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Assessment of DRAINMOD-NII model for prediction of nitrogen losses through subsurface drained sandy clay under cultivation in south west Punjab, India

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ABSTRACT

In the present study, DRAINMOD-NII model was calibrated for the years 2018-2019 and validated for the period 2019-2020 over the two cropping years. The model simulations were statistically evaluated by comparing the measured drain flows and nitrate-nitrogen ($\text{NO}_3\text{-N}$) with the model simulated drain outflows and nitrate loss. The study results depicted closer agreement between the simulated and observed results for both the calibration and validation periods. The Root Mean Square Error (RMSE) of the drainage rate was 8.88 cm more than observed data, 15.41, 0.53 and 0.57 cm were the values recorded for PBIAS, modelling efficiency (NSE) and R^2 . The similar parameter values for nitrogen load were recorded to be 0.14, 2.76, 0.84 and 0.88 respectively during the calibration period for rice wheat system. The model was statistically tested during the validation period also, confirming DRAINMOD-NII has the capability to simulate nitrogen losses from the area subjected to subsurface drainage system

Keywords: Subsurface Drainage, Rice-wheat system, Drainage rate, Nitrogen losses, DRAINMOD-NII

1. Introduction

A major source of surface and groundwater pollution has been attributed to drained agricultural lands (Stoate et al., 2001; Randall and Mulla, 2001). Extensive use of manure and fertilizers to boost the production of food production can increase the risk of nitrogen (N) contamination of surface water and groundwater, promoting eutrophication (Carpenter et al., 1998). Nitrate-nitrogen ($\text{NO}_3\text{-N}$) polluted drainage waters have been described as a key non-point source of surface water contamination (Jacobs and Gilliam, 1985; David et al., 1997). In highly productive agricultural areas with poorly drained soils, seasonal perched water tables, or shallow groundwater, subsurface drainage is the most widely used water management technique. This method of water management boosts crop production, lowers risk, and enhances crop producers' income.

In Punjab, the problem of waterlogging is widespread across all the Muktsar blocks, which is one of the districts of Punjab. In the last three decades, the water table has risen steadily, and coming closer to 1 meter or less from the surface over large areas (Government of Punjab, 2008). The percentage of waterlogged areas increased from 62.54 % of Punjab's total waterlogging area in 1998 to 89.17 % in Muktsar district in 2006. (Singh, 2012). The issue is widespread throughout all blocks of the Muktsar district (Muktsar, Lambi, Gidderbaha and Malout). In several villages, the water level rises nearly to the surface during the rainy season, causing significant harm to standing crops. Water logging and soil salinity are thus an inevitable off-flow of irrigation and have a detrimental effect on the output and productivity of irrigation control areas in the south-west of Punjab, resulting in enormous economic losses. Therefore, serious questions about the long-term viability of irrigated agriculture have been rightly raised, unless the problem of environmental degradation is not properly addressed. Initiation of the water logging problem, its scope and degrees, in this part of Punjab are regulated by several variables. The vast network of unlined canal distribution and their field channels recharge the ground water body due to infiltration from and return of irrigation into the fields accounts for one of the reasons of water logging in Punjab. The two major lined canals, i.e., the Rajasthan feeder and Sirhind feeder running parallel to the east of the district of Muktsar,

although lined cause major damage to the region due to cracks in the lining of their bed and sides, by the inflow of excess water into the area. Water logging is also responsible for the inadequate operation of the current surface drainage system. With the development of canal network, the parallel drains have not been properly built. The maintenance of these drains is of very low standard, except where drains have been properly installed. Owing to low groundwater quality, there is much less withdrawal of underground water for irrigation. The water table rise in this area is also caused by the lateral movement of groundwater flow from South-West to North-Eastern areas, the water table depth contours from North-West Punjab to Bathinda and Malout towns with an average travel rate of about 0.29 kms per year (Uppal and Mangat, 1981). The cropping pattern of the district of Muktsar, commonly known as the cotton belt in the South-West area of Punjab, has also changed. For several reasons, the share of other crops decreased from 40.13 % in 1995-96 to 10.51 % in 2009-10. (Gupta, 2002). Wheat, the main food grain, has always remained very environment friendly. In the district, it has been the major rabi crop. Roughly 44.50 % of the total cropped area in that district was under wheat in 1995-96, which increased marginally to 45.65 % in 2009- 10. (Ladha et al., 2000). Paddy, which was originally grown in the district's waterlogged field, is now the second main crop. It was barely grown in 1995-96 on 1.57% of the area and is now the second dominant crop with 22.27% of the total cropped area recorded in 2009-10. Cotton has always remained the traditional crop of the Muktsar district. The area under cotton that occupied 15.21 % of the gross cropped area increased in 1995-96 to 21.38 % in 2009-10 (Gupta, 2006). However, due to changing climate conditions, and rising water table, the annual variations in the yield and area under various major crops declined. The water table is increasing at an alarming pace in this region of Punjab. In the irrigation control area of this region in Punjab, water logging adversely affects the cropping pattern and crop productivity, resulting in enormous socio-economic losses. Cotton is completely substituted by paddy due to the problem of water logging. Earlier cotton covered 80% of the region's total area, but now it is completely eliminated from the cultivation process, due to its sensitiveness to excess water stress. Due to relative drawbacks, sugarcane, seson and other crops were also eliminated from cultivation. The yields of the most important crops such as wheat and paddy have decreased to almost 50 percent compared to normal soil (Gupta, 2006). This has

raised production costs because more fertilizers, pesticides and insecticides are being used by farmers to improve crop productivity. $\text{NO}_3\text{-N}$ is the common contaminant to the groundwater reservoir, due to excess use of fertilizers, in the region. Waterlogging has led to a significant decrease in net returns from crop production and income from farmers, thereby affecting the well-being of the rural population in this Punjab region. A burning problem in the Punjab economy is debt and suicides, especially among marginal and small farmers, due to low net returns from agriculture. Since 2016, government of Punjab, has initiated many schemes for the reclamation of these areas, mostly affected by waterlogging and excess salinity. Subsurface drainage technology, is one among the initiatives, which has been undertaken to reclaim 12,882 acres of waterlogging affected areas in this district of Punjab. DRAINMOD-NII which is a field scale model, was developed for poorly and artificially drained lands to simulate their hydrology. The calibration area should be of field scale size, with installed subsurface drainage system (SSD), that should reflect field conditions. The calibration area for agricultural fields should usually consist of not less than three lateral drains, developed to continuously measure drain flow rates and water table behaviour in between the laterals (Skaggs et al., 2012). Furthermore, the modeled region should represent normal drainage boundary conditions. The main objective of this study was to evaluate the DRAINMOD-NII model for Punjab conditions, determining the volume of drainage and nitrogen losses from a newly installed subsurface drainage system at Thehri, Muktsar, Punjab, in order to validate its design for better crop conditions and, as a result, minimize nitrogen loss to surface and subsurface waters from these reclaimed areas.

2. Methodology

2.1 Site description

The experimental site was established at Thehri, Muktsar, Punjab, some 35 km from the district headquarters of Bathinda, for DRAINMOD-N II model evaluation (Fig.1). The total cultivated area selected was 4.5 hectares. The study site's soil texture ranges from sandy clay to clay loam and extends up to 2 meters below ground level (bgs). With an EC of more than 7 dS/m and a hydraulic conductivity of 0.43 m/day (1.8 cm/hr), the soil is saline. The groundwater is shallow, with a depth of 60-70 cm bgs on an average. The source of irrigation is canal water, from Indira Gandhi canal located at 2 km from the study

area. The average NO₃-N concentration in irrigation water was recorded to be 3-4 mg/l. The subsurface drainage system was installed in the study area under the Agricultural Credit Association (ACA) (Mihir Shah Project) *Project Division 1, Drainage Gidderbaha, Subsurface Drainage System, Village Thehri, Pocket No.2*. The layout of the experimental field is shown in Fig. 2. The laterals were installed at 1.9 m bgs depth and 30 m bgs spacing throughout the field, having multiple laterals and single collector which is joined to a sump, where the drain water is continuously being pumped out by a 2.2/3.0 (Kw/HP) pump motor assembly (Fig.3). The water table depth was observed through observation wells installed all over the field (Fig.4). The field was cultivated with rice during the summer season of 2018 followed by wheat crop during the winter season of 2018/2019. The same cropping pattern was followed for the year 2019 and 2020 respectively. The agricultural management practices were kept similar during all the growing seasons. The rice seasons were under flood irrigation, whereas the wheat crop was irrigated based on grower's recommendation. The drainage water quality was analysed for nitrate concentration at the outlet, twice in a month, during the whole season. Rice was cultivated in June 2018 and harvested in October 2018, followed by wheat in November and harvesting in April 2019. The similar dates were repeated for the years 2019 and 2020 respectively. "Field preparations were carried out by adding farmyard manure to improve the soil chemical properties. Urea with 46.6% Nitrogen was applied at a rate of 287 kg/ha for rice and 337 kg/ha for wheat during the two growing seasons. During the two seasons other fertilizers like granule sulfur, soft sulfur, super phosphate, Nitrate- nitrogen (33.3%) were also added to increase the crop productivity. The crop residues after rice harvest were incorporated in the soil, before the beginning of the next wheat crop.

Fig.1.Study area location

Fig.2.Installed subsurface drainage system layout at Thehri, Muktsar

Fig.3. Sump well and water being drained out

Fig.4. Observation wells for measuring water table depth

2.2 Simulation procedure

Model simulations were performed, using the data from the study area (Fig.1). Input parameters included soil properties, meteorological parameters, crop characteristics, drainage system design parameters and irrigation (Table 1). Parameters related to Nitrogen, including N transport and transformation, organic matter parameters and crop management were required for DRAINMOD-NII

simulation. Precipitation data was obtained from Bathinda weather station, Punjab Agricultural University. Irrigation was applied to the crops on weekly basis for rice and after a fortnight for wheat crop. Potential evapotranspiration (PET) depends on net radiation, wind velocity and humidity within the region. Daily PET was computed, using Thornthwaite method (1948), in the model using weather data from 2018-2020. Soil samples were collected for various soil parameters and nitrate content from different locations using gps based, sampling points, considering the latitude and longitude of that particular point. The samples were collected from various depths to a maximum depth of 1.8 m, between the laterals. Hydraulic conductivity was measured insitu, during both the rice and wheat seasons, using augur hole method and an average representative value was selected for the whole study area. Soil properties at the study area are listed in Table 2. DRAINMOD-NII simulates cropping systems, comprising more than one crop. The simulation study was based on rice wheat cropping rotation, which takes almost one year to complete. The study was repeated for the two years having rice wheat cropping system. The input data for each crop consist of the major dates of planting, the effective rooting depth, harvesting and stress counting parameters. “Crop parameters included N uptake and yield parameters. Yield parameters of harvest index (HI), root/shoot ratio (RSR), N content of plant grains, roots, shoots and potential crop yield were included in the model. The N uptake during the entire growing season is estimated from yields parameters by DRAINMOD-N II model. The maximum crop yield obtained in absence of soil water related stresses is defined as the potential crop yield by Evans et al. (1991). In DRAINMOD the crop yield was calculated based on the product of potential yield and the DRAINMOD predicted relative yield. The ratio of crop yield to the total above-ground biomass is defined as the Plant HI by Hay (1995). Hoad et al. (2001) described the RSR as the mass ratio between root dry matter and shoot dry matter. The HI and RSR are used by the DRAINMOD-N II model to estimate nongrain above-ground dry matter and below-ground dry matter from DRAINMOD-N II predicted or field-measured crop yields (Youssef et al., 2005). Table 3 shows the possible yields and nitrogen content of rice wheat based on field measurements. Salazar et al. (2009) listed the popular ranges of rice wheat crop N, C, and lignin contents as in Table 3. The N-uptake tabulated feature proposed by Youssef et al. (2003) and Shedekar et al. (2021) was used for crop modeling in addition to the

163 harvest index, root/shoot ratio, shoot N, and root N in rice wheat that were calculated based on observed
164 field data.

165 **Table 1 Parameters for drainage design considered in the model**

Parameters	Value
“Drain depth, (cm)	198.12
Drain spacing, (cm)	3048
Drainage coefficient, (cm/day)	2.35
Impermeable layer depth form surface, (cm)	350
Effective drain radius, (cm)	1.5 (for 4in dia lateral pipe)
Maximum surface storage, Sm (cm)	1.5
Surface micro-storage, SI (cm)	0.75
Initial depth to water table (cm)”	60

166 **Table 2 Soil properties of study area**

Soil Layer	Thickness(cm)	Sand %	Silt %	Clay %	Saturated Water content (cm ³ /cm ³)	$\theta_{0.1 \text{ bar}}$ (cm ³ /cm ³)	$\theta_{0.33 \text{ bar}}$ (cm ³ /cm ³)	Wilting point 015 bar (cm ³ /cm ³)
1	0-15	89.05	3.15	7.8	0.57	0.30	0.26	0.12
2	15-30	83.35	8.45	8.2	0.53	0.23	0.20	0.10
3	30-60	81.15	9.85	9	0.61	0.29	0.20	0.13
4	60-90	79.65	10.35	10	0.61	0.28	0.22	0.12
5	90-120	78.25	13.15	8.6	0.62	0.30	0.26	0.16
6	120-150	80.85	9.75	9.4	0.63	0.32	0.21	0.10
7	150-180	80.25	11.35	8.4	0.68	0.36	0.29	0.12
Bulk Density =1.76 g/cm³, K_{sat}=1.8 cm/hr								

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168 **Table 3 Crop parameters considered in the DRAINMOD-NII model**

Input parameters	<i>Crop</i>	
	<i>Rice</i>	<i>Wheat</i>
<i>Crop data</i>		
Planting data	05-06-2018 (05-06-2019 for the year 2019)	08-11-2018 (08-11-2019 for the year 2019)
Total growing period (days)	129	155
“Input N fertilizer (kg N/ha)	Urea 287.5+Ammonium 62.5	Urea 337.5+Ammonium 62.5
Potential yield (grain/seed) (kg/ha)	8500	6500
Root/Shoot ratio	0.46	0.11
Harvest Index	0.15	0.24
<i>Plant biochemical composition</i>		
Crop Nitrogen (%)	2.29	1.5
Root N (%)	0.91	0.5
Root C (%)	36.5	40
Root lignin (%)	9.5	8.3
Shoot N (%)	1.76	0.5
Shoot C (%)	41.5	40
Shoot lignin (%)”	5.7	3.5

169

170 Denitrification, nitrification, fertilizer dissolution, pH regulation, and volatilization were among the carbon

171 and nitrogen transformation parameters considered in the model simulation. Organic matter parameters

172 define the possible rates of decomposition (Kdec) and C/N ratios organic matter and litter in soils (SOM)

173 pools. The model was initialized with NO₃-N, NH₄-N, and Organic Carbon (OC) concentrations measured

in the region. The model was simulated using the procedure defined by Youssef et al. (2006). The nitrogen initial transport parameters and NH_4 distribution coefficient input parameters for DRAINMOD-NII are shown in Table 4. Table 5 shows the values chosen during model calibration. All of the values mentioned were derived from Salazar et al. (2009) and Shedekar et al. (2021).

Table 4 Nitrogen transport and transformation parameters for the study area

Parameters	Value	
Nitrogen Transport		
“Rain NO ₃ -N concentration	0.32	
Rain NH ₄ -N concentration	0.34	
Air NH ₃ -N concentration	0	
Tortuosity	0.5	
Longitudinal dispersivity, cm	25	
Initial/Boundary Conditions	15cm	180 cm
Initial NO ₃ -N Concentration (mg/L)	4.5	2.5
Initial NH ₄ -N Concentration (mg/L)	3.5	0.5
Nitrification parameters		
Michaelis-Menton rate constant (μg N/g soil-day)	10	
Half-saturation constant (μg/Ng soil)	20	
Optimum temperature (°C)	25	
Coefficient for Empirical shape	0.5	
Denitrification parameters		
Michaelis-Menton rate constant (μg N/g soil-day)	0.6	
Half-saturation constant (mg/L)	25	
Optimum temperature (°C)	30	
Coefficient for Empirical shape	0.29	

Urea Hydrolysis	
Michaelis-Menton rate constant ($\mu\text{g N/g soil-day}$)	50
Half-saturation constant ($\mu\text{g/L}$)	50
Optimum temperature ($^{\circ}\text{C}$)	51.6
Other processes	
Fertilizer dissolution - zero-order rate coefficient (d^{-1})	1
Soil water threshold content (cm^3/cm^3)	0.16
Soil pH at threshold	7.5
Maximum soil buffering capacity	100000
Empirical resistance factor (s/cm)	50

179

180 **Table 5 Range of parameters of DRAINMOD-NII model during calibration**

Parameter	Range	Calibrated Value
Hydrology		
“Hydraulic conductivity of 3 layers (K_{sat}), cm h^{-1} ”	0.05-100	3.3, 0.5, 0.5
Maximum surface storage, S_m (cm)	0.25-10	1.5
Surface micro-storage, S_I (cm)	0.25-10	0.75
Drainage coefficient (cm day^{-1})	0.5-10	2.5
Critical ice content above which infiltration stops”	0.01-0.5	0.2
Nitrate		

“Longitudinal dispersivity, cm	5-30	25
Denitrification parameters		
Michaelis-Menton max rate (µg N g-soil ⁻¹ day ⁻¹)	0.5-60	0.6
Parameters half-saturation constant (mg L ⁻¹)	1-60	35
Optimum temperature (°C)”	18.5-74	50
Transformation parameters for Soil Organic Carbon		
“Active pool decomposition rate (day ⁻¹)	1E ⁻² to 4E ⁻⁴	2.00000E ⁻²
Slow pool decomposition rate (day ⁻¹)	2.7E ⁻⁴ to 11E ⁻⁴	5.47945E ⁻⁴
Passive pool decomposition rate (day ⁻¹)”	6.2E ⁻⁶ to 24.7E ⁻⁶	12.3288E ⁻⁵

181

182 2.3. Calibration and verification efficiency

183 For simulated and observed drainage outflows and NO₃-N losses in subsurface drains, the Root
184 Mean Square Error (RMSE), percentage of Bias (PBIAS), coefficient of determination (R²), and modeling
185 efficiency (NSE) were considered and compared using the following statistical formulations:

$$186 \quad RMSE = \sqrt{\left(\frac{1}{N} \sum_{i=1}^N (P_i - O_i)\right)^2} \quad (1)$$

$$187 \quad PBIAS = \frac{100 \sum_{i=1}^{i=n} (O_i - P_i)}{\sum_{i=1}^{i=n} O_i} \quad (2)$$

$$188 \quad R^2 = \frac{\{\sum_{i=1}^N (O_i - \bar{O})(P_i - \bar{P})\}^2}{\sum_{i=1}^N (O_i - \bar{O})^2 \sum_{i=1}^N (P_i - \bar{P})^2} \quad (3)$$

$$NSE = 1 - \left[\frac{\sum_{i=1}^{i=n} (O_i - P_i)^2}{\sum_{i=1}^{i=n} (O_i - \bar{O})^2} \right] \quad (4)$$

O_i represents the observed value at time i , P_i represents the simulated value at time i . $\bar{O}$ represents the observed mean value, and n represents the number of paired observed-simulated values. When the RMSE (Equation (1)) equals 0 (zero), it implies a perfect match between observed and expected values, whereas increasing RMSE values imply a worsening match. According to Singh et al. (2004), RMSE values less than half the standard deviation of the observed (measured) data are considered low and suggest a strong model prediction. Nash–Sutcliffe efficiency (Equation (2)) can range from $-\infty$ to 1, according to Nash and Sutcliffe (1970). An efficiency of 1 ($E = 1$) corresponds to a perfect match between the simulated and observed results. When the efficiency is zero ($E = 0$), the model predictions are as accurate as the mean of the observed results. Efficiency less than zero ($E < 0$) means that the observed mean is a better predictor than the model. The coefficient of determination, R^2 , (Equation (3)), ranges from 0 to 1 that defines how much of the variance in the calculated data is explained by the model, with higher values meaning less error variance, $R^2 > 0.5$ is usually considered appropriate (Santhi et al., 2001; Van Liew et al., 2003). The average tendency of the simulated data to be greater or smaller than their observed counterparts is measured by the percentage of bias (PBIAS) (Gupta et al., 1999). PBIAS optimal value is 0, with low magnitude values suggesting a good model simulation. Underestimation bias is indicated by positive values, while overestimation bias is indicated by negative values (Gupta et al., 1999). The results of a statistical analysis were used to verify the model's reliability during the calibration and validation periods, and the results are shown in Table 6 and 7. The significance of R^2 was determined using a partial F test, which revealed a substantial correlation at a 5% level of significance, as shown in Table 6 and 7 and discussed in sections 3.1.1. and 3.2.1 respectively.

3. Results and discussion

3.1 Calibration

3.1.1 Simulated drainage outflows

The performance of DRAINMOD in simulating monthly drainage outflows during the calibration period (2018-2019) is summarized in Table 7. The model efficiency (NSE) for monthly flows was 0.53 with a R^2 value of 0.57, PBIAS of 15.41, and RMSE of 8.88. These efficiency criteria suggest the model performance to be good (Moriassi et al., 2007) to excellent (Skaggs et al., 2012). The predicted and observed monthly subsurface drainage outflows at Thehri in 2018 and 2019 are compared in Figs.5(a and b), respectively. It is evident from the figures that the model underestimated the drainage outflows except in the months of May, September and October. The under-prediction of subsurface drainage in these months was most likely due to variations in precipitation events at the experimental plots versus the rain gauge site. In both years, the greatest discrepancies between the model simulated and observed monthly drain outflows occurred in March, June, and July. There was less rainfall during this period, but more drainage was observed. The model appears to be more sensitive to rainfall than the observed data suggests. The expected monthly drain outflows were, however, in good agreement with the observed values during all other periods. Overall, 48% of the outflow from the study area was recorded in the months of Jan, March, July, August and December. The comparison between the observed and predicted cumulative drain outflows (Fig.5 a and b) indicated that the simulated annual subsurface drainage depth was only about 74 cm less than observed drain depth in these two years. “Tian et al. (2012) reported large differences between measured and predicted daily drainage rates. Salazar et al. (2009) also reported higher simulated drainage outflows than measured values during high intensity precipitation events.

Table 6 Model performance during calibration period (2018-2019) for rice wheat cropping system

Parameter	RMSE	PBIAS (%)	Nash-Sutcliffe coefficient (NSE)	R^2
Drain flow depth	8.88	15.41	0.53	0.57*

Nitrogen load (kg/ha)	0.14	2.76	0.84	0.88*
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*R² is statistically significant, using partial F test for p =1 and α=5%

Fig.5. Observed and simulated monthly and cumulative drain outflows for rice- wheat cropping system during calibration period (a) 2018 (b) 2019

In the calibration period, the average of simulated daily drainage discharges during the rice wheat season (0.88 cm day^{-1}) was closer to that observed (1.02 cm day^{-1}). Flow events during the growing season are predicted well, but there are discrepancies in the magnitude of some events, especially during wet months, such as June and July, when drainage was under-estimated. Since, subsurface drainage and evapotranspiration are the two main pathways of water loss considered in this simulation study's water balance, any over- or under-estimation of subsurface drainage is balanced by adjustments in simulated ET. Actual ET is calculated using daily potential ET and soil moisture availability within the crop rooting depth by the DRAINMOD model. Daily potential ET was calculated using the Thornthwaite equation and crop

coefficients by (Allen et al., 1998) as input to the model in this modeling research. Actual crop water use varies on year-to-year basis depending on moisture availability, and crops can change their water use by their rooting depth. In the summers of 2018 and 2019, simulated drain flow depths matched well with the observed drain flow depths, but drainage was underestimated in June and July. This implies that better ET estimation will help the model perform better. However, this is only possible if more accurate weather data or calculated crop ET are available at the desired location.

3.1.2 Simulated nitrate loads

In many studies, the movement of $\text{NO}_3\text{-N}$ has been linked to the movement of water in agricultural soils (Armstrong and Burt, 1993). Figure 6 depicts the effects of daily and accumulated $\text{NO}_3\text{-N}$ losses in subsurface drainage. Table 6 shows the statistical indices estimated for the predicted and observed daily $\text{NO}_3\text{-N}$ losses. The calibration for the study area appears to be satisfactory, and the total expected $\text{NO}_3\text{-N}$ losses are in good agreement with the observed values, as shown in Fig. 6. The cumulative predicted $\text{NO}_3\text{-N}$ losses of 32.15 kg ha^{-1} was recorded during the growing season in subsurface drainage over the calibration period which was 2.9% less than the observed $\text{NO}_3\text{-N}$ losses of 33.07 kg ha^{-1} . King et al. (2015) analyzed the effects of crop type and season on subsurface drainage discharge and nutrient loads. “Bjorneberg et al. (1996) reported over a three-year period in Iowa that up to 85% of annual tile flow and $\text{NO}_3\text{-N}$ loads from a corn–soybean and continuous corn rotation on loam soils occurred during the non-growing seasons. The averages of daily simulated and measured $\text{NO}_3\text{-N}$ losses were, 1.53 and 1.57 kg ha^{-1} , respectively during calibration (Table 8) under the rice wheat growing season. The $\text{NO}_3\text{-N}$ losses in drain outflows were strongly dependent on outflow rates in the study area. The calibrated and validated daily drain flows were significantly different than their corresponding simulated values (Table 8) when confirmed using t test at 5% level of significance. Following the under-estimated drainage outflows, DRAINMOD-NII slightly under estimated the nitrogen losses in June, July, December and January months of both years during the calibration period (Fig.6). Similar under estimations were reported by Salazar et al. (2009) and Hassanpour et al. (2011). Higher $\text{NO}_3\text{-N}$ concentrations in drainage water in the years 2018–2019 growing season could partly be due to more urea application. The grower applied 287 kg ha^{-1} urea in rice and 337

kg ha⁻¹ in wheat during this season. During the experiment, Kladvko et al. (2004) reported a substantial decrease in nitrate concentration in drainage water as a result of both the addition of a winter cover crop and a reduction in fertilizer N applications. Jafari-Taloukolae et al. (2018) reported on the effectiveness of subsurface drainage systems in improving the soil structure of the study area by providing improved conditions for soil aeration and increased saturated hydraulic conductivity. Such improvement could eventually lead to the formation of flow paths from the soil surface to drains, which could be a major contributor to rising NO₃-N concentrations variation. However, increased nitrate losses, particularly after fertilization or heavy rainfall, may have negative implications for receiving water bodies. Special management techniques, on the other hand, should be used to control nitrate losses in light-textured subsurface drained soils

Fig.6. Observed, simulated and cumulative nitrogen losses in subsurface drains for rice- wheat cropping system during calibration period

3.2 Validation

3.2.1 Simulated drainage outflows

The experimental plot data was used to validate the calibrated model DRAINMOD-N II for the period (2019-2020). As shown in Figs.7 (a and b), the results visually indicate strong agreement between the field measurements and the simulated values for monthly drainage outflows. The comparisons were tested using t test, whereby the differences between observed and simulated drainage outflows were non-significant for the year 2018 while as significant difference was found in the years 2019 and 2020, respectively. The DRAINMOD-NII model predicted values of monthly subsurface drainage outflows matched well with the observed data, during the validation period, except in the months of March, June and July of 2019 and 2020 respectively (Fig.7. a and b). This may be due to, differences in precipitation between the rain gauge site and experimental plots, which might probably, have affected predictions in March (having observed subsurface drain outflow of 36.51 cm and precipitation 1.06 cm), June and July (having observed subsurface drain outflow of 35.36, 36.51 and precipitation of 3.2 and 39.74 cm, respectively). In March, June of 2020 also, the observed subsurface drain outflows were (36.50 and 35.34 cm, respectively) which was unrealistically very high (79% and 88%) when compared to precipitation (7.33 cm and 4.2 cm respectively). Overall, the model performance during the validation period was “good” with NSE = 0.47; PBIAS=19.52; RMSE=9.66; $R^2 = 0.53$ (Table 7). The predicted monthly subsurface drainage values were more variable compared to observed data, as indicated by larger than calibrated PBIAS values in case of simulated data (Table 7). The cumulative predicted subsurface drainage outflow of 296.57 cm was recorded over the entire validation periods, which was 20% lower than the observed subsurface drain outflow of 376.45 cm. The average of simulated daily drainage discharges was 0.84 cm day^{-1} during the rice-wheat cropping season which was closer to that of the observed 1.08 cm day^{-1} , during the validation period. During the two growing seasons, there were more discrepancies between simulated and observed drain discharges in both the calibration and validation processes. The major reason for such discrepancy in the model can also be related to the differences in soil conditions and rainfall amount and pattern in different

growing seasons. After a precipitation or irrigation event, the infiltrated water is used to replenish the moisture lost from the dry zone first, and the remaining portion joins the excess soil moisture, eventually causing a rise in water table. An under-estimation of drainage outflow may occur when a portion of precipitation was used to replenish the dry zone, resulting in lower water table rise than expected. During rainfall events, model predictions were usually lower than observed values, suggesting that simulated effects were more unpredictable. Due to the existence of a hard pan layer below the plough pan of the study field (Darzi-Naftchali et al., 2013), part of the excess water travels horizontally in the plough layer to a drain trench, then vertically to a drain pipe. The vertical hydraulic conductivity or vertical resistance of the soil layer beneath the plough pan significantly influences flow to drains under these conditions, which was not taken into account in DRAINMOD simulations. After evaluating uncertainties related to DRAINMOD predictions for drainage outflows, Wang et al. (2006) concluded that vertical saturated hydraulic conductivity of the restrictive layer is the most sensitive parameter. The different paths of seepage were not included in the current analysis, with the exception of vertical seepage, which forms a major part of the water balance. It is said to have a significant impact on the DRAINMOD model predictions (Chang et al., 1983), which depend on exact quantification of all water balance components.

Table 7 Model performance during validation period (2019-2020) for rice wheat cropping system

Parameter	RMSE	PBIAS (%)	Nash-Sutcliffe coefficient (NSE)	R ²
Drain flow depth	9.66	19.52	0.47	0.53*
Nitrogen load	0.12	-5.19	0.82	0.85*

*R² is statistically significant, using partial F test for p =1 and $\alpha=5\%$

Fig. 7. Observed and simulated monthly and cumulative drain outflows for rice- wheat system during validation period (a) 2019 (b) 2020

3.2.2 Simulated nitrate loads

The values of statistical parameters comparing simulated and observed $\text{NO}_3\text{-N}$ losses were lower in validation period than in calibration (Table 7). The PBIAS value was $-5.19 \text{ kg N ha}^{-1}$, the modelling efficiency (NSE) was 0.82 and R^2 0.85. The slightly lower agreement shown by statistical parameters for validation when compared with calibration period was caused by a few events with larger discrepancies between the simulated and observed $\text{NO}_3\text{-N}$ losses (Fig. 8). The majority of these discrepancies occurred

in the months of July, November and January (Table 8), in the remaining months, predicted NO₃-N losses in subsurface drainage matched well with the observed losses. The predicted NO₃-N losses in subsurface drainage were much less variable compared to observed data (Fig. 8). The cumulative predicted NO₃-N losses of 28.77 kg ha⁻¹ was recorded in subsurface drainage over the validation period which was 6.5% more than the observed NO₃-N losses of 26.88 kg ha⁻¹. The model might have under predicted denitrification during the validation period, leaving more mineral N susceptible to leaching in the drainage outflow (Fig.8). It is possible that the overprediction of model for N mineralization rates, could partly contribute to the errors in predicting NO₃-N losses with drain outflow during these periods. Neither N mineralization nor denitrification was possible to measure, in the field to test the accuracy of model prediction for these quantities. However, the value of these parameters was taken from the literature rather than field and laboratory values that may cause some errors in predicting monthly NO₃-N drainage losses using DRAINMOD-NII model.

358 **Fig. 8. Observed, simulated and cumulative nitrogen losses in subsurface drains for rice- wheat**
359 **cropping system during validation period**

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Table 8 Observed and simulated daily drain discharge (cm day⁻¹) and NO₃-N loss (kg ha⁻¹) during the study period

Crop growing season	Day of Sampling	Observed drain flow (cm day ⁻¹)	Observed NO ₃ -N loss (kg/ha)	Simulated drain flow (cm day ⁻¹)	Simulated NO ₃ -N loss (kg/ha)
2018-19	19-Jun-18	1.16	1.01	0.62**	0.96*
	07-Jul-18	1.17	1.51	0.70**	1.14*
	19-Jul-18	1.15	1.83	0.81**	1.94*
	30-Jul-18	1.14	1.63	0.87**	1.41*
	08-Aug-18	1.15	2.39	0.97**	2.27*
	21-Aug-18	1.18	1.38	0.98**	1.21*
	03-Sep-18	0.98	1.25	1.14**	1.31*
	13-Sep-18	0.95	1.18	1.14**	1.09*
	26-Sep-18	0.97	1.96	1.13**	1.90*
	02-Oct-18	0.78	1.62	1.10**	1.77*
	30-Oct-18	0.72	2.15	0.97**	2.16*
	15-Nov-18	1.17	1.70	0.91**	1.96*
	24-Nov-18	1.15	1.38	0.88**	1.41*

	05-Dec-18	1.19	1.56	0.84**	1.45*
	16-Dec-18	1.11	1.84	0.89**	1.91*
	09-Jan-19	1.12	1.01	1.00**	0.95*
	31-Jan-19	1.10	1.40	0.91**	1.38*
	05-Mar-19	1.13	1.26	0.79**	1.10*
	18-Mar-19	1.11	1.68	0.74**	1.63*
	08-Apr-19	0.78	1.37	0.68**	1.34*
	24-May-19	0.39	1.96	0.56**	1.80*
	Average	1.02	1.57	0.88	1.52
	SD	0.20	0.36	0.16	0.39
2019-20					
	10-Jun-19	1.17	1.60	0.63**	1.98*
	03-Jul-19	1.16	1.29	0.72**	1.16*
	22-Jul-19	1.18	1.37	0.84**	1.34*
	05-Aug-19	1.17	1.11	0.89**	1.16*
	18-Aug-19	1.10	1.63	1.09**	1.67*
	04-Sep-19	0.98	1.34	1.03**	1.33*
	26-Sep-19	0.96	1.71	1.03**	1.82*

	15-Oct-19	0.78	1.45	0.95**	1.55*
	25-Oct-19	0.75	1.35	0.91**	1.47*
	04-Nov-19	1.17	1.55	0.87**	1.65*
	25-Nov-19	1.17	1.33	0.80**	1.28*
	16-Dec-19	1.18	0.86	0.82**	0.98*
	31-Dec-19	1.16	1.25	0.96**	1.27*
	07-Jan-20	1.19	1.19	0.94**	1.20*
	22-Jan-20	1.15	1.15	0.88**	1.13*
	01-Feb-20	1.14	1.24	0.84**	1.29*
	25-Feb-20	1.16	1.25	0.76**	1.35*
	10-Mar-20	1.17	1.30	0.72**	1.45*
	25-Mar-20	1.16	1.63	0.67**	1.78*
	15-Apr-20	0.78	1.28	0.61**	1.39*
	Average	1.08	1.34	0.84	1.41
	SD	0.14	0.20	0.13	0.25

**designates Significant and *designates Non-significant difference between daily observed and simulated drainage values and nitrogen loss values

at 5% level of significance using t test

4. Conclusions

DRAINMOD-NII was successfully calibrated and validated over a two-year cultivation period in Thehri, Muktsar, Punjab, using data sets from conventional drained plots. The statistical comparison of simulated and observed drain flows and nitrogen losses revealed a stronger agreement with some discrepancies between the two data sets. For the DRAINMOD-N II, statistical goodness-of-fit measurements such as root mean square error (RMSE), percentage of bias (PBIAS), modeling efficiency (NSE), and coefficient of determination (R^2) confirm that the model results and field observations are in strong agreement. The findings show that DRAINMOD-N II has the ability to simulate drainage rates and nitrogen losses from agricultural lands in Indian conditions for newly reclaimed lands. However, since this model was only tested for a shorter time period and with a single cropping method, inconsistencies that caused conflict with a specific set of values must be resolved for wider application of this model.

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Conflict of Interest

The authors declare no competing interests

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