Ceres-N Module to Predict Rainfed Rice Productivity in the Gangetic Plain Region of Varanasi

Mahendra Kumar Verma[1], Arijit Barman[2], Nirmal De[*3], Priyankar Raha[3], S.C. Datta[4]

[1] *Research Scholar, Department of Soil Science and Agricultural Chemistry, IAS, BHU, Varanasi, U. P.,*
[2]*Research Scholar, Division of Soil Science and Agricultural Chemistry, IARI, New Delhi*
[*3, 3] *Professor Department of Soil Science and Agricultural Chemistry, IAS, BHU, Varanasi*
[4]*Principal Scientist, Division of Soil Science and Agricultural Chemistry, IARI, New Delhi*

Abstract*- Nitrogen availability and translocation at different critical physiological crop growth stages of rice cv. NDR 97 and its impact on the productivity in the Gangetic alluvial soil of Varanasi under rainfed situation was investigated. The experimental data was generated from on farm ($82^0$52' E longitudes and $25^0$10' N latitude) research under long term experiment of All India Coordinated research project on dry land agriculture operative in the Institute of Agricultural Sciences, Banaras Hindu University. The soil (mixed hyperthermic udic ustochrept) was a sandy loam in texture, neutral in reaction and falls under *transect -4* of the IGP region. The experiment was conducted with combination of different doses of N using both organic and inorganic sources out of which four different treatments were selected. The cultivar used for rainfed rice was NDR-97 and seeds were sown during last week of June and or first week of July depending upon the onset on monsoon for two consecutive seasons. In the present paper we have discussed how the available quantity of nitrogen in two different forms i.e., NO_3^- and NH_4^+ varies at different crop growth stages under the influence of different management inputs *viz.*, no fertilizer /manure (F_0), 100 % NPK, i.e., total N, P and K rates of 80, 40 and 40 kg ha^{-1} (F_1), 50 % NPK plus 50 % N from farmyard manure (F_2), 100% N from farmyard manure (F_3) and compared with the yield of the crop. The average potential yield for rice *cv.* NDR-97 under F_0, F_1, F_2 and F_3 treatments were 17, 25, 26 and 31.2 q ha^{-1}. The result of this study was further utilized for modifying the nitrogen management module in the CERES- N dynamics model for better prediction of yield behaviour under rainfed condition and its application during potential growth stages for enhancing the rainfed rice productivity in the Gangetic alluvial soil.

Keywords: Rainfed, rice productivity, integrated nitrogen management, content NO_3^- and NH_4^+, CERES-N

I. INTRODUCTION

Rice (*Oryza sativa*) is one of the most important staple food crops for more than half of the world population, especially for south-eastern Asia, where 90% of the world production of rice is grown and consumed providing over 21% of the calorific needs of the world's population and up to 76% of the calorific intake of the population of South East Asia. In India, it occupies 44 million ha of land and produces about 104.3 million tonnes of grain with the productivity of 23.5 quintal ha^{-1}[1]. In India, more than half of the annual rice crop continues to be grown during the summer monsoon season (kharif), despite increased dry-season harvests made possible by expanded irrigation. During kharif season methane emission is very important due to extended flooding condition but nitrous oxide emission may be not create so much problem due to much more reduction of nitrate to elementary nitrogen but alternate wetting and drying is more favourable condition for emission of nitrous oxide. These gases contribute to global warming to a great extent. It has been seen that that the productivity of rice crop declines by 41% for 4°C increase in temperature [2] Well calibrated and validated crop weather models could be used as an effective tool for assessing the impacts of future changes in climate [3]**.** It is important to develop suitable adaptation strategies for sustaining the rice productivity to meet the demand of a growing population [4]. So, simulation modelling is a scientific discipline that uses mathematically-based representations to enhance understanding and prediction of future climate change, and to assess strategies for climate change mitigation and adaptation. We were used SOIL-N module on direct seeded rice for prediction of denitrification and mineralization of organic matter and effect of nitrogenous fertilizer application on these processes. Here we also scheduled application of nitrogenous fertilizer for enhancing rice productivity by increasing nitrogen use efficiency.

II. MATERIALS AND METHODS

1) *Field Experiments -*

The experiment was carried out in research farm of the Institute of Agricultural Sciences, Banaras Hindu University, with 82.52^0 E longitudes and $25^0$10' N latitude under long term experiment of All India Coordinated research project on dry land agriculture. The experiment was conducted with different doses of N using both organic and inorganic sources of nutrient in a combination of four different treatments viz., no fertilizer /manure (F_0), 100 % NPK, i.e., total N, P and K rates of 120, 60 and 60 kg ha^{-1} (F_1), 50 % NPK plus 50 % N from farmyard manure (F_2), 100% N through FYM (F_3). Daily weather data included maximum and minimum temperatures, precipitation, and total solar radiation measured at the site. Total rainfall received during the crop period (June 25 to October 14 of 2011) was 1026 mm. The weekly maximum and minimum temperature during the experimentation ranged from 28.9 to 34.7 ^{0}C and 23.5 to 29.0 ^{0}C, respectively. Weekly water balance-status during crop growth period by using Thornthwaite-method was presented in Table1.The cultivar used for rainfed rice was NDR-97 and seeds were sown during last week of June and or first week of July depending upon the onset on monsoon for two consecutive seasons. Number of replication was three. Soil and plant sample were collected from different successive growth stages of crop at 15 days interval of 0-15cm depth and were analysed for different physical {Bulk Density [5],Maximum Water Holding Capacity, [5], Field Capacity (FC), Permanent Wilting Point (PWP), Volumetric Moisture Content (THETA), Soil Temperature (ST), chemical Organic Carbon [6], Microbial Biomass Carbon [7], Labile Carbon [8], Ammonical nitrogen (Indophenol Blue colour method) of [9], Nitrate nitrogen (Nitrate electrode method) of [10], Available nitrogen [11], Labile nitrogen [8] and Plant parameter (plant nitrogen, dry matter content, protein content and yield). The results of this study was further utilized for modifying the nitrogen management module in the SOIL- N dynamics model for better prediction of yield behaviour under rainfed condition and its application during potential growth stages for enhancing the rainfed rice productivity in an Inceptisols.

2) Description of the Model

Crop Estimation through Resource and Environment Synthesis (CERES) is an American model and shares a common Nitrogen sub model called CERES-N by [12]. This is originated from earlier model called Production of Arid Pasture limited by Rainfall and Nitrogen (PAPRAN) model [13], which considers two pools of organic matter: straw and root residues (Fresh Organic Matter, FOM), and humus (SOM). The FOM is split into three fractions (20% carbohydrates, 70% cellulose, and 10% lignin, w/w), each decaying at a specific rate (0.2, 0.05, and0.0095d^{-1}, respectively). The humus pool is highly stable, with a decay rate of 8.3 x 10^{-5} d^{-1}[12]; its C/N ratio is fixed at 10. The CERES-N sub-model simulates soil N transformations, including mineralization, different nitrogen pools etc. Briefly, the mineralization and immobilization subroutine simulates the decay of two types of organic matter: FOM and HUM. The model requires the dry weight of the fresh residue applied its C/N ratio, and the depth to which the residue was incorporated. But predicting the amount of nitrogen mineralized from them is a complex process due to the many factors involved (temperature, soil reaction, C: N ratio, water content, residue quality, etc.). Temperature factor (TF) can be calculated with the help of equation-1. Moisture factor (MF) can be calculated with the help of equation-2 and C/N ratio factor (CNRF) can be calculated with the help of equation-3.

MF = (THETA-WP)/ (FC-WP) …………. 1

TF = (ST-5.0)/30 ……………2

CNR = (0.4*FOM)/(FON+TOTN)

CNRF = EXP{0.693*(CNR-25)/25.0}……3

Rate equations for transformation of various soil organic matter pools are described by first-*order* or *Michaelis-Menten* (Monod) kinetics. The rate of a first order reaction is proportional to the substrate concentration ($dC/dt = - k_1 C$). In Monod-type kinetics, the reactions are described as biological processes with rates depending on the amount of microbial biomass which is involved in the utilization of a substrate ($dC/dt = - (dC/dt)_{(max)} C/ (K_c + C)$). In these equations, k_1 is the relative rate constant for a first order reaction, and K_c represents the half-saturation concentration, where the rate is equal to half of the maximum ($(dC/dt)_{(max)}$), defined as a function of microbial biomass. The mineralization rate (Dn), immobilization rate (Gn) and net mineralization rate (Nmin) can be calculated with the following formula:

Dn = k*Cs / (C/N) s

Gn = k*Cs*f / (C/N) b

Nmin = k*Cs {1/ (C/N) s – f/ (C/N) b}

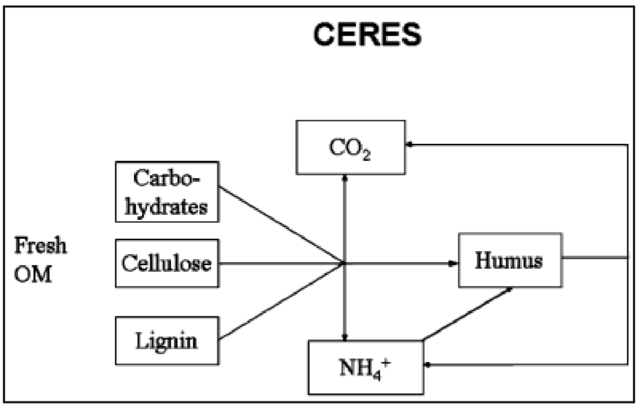
Nitrification rate (dNH_4/dt) and Denitrification rate (dNO_3/dt) can be calculated with the help of following formula:-

$$dNH_4/dt = K_n * e_t * e_m * e_{pH} * e_{NH4}$$

$$dNO_3/dt = = K_d * e_t * e_m * e_{NO3}$$

Where, Kn = Nitrification rate constant, Kd = Denitrification rate constant, e_{NH4} = Response function of ammonium content, e_{NO3}= Response function of nitrate content, e_t and e_m are temperature and moisture factor respectively.

Input parameters of this model are Fresh organic matter in Kg/ha and its nitrogen percentage, Soil Nitrate and Ammonium in kg/ha, Volumetric moisture content, Wilting point, Field capacity, Mean soil temperature, Time step, Finish time, Organic carbon percentage and its Mineralization rate constant. Output parameters of this model are Organic carbon percentage, Residue left, C/N ratio, Soil ammonium and Nitrate, Composition of residue left in percentage, C/N Ratio of residue left.Thus, computer models that can take all of those factors into account should be powerful tools for predicting net nitrogen mineralization. The nitrogen released from crop residues may be lost to the atmosphere through ammonium volatilization or denitrification, taken up by plants, leached, or immobilized in the soil. Models that simulate all nitrogen transformations in a whole crop-soil system are the most suitable for field application, but they are scarce because their development and validation involve many human and economic resources.



The CERES models are some of the more widespread models for simulating the whole crop-soil system, including nitrogen transformations.

3) Model evaluation

Two average indicators were also calculated, giving a more immediate idea of the simulations' accuracy: the mean deviation [MD = Σ(observed - simulated)/N], and the RMSE [{Σ(observed — simulated) ^{2}/N} $^{-1/2}$]. The MD reveals a possible trend of the model to underestimate or overestimate the output investigated, whereas the RMSE quantifies the dispersion between simulated and measured data [14]. Different statistics indexes were determined, including the normalized root mean square error (RMSE) expressed in percent, calculated according to [15] with Eq. (1).

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \times \frac{100}{M} \qquad (1)$$

Where *Pi* and *Oi* refer to predicted and observed values for the studied variables, respectively, e.g., ammonium and nitrate nitrogen, and organic carbon. *M* is the mean of the observed variable. Normalized RMSE gives a measure (%) of the relative difference of simulated versus observed data. The simulation is considered excellent with a normalized RMSE less than 10%, good if the normalized RMSE is greater than 10 and less than 20%, fair if the normalized RMSE is greater than 20% and less than 30%, and poor if the normalized RMSE is greater than 30% [16].

III. RESULT AND DISCUSSION

1) *Physical Characteristics of soil*

From Table 2, it was clear that application of manure with fertilizer (F_3 treatment) improved soil bulk density, water holding capacity, field capacity over control, 100% NPK and 50% NPK+50% N through FYM because increase porosity and soil aggregation). [17] reported that all soil physical properties mainly bulk density, water holding capacity etc. increased with the application of organic manure. The data also depicted that there was an inverse relationship between volumetric moisture content and soil temperature. So, physical characteristics of soil, was improved due to application of FYM, had directly or indirectly effect on chemical properties of soil and ultimately govern the nutrient, specially nitrogen, dynamic in soil.

2) Chemical Characteristics of soil

Integrated nutrient approach (F_2 treatment) improved all carbon and nitrogen pools in soil over control (F_0 treatment) and inorganic fertilizer (F_1 treatment) which has been presented in Table 3. Results of long term fertilizer trials also shown that balanced application of fertilizers along with FYM could sustain the level of available nitrogen in soil (except in mollisol, Pantnagar) even after 20 years of intensive cropping [18]. The C/N ratio of surface soil ranges from 11-17:1 to 15-45:1. Due to application of manure physical properties as well as organic matter content was also increased which favour to develop soil microbial biomass and increased the availability of nitrogen to plant. So, plant quality and yield was also increased. This corroborates with the findings of several researchers that application of manures and fertilizers at optimum rates increased the crop productivity, which in turn resulted in greater residue inputs leading to enhanced build up of carbon in soils [19], [20].

3) *3) Plant Characteristics*

All plant attributes like nitrogen content and uptake, yield were improved due to integrated nutrient approach over other treatments (Table 4). These plants attributes are mainly governed by soil physical, chemical and meteorological factors. So, for predicting yield of rice in rainfed area all above physical, chemical and environmental parameters were recorded at different successive growth stages of rice which were used as an input parameter of CERES-N.

4) *4) Prediction on N dynamics of surface soil in direct seeded rice by CERES-N model*

Nitrogen dynamics of surface soil is predicted in direct seeded rice by CERES –N model. Simulation of soil ammonical and nitrate nitrogen by CERES-N under different treatment is considered excellent as normalized RMSE value is less than 10% (Table 5). Figure a, b, c and d shows that there is a good performance of CERES-N in case of nitrate nitrogen under four treatment, whereas, the model tended to give slightly over prediction in case of ammonical nitrogen under control. Upto 49 days after sowing, there is good prediction among simulated and observed ammonical nitrogen under treatment of 100 % NPK, 50% NPK + 50% Nitrogen through FYM and 100% N through FYM, but after that over prediction is done by the model. [21] observed a good correlation between simulated and measured total N under variable irrigation and fertilizer N regimes. Total mineralization of control and 100% NPK was 2.43 ppm throughout the growing season, whereas, total mineralization of integrated nutrient plot was 38.93 ppm throughout the growing season. So, mineralization is increased due to application of manure. After crop season final residue left in the plot of integrated nutrient was 236.85 kg/ha, whereas, 1.48 kg/ha residue was left in the plot of without manure. So, there was also build up of organic matter in the soil. It has been seen that organic carbon percentage was maximum in treatment of 100% N through FYM. [22] reported a good comparison between simulated and observed data of SOC and Total N for Ludhiana-3 under different treatment (control, 100% NPK, 50% NPK+50% FYM). In general, the performance of the model was to predict amount of nitrogen left after uptake of main paddy crop or at successive growth stages of rainfed paddy and loss to environment (NH_4^+ form) from soil *in situ* in an Inceptisol soil of Varanasi, India.

IV. CONCLUSION

The potential of CERES-N in simulating soil carbon and nitrogen pool and yield of direct seeded rainfed rice cultivar under different N-fertilizer application were explored. The integrated approach of organic and inorganic nutrient supplementation improves carbon and nitrogen pool coupled with higher uptake of nutrient improving nitrogen use efficiency. The results from this study showed an acceptable agreement between simulated and observed values for soil nitrogen pool. Some differences between observed and simulated values were due to environmental factor (rainfall and temperature) or other associated crop growth factor. This model may help for proper scheduling of nitrogen under rainfed condition which ultimately helps the resource poor farmers.

ACKNOWLEDGEMENT

We acknowledge invaluable help from Dr. R. P Singh and Dr. S.R. Singh, Chief Scientists of AICRP, Dry land Agriculture, Banaras Hindu University for technical support and CRIDA, Hyderabad for financial support.

REFERENCES

[1] Anonymous, 2012. Agriculture statistics at a glance. Department of Agriculture and Co-operation, Ministry of Agriculture, Government of India, New Delhi.

[2] Lal, M., Singh, K. K., Rathore, L. S., Srinivasan, G. and Saseendran, S. A. 1998. Vulnerability of rice and wheat yields in NW India to future changes in climate. *Agric. For. Meteorol*. **89**: 101–114.

[3] Saseendaran, S. A., Singh, K. K., Rathore, L. S., Singh, S. V. and Sinha, S. K. 2000. Effects of climate charge on rice production in the tropical humid climate of Kerala, India. *Climate Change*, **44**:495–514.

[4] Hoanh, C. T., Guttman, H., Droogers, P. and Aerts, J. 2003. Water, climate, food and environment in the Mekong Basin in Southeast Asia. Final Report ADAPT Project, Adaptation Strategies to Changing Environment, Amsterdam, p. 52.

[5] Black, C.A. (Ed.) 1965. Methods of Soil Analysis. Part I and II. American Society of Agronomy, Inc., Publishers, Madison, Wisconsin, USA.

[6] Walkley, A. and black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, **37**: 29-38.

[7] Jenkinson, D.S. and Ladd, J.N. 1981. Microbial biomass in soil: Measurement and turnover. *Soil Biochemistry*, **5**: 415-471.

[8] Blair, G.J., Lefroy, R.D.B. and Lisle, L. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Australian Journal of Soil Research*. **46**:1459-1466.

[9] Nikolaos, M., Tzollas, George A., Zachariadis, Aristidis N., Anthemidis and John, A. Stratis. 2010. A new approach to indophenol blue method for determination of ammonium in geothermal waters with high mineral contenty. *Intern. J. Environ. Anal. Chem*., **90**(2): 115–126.

[10] Stanley, E. Manahan. 1969. Nitrate Ion-Selective Electrode in Microbial Media. *Applied microbiology*, **18**(3): 479-481.

[11] Subbiah, B.W. and Asija, G.L. 1956. A rapid procedure for estimation of available nitrogen in soil. *Current Science*, **25**(8): 259-260.

[12] Godwin, D.C., and Jones, C.A. 1991. Nitrogen dynamics in soil plant systems. In R.J. Hanks and J.T. Ritchie (ed.) Modelling plant and soil systems. Agron. Monogr. 31. ASA, CSSA, and SSSA, Madison, WI. P. 287-321.

[13] Seligman, N.C., and Van Keulen, H. 1981. PAPRAN: A simulation model of annual pasture production limited by rainfall and nitrogen. In M.J. Frissel and J.A. Van Veen (ed.) Simulation of nitrogen behaviour of soil-plant systems. PUDOC, Wageningen, the Netherlands. p. 192-221.

[14] Addiscott, T.M., and Whitemore, A.P.1987.Computer simulation of change in soil mineral nitrogen and crop nitrogen during autumn, winter and spring. *The Journal of Agricultural Sciences*. **109**:141-157.

[15] Loague, K., and Green, R. E. 1991. Statistical and graphical methods for evaluating solute transport models: Overview and application. *Journal of Contaminant Hydrology*, **7**: 51–73.

[16] Jamieson, P.D., Porter, J.R., Wilson, D.R. 1991. A test of the computer simulation model ARC-WHEAT1 on wheat crops grown in New Zealand. *Field Crops Res.* **27**: 337–350.

[17] Bandyopadhyay, P. K. and Subita Saha Mallick, S. 2011. Comparison of soil physical properties between a permanent fallow and a long-term rice-wheat cropping with inorganic and organic inputs in the humid subtropics of eastern India. *Communications in Soil Science and Plant Analysis*, **42**(4): 435-449.

[18] Singh, M.V., Wanjari, R.H. and Adhikari, T. 2004. Nutrient dynamics, crop productivity and sustainability under long term fertilizer experiments in India. AICRP-LTFE. Indian Institute of Soil Science (ICAR), Nabibag, Bhopal: 1-120.

[19] Ismail, I., Blevins, R.L. and Frye, W.W. 1994. Long-term no-tillage effects on soil properties and continous corn yields. *Soil Science Society of America Journal*, **58**:193-198.

[20] Graham, M.H., Haynes, R.J. and Meyer, J.H. 2002. Soil organic matter content and quality: Effects of fertilizer applications, burning and trash retention on long-term sugarcane experiment in South Africa. *Soil Biology and Biochemistry*, **43**: 93-102.

[21] Arora, V.K., Singh, H. and Singh, B. 2007. Analyzing wheat productivity responses to climatic, irrigation and fertilizer-nitrogen regimes in a semi-arid sub-tropical environment using the CERES-Wheat model. *Agricultural Water Management*, **94**: 22-30.

[22] Shibu, M.E., Van Keulen, H. and Leffelaar, P.A. 2007. Long-term dynamics of soil C and N in intensive rice-based cropping systems of the Indo-Gangetic Plains (IGP): A modeling approach. PhD thesis, Wageningen University, Wageningen, The Netherlands. With summaries in English and Dutch: 225.

Table 1: Weekly Waterbalance-Thornthwaite (Standard week-wise) during the crop growing season of 26 to 41 weeks of 2011 (Available Water Holding Capacity: 78 mm)

Week	Precipitation (mm)	PET (mm)	Plough depth soil moisture (mm)	AET (mm)	Surplus (mm)	Deficit (mm)	Moisture availability index	Deviation	Soil Moisture Index
26	130	3.7	78	3.7	126.3	0.0	1.00	0.00	1.00
27	25	5.1	78	5.1	19.9	0.0	1.00	0.00	1.00
28	6.2	5.2	78	5.2	1.0	0.0	1.00	0.00	1.00
29	114.2	2.4	78	2.4	111.8	0.0	1.00	0.00	1.00
30	19.6	3.7	78	3.7	15.9	0.0	1.00	0.00	1.00
31	1.8	3.0	76.8	3.0	0.0	0.0	1.00	0.00	0.98
32	183	2.0	78	2.0	179.8	0.0	1.00	0.00	1.00
33	106.6	2.4	78	2.4	104.2	0.0	1.00	0.00	1.00

34	2.8	3.4	77.4	3.4	0.0	0.0	1.00	0.00	0.99
35	0.2	5.4	72.4	5.2	0.0	0.2	0.96	0.04	0.93
36	42.8	3.4	78	3.4	33.8	0.0	1.00	0.00	1.00
37	28.6	3.0	78	3.0	25.6	0.0	1.00	0.00	1.00
38	68.8	2.7	78	2.7	66.1	0.0	1.00	0.00	1.00
39	296.4	2.6	78	2.6	293.8	0.0	1.00	0.00	1.00
40	0.0	3.6	74.5	3.5	0.0	0.1	0.98	0.02	0.95
41	0.0	2.9	71.8	2.7	0.0	0.2	0.94	0.06	0.92

Table 2: Physical characteristics of soil

Physical characteristics		**Treatment**				**LSD $_{0.05}$**
		F0	**F1**	**F2**	**F3**	
bulk Density (Mg m^{-3})	0-15 cm	1.38[b]	1.42[a]	1.36[c]	1.35[e]	0.01
Soil wetness θ (%)	0 (θs)	47[c]	51.2[b]	54.1[a]	55.9	2.25
	0.33 (FC)	19.4[a]	19.8[a]	20.1[a]	21.7	2.61
	15 (PWP)	8.5[b]	8.8[ab]	9.7[a]	9.2	0.94
Volumetric moisture content (%)	0-15 cm	25.15[c]	26.66[b]	29.04[a]	29.15	0.54
Soil temperature (^{o}C)	0-15 cm	31.7[a]	30.5[b]	29.2[c]	30.8	0.71

Table 3: Chemical characteristics of surface soil (0-15 cm)

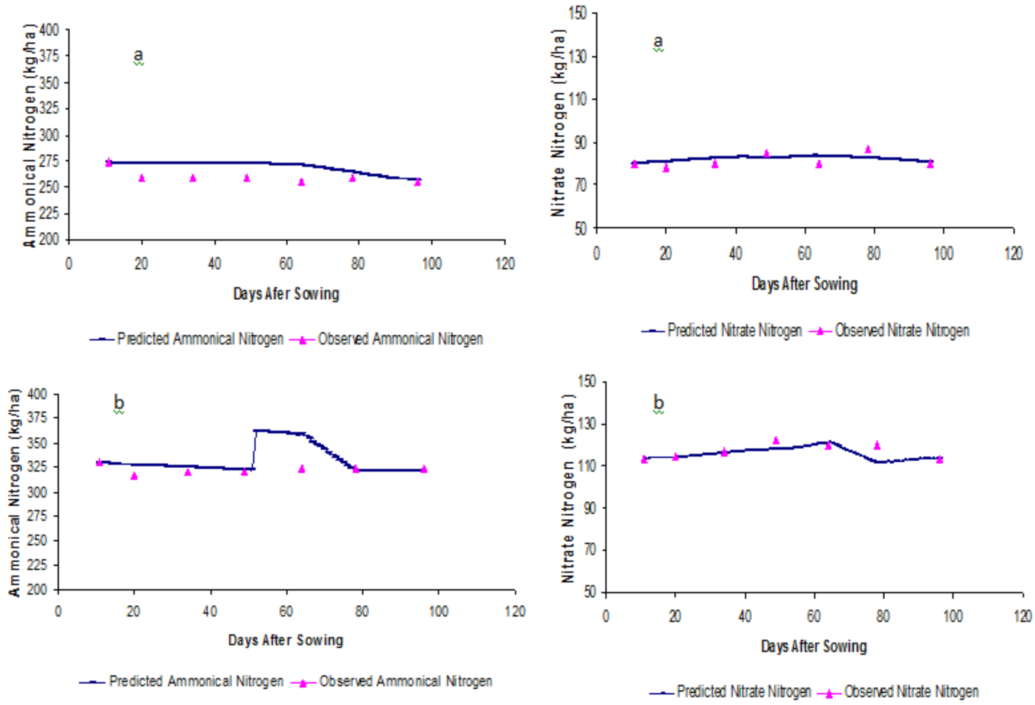
Chemical characteristics	**Treatment**				**LSD $_{0.05}$**
	F0	**F1**	**F2**	**F3**	
Walkley and Black carbon content (%)	0.23[b]	0.24[b]	0.31[a]	0.33[a]	0.02
Soil Microbial Biomass Carbon (mg/kg)	161[c]	237[b]	287[a]	263[b]	0.91
Labile Carbon (%)	0.17[b]	0.19[b]	0.25[a]	0.27[a]	0.03
Labile Nitrogen (%)	0.012[c]	0.017[b]	0.019[a]	0.016[bc]	0.001
C:N Ratio	15.45[a]	11.17[c]	13.16[b]	16.88	0.40
Available Nitrogen (kg/ha)	110[c]	225[b]	230[a]	205[c]	2.18
Ammonical Nitrogen (kg/ha)	264[c]	327[b]	355[a]	313[d]	6.89
Nitrate Nitrogen (kg/ha)	83[c]	118[b]	131[a]	118[b]	3.77

Table 4: Plant attributes

Plant attributes	Treatment F0	F1	F2	F3	LSD $_{0.05}$
Nitrogen Content (%)	0.90^{c}	1.86^{b}	2.24^{a}	1.55^{d}	0.06
Nitrogen Uptake (kg/ha)	17.22^{c}	59.60^{b}	78.07^{a}	48.26^{d}	1.77
Protein Yield (kg/ha)	108^{c}	373^{b}	488^{a}	302^{d}	11.24
Yield (kg/ha)	1920^{c}	3210^{b}	3480^{a}	3120^{c}	21.19

Table 5: Mean deviation (MD), root mean square error (RMSE) and normalized root mean square error (N-RMSE) of measured and simulated surface soil ammonical and nitrate nitrogen (kg/ha) under different treatment

Treatment	Ammonical Nitrogen			Nitrate Nitrogen		
	MD	RMSE	N-RMSE	MD	RMSE	N-RMSE
Control (F0)	-9.08	11.02	4.24	-0.35	2.55	3.14
100%NPK (F1)	-7.15	14.45	4.48	1.76	3.73	3.18
50%NPK+ 50% FYM (F2)	-18.86	31.48	9.03	2.38	4.41	3.38
100%N FYM(F3)	-29.34	54.94	17.84	-2.50	5.40	4.61



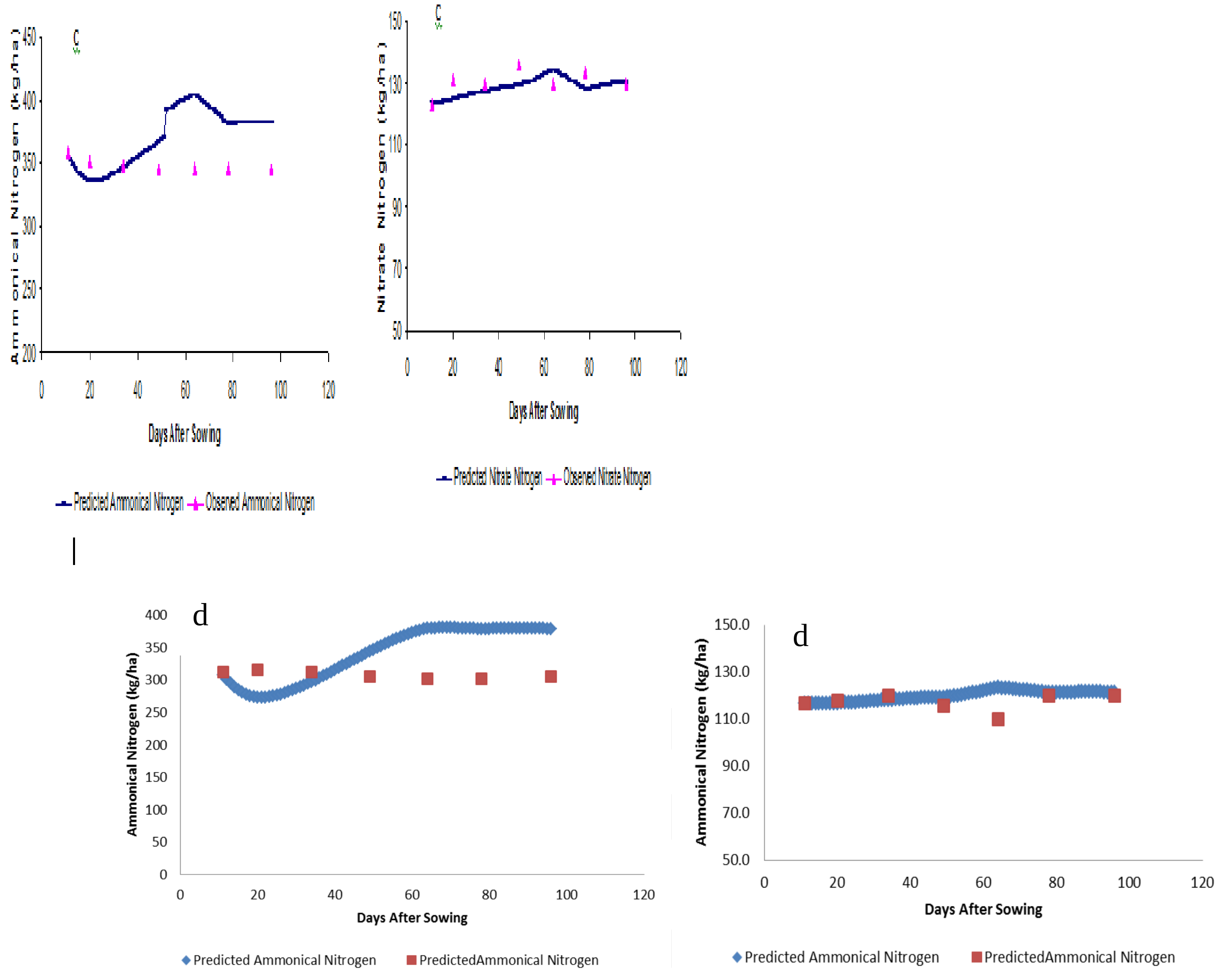


Figure a, b, c and d. Predicted (lines) and observed (symbols) soil ammonical and nitrate nitrogen for treatment of: (a) control, (b) 100 % NPK, (c) 50 % NPK + 50 % N through FYM and (d) 100% N through FYM in an Inceptisol soil of Varanasi, India.