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DNDC MODEL BASED ESTIMATION OF CARBON AND NITROGEN DYNAMICS UNDER INTEGRATED NUTRIENT MANAGEMENT PRACTICE IN RICE-RICE CROPPING SYSTEM

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Abstract

A study was done to estimate C and N turnover following DNDC model in paddy soils of Gazipur and Rajshahi regions under integrated nutrient management (INM) practice with BRRI organic fertilizer. DNDC is a point-scale model; it can extrapolate to a large spatial extent using remote sensing and GIS approaches. This model based estimation of carbon and nitrogen dynamics in two different soils and climates showed that application of BRRI-organic fertilizer (2 t ha^{-1} dry weight basis) along with 70% recommended urea-N and 100% MoP and Gypsum following integrated nutrient management (INM) approach improved soil organic carbon stock and reduced N_2O emission as well as global warming potential (GWP) in the rice-rice cropping system compared to exclusive use of recommended dose (RD) of chemical fertilizers. Ten years' average data demonstrated that soil organic carbon increased about 9% in Gazipur and about 40% in Rajshahi due to the use of INM over chemical fertilizer practice. Moreover due to INM practice with BRRI-organic fertilizer, the net GWP decreased by 5.89% in Gazipur and 9.53% in Rajshahi region. The model was calibrated and validated (RMSE and *d* value) using 10 years' grain yield data of the two regions and found satisfactory up to the level.

Keywords: BRRI-organic fertilizer, Carbon stock, Global Warming Potential, N_2O emission, RMSE & *d* value

1. Introduction

Soil is one of the greatest carbon (C) reservoirs of the planet. It has potential for C sequestration and thus slows down global warming by reducing CO_2 emissions depending on environmental conditions (Karlen *et al.,* 2001). Soil biochemical and physical processes are governed by the environment and management practices such as methods of cultivation, types of crop, nutrient management practices, temperature, moisture, soil texture, etc.

BRRI-organic fertilizer could be a good source of nutrients, especially N and P for rice production (Naher *et al.,* 2020). Healthy soil biology and ecosystem depend on soil organic matter (SOM) content and its application in an agricultural land can improve soil quality and crop yield (Sun *et al.,* 2010).

BRRI-organic fertilizer is made of vegetable wastes/degradable kitchen wastes (80%), rice husk biochar (15%), rock phosphate (5%) and consortium (10) of plant growth promoting bacteria. Added phosphate solubilizing bacteria are able to ensure bio-available P from rock phosphate. The beneficial bacteria added in this biofertilizer are indigenous and isolated from favorable and unfavorable rice ecosystems (drought, saline and acid soil). The microorganisms involved in this BRRI-organic fertilizer are grouped as free-living N_2 fixing bacteria, phosphate solubilizing bacteria (PSB) and indole acetic acid (IAA) producing bacteria. The prepared biofertilizer has been tested during 2016 to 2020 in Aus, Aman and Boro rice seasons at BRRI farm Gazipur, BRRI R/S Rajshahi, BRRI R/S Barisal, BRRI R/S Cumilla, and at farmers' fields of Rajshahi, Pirojpur, Kuakata, Kishoreganj, Borguna and Dacope. The results of the research stations and farmers field proved that application of BRRI-organic fertilizer @ 1 t ha^{-1} in Aus and 2 t ha^{-1} in both T. Aman and Boro season can save fulfill 25-30% urea and 100% TSP fertilizer requirement for rice production and gave statistically similar or higher (0.5 to 1 t ha^{-1}) grain yield compared to full (100%) chemical fertilizer. The research result also proved that application of BRRI-organic fertilizer in the BRRI farm Gazipur for five consecutive years improved soil carbon stock for by 6 to 13% (Naher *et al.,* 2021). However, its impact on environment such as Nr turnover in different soils is not studied yet. The DNDC model can assess the soil organic matter turnover, which can indirectly indicate the state of degradation (Li *et al.,* 2016). It is a point-scale model and can extrapolate to a large spatial extent using remote sensing and GIS approaches. In the present study we used DNDC model to predict long term fate of use BRRI organic fertilizer for rice production in two different regions having diverged soils and climates. Hence, the objective of this study was to estimate C and N turnover following DNDC model in paddy soils at Gazipur and Rajshahi due to INM practice using BRRI organic fertilizer

2. Materials and Methods

2.1 Experiment set up

BRRI Gazipur site is located at Bangladesh Rice Research Institute (BRRI) farm, Gazipur (29.54^{0}N, 90.24^{0}E), . The climate of the site is sub-tropical humid, with a dry season from November to February. Annual rainfall is 2200 mm and annual mean temperature is 29^{0}C. Mean temperatures for the warmest and coolest months vary by less than 5^{0}C and mean annual relative humidity is 89%. The farm represents grey terrace soil, clay loam in texture. SOM 1.14% and total N 0.08%. In this study, yearly rice was grown in two seasons as irrigated Boro (January–May) and rainfed T. Aman (July–December). Rajshahi, is located at latitude, 24.3740; longitude, 88.6011 at an elevation of 22.01 meters (72.21 ft) above sea level, Rajshahi has a sub-tropical wet and dry or savanna climate (Classification: Aw). Its temperature is 28.49^{0}C (83.28^{0}F) which 0.75% higher than Bangladesh average. Under the Köppen climate classification, Rajshahi has a tropical wet and dry climate. In Rajshahi, the average hot maximum temperature is about 32 to 36^{0}C and minimum temperature recorded in the January is 7 to 16^{0}C. On the contrary, in Gazipur average maximum temperature is 32.74^{0}C and minimum is 8.26^{0}C. The experiment was done in clay loam soil, having 7.2 pH and 1.25.% organic matter. The treatment combinations for both locations were: T_1: Exclusive chemical fertilizers (balanced doses of N, P, K, S and Zn); T_2: Integrated nutrient management (INM) - (70% N as urea + 100% K +S+Zn) + (2 t ha^{-1} BRRI-organic fertilizer), and T_3: control (no any fertilizer). The recommended (100%) dose of chemical fertilizers for N–P–K–S–Zn were applied @ 138–10–80–20–1 kg ha^{-1} in Boro season rice and @ 80-10-50-10-1 kg ha^{-1} in T. Aman season. The fertilizer rate was calculated following soil test based nutrient requirement with a yield target of 7.5 t ha^{-1} for Boro and 6.0 t ha^{-1} for T. Aman seasons.

2.2 DNDC model calibration and validation

The DNDC9.5 version was used for this study. Experimental file was initiated using original field datasets of each treatment. Weather file was created from weather data obtained from Gazipur and Rajshahi meteorological stations. Agronomic management practices such as seeding, transplanting, seedling weight, fertilizer application, organic amendment and irrigation schedule were done according to model requirements for each season. Genetic crop coefficient parameters were adjusted using a default rice variety for Boro rice. The model was calibrated and validated (RMSE and d value) using original SOC data of the last 10 years.

Fertilizer inputs, management practices, manure amendments, irrigation and flooding, crop rotation, land preparation and harvesting dates were fed to the model according to the experiment schedule. The SOC analysis data of different treatments were the base to calibrate the DNDC model. However, microbial activity index parameter was set at 1% for INM (T_2), and 0.6% for balanced fertilizer treatments. During the calibration process, all parameters related to SOM and crop growth were chosen based on sample analysis in the laboratory.

2.3 Statistical analysis

Evaluation of model performance was done based on comparison of the simulated values provided by the model with actual values obtained from field measurements. However, statistical model evaluation was done using correlation coefficient, mean ratio and mean difference (RMSE), and mean difference between observations and simulation.

3. Results and Discussion

3.1 Crop yield

Irrespective of treatments, the average annual grain yield (Boro + T. Aman) of the last 5 years showed higher grain yield in the INM practice (BRRI-organic fertilizer + 30% reduced N fertilizer +100% K, S, Zn) compared to recommended fertilizer (RD) practices (Fig. 1). Comparing annual average grain yield of two locations grain yield was higher at Gazipur than Rajshahi (Fig. 1).

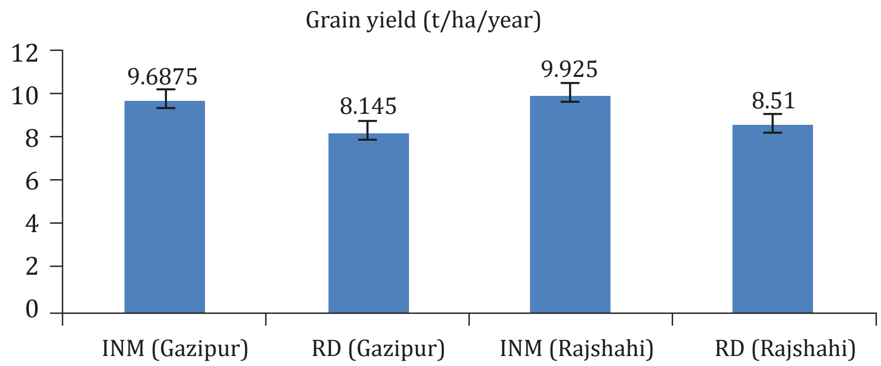

Fig. 1 *Annual grain yield recorded in Gazipur and Rajshahi due to different treatments (ten years' average data)*

3.2 Carbon and nitrogen dynamics

Annual N uptake is higher in the Gazipur compared to Rajshahi. Compariing the two treatments, the INM practice showed lower N_2O emission which could be due to the addition of organic matter. In contrast a negative N balance was observed in the recommended fertilizer treatment. Between two locations, significantly higher negative N balance was noted in the Rajshahi soil than that in Gazipur soil (Fig. 2)

In Rajshahi, there was no significant difference found for CH_4 emission in both of the treatments. The higher temperature may induce methanogens activity. However in the Gazipur higher CH_4 emission was observed in the recommended fertilizer treatment, this may be due to the BRRI-organic fertilizer which was fully decomposed. Obviously, SOC storage is higher in case of INM practice (BRRI organic fertilizer 2 t/ha + 70% RD-N + 100%

K, S, Zn) practice compared to recommended fertilizer dose. Net Global warming potential is higher in the recommended practice compared to INM practice. Between two locations net global warming potential is higher in Rajshahi compared to Gazipur area (Fig. 2).

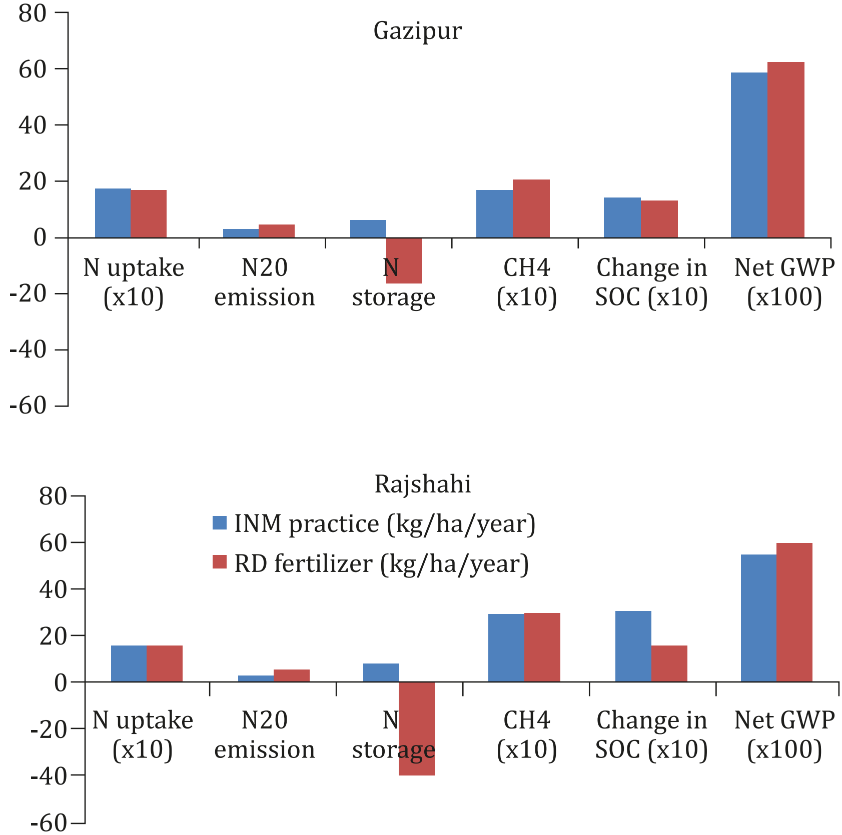

Fig. 2 *Carbon & nitrogen dynamics and GWP in Gazipur and Rajshahi soil under INM approach (ten years' average data)*

3.3 Model evaluation

Model evaluation was performed using crop yield data generated from original experiments conducted in the both Gazipur and Rajshahi. Statistical analysis for root mean square error (RMSE), and mean difference between observations and simulation was performed (Table 1). Statistical values (nRMSE) obtained for INM and balanced chemical fertilizer treatment were within the range, and *d* value gave the best fit for all the treatments for all models. Moreover, values estimated using the DNDC model was closer to the observed data.

Table 1. Statistical analysis of model-generated data for rice–fallow-rice cropping system

Treatments	nRMSE	D
INM (BRRI organic fertilizer +70% Urea-N)	7.9	0.99
Recommended fertilizer	4.1	0.96
Control	3.6	0.97

4. Conclusions

Application of BRRI-organic fertilizer along with 70% recommended urea-N and 100% recommended K-S-Zn improved SOC stock and reduced almost 30-50% N_2O emission and global worming potential in the rice – rice cropping system compared to recommended chemical fertilizers.

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Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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