wilgotności, temperatury gleby, odczynnika pH i stężenia substratu, które są determinowane przez parametry ekologiczne, takie jak gleba, klimat, działalność antropogeniczna i roślinność. Składa się z podmodułów: wzrostu i rozkładu roślin, klimatu i gleby. Drugi

moduł ekstrapoluje emisje gazów z układów roślinno-glebowych, takich jak metan (CH_4), podtlenek azotu (N_2O), tlenek azotu (NO), diazot (N_2), amoniak (NH_3) i dwutlenek węgla (CO_2). Model zawiera równania empiryczne opracowane na podstawie badań laboratoryjnych i opiera się na klasycznych prawach chemii, fizyki i biologii. Równania empiryczne wykorzystują parametryzację określonych reakcji biochemicznych lub geochemicznych. Cały model łączy podstawowe czynniki ekologiczne z biogeochemicznymi cyklami węgla i azotu (zob. ryc. 1 i 2).

Wyniki i wnioski

W badaniu zastosowano model DNDC do oszacowania bilansu azotowego na wyznaczonym obszarze. Po kalibracji i walidacji model DNDC wykorzystano do symulacji utraty NO_3-N w odpływach i odciekach z systemu uprawy ryżu i pszenicy w latach 2018–2020. Na badanym obszarze całkowity bilans azotu oszacowany za pomocą modelu DNDC był ujemny (–99,44 kg N ha^{-1} rok^{-1}) dla ryżu i dodatni (69,1 kg N ha^{-1} rok^{-1}) dla pszenicy.

Słowa kluczowe: bilans azotowy, system upraw ryżu i pszenicy, model DNDC, system drenażu podpowierzchniowego