Working Paper

N_2O emission from Synthetic Fertilizer
A Scenario Analysis and its Impact on Indian Agriculture

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Emissions from synthetic fertilizer need considerable attention in order to ensure greenhouse gas (GHG) reduction. The emissions can be reduced by adoption of suitable technologies and appropriate policy measures. In this paper, a scenario analysis of synthetic fertilizer's usage in Indian agriculture and its potential towards contributing in GHG emissions is presented.

SCENARIO ANALYSIS

The impact of augmented irrigation on direct N_2O emissions has been studied in many cropping systems across the globe. There have been clear linkages of optimal, surplus, and deficit irrigation situations with tillage (land-based practices) and fertilization, which provided a platform for the development of various scenarios in this study. As per a study based on *in situ* farm measurements and regional variabilities across five different regions in Southeast Asia (India, Pakistan, Nepal, Bangladesh, and China), the seasonal N_2O flux was found to be ranging from 0 to 33 kg N_2O/ha and an hourly flux from -200 to 15,000 µg N_2O/m^2 (Kritee, Nair, Zavala-Araiza, *et al*. 2018), as shown in Table 1. Curve fittings on the time series from 2005 till 2050 showed a linear fit ($R^2 = 0.95$), as shown in Figure 1A. Considering the total rice paddy area of approximately 44 million ha (Statista 2018) and the emission factor as 0.3 (Sapkota, Vetter, Jat, *et al*. 2019), the base case calculations were projected till 2050, which were also verified and tallied with the N_2O direct emission values estimated by FAO for 2005 to 2015 (FAO n.d.). The GHG emissions linked to direct N_2O emissions by 2030 and 2050 are given under the Business-As-Usual (BAU) scenario. Two ensembles were considered to project various mitigation scenarios. Broadly, the following two abatement ensembles comprising various scenarios were considered in the present study: a) improved farming practices through better land and irrigation management (Figure 1B); and b) options to improve nitrogen-use efficiency (NUE; Figure 1C).

By considering the ensemble where studies were conducted to understand the impact of the interaction of tillage and augmented irrigation on direct N_2O emissions from rice fields, five cases were observed. As per a study conducted by Fangueiro, Becerra, Albarrán, *et al*. (2017) in a loam soil (Extremadura, southwest Spain [39° 06′ N; 5° 40′ W]), sprinkler irrigation with no-till resulted in 57% less N_2O emissions as compared to controls. This accounts for 120,002 and 140,283 Gg N_2O emissions (Case 1) projected for 2030 and 2050, respectively (Base Case, i.e., BAU; FAO), considering approximately 50% of the total rice paddy cultivation (~22 million ha) under irrigated paddy as compared to BAU, which is 152,869 and 178,704 Gg. Similarly, in the case of conventional tilling with sprinkler irrigation systems, 25% N_2O emissions from rice fields were estimated, which accounts for 38,217 and 44,676 Gg of N_2O emissions (Case 2; Figure 1B) for projected years 2030 and 2050, respectively. Suitable water-saving irrigation systems including sub-surface and surface drip irrigation systems were studied by Maris, Teira-Esmatges, Arbonés, *et al*. (2015). The study found that the systems resulted in 68% reduction in N_2O emissions which translates to the projection of 74,906 and 87,565 Gg of N_2O emissions for 2030 and 2050, respectively (Case 3), and thus, are advantageous over the drip systems (36% reduction in N_2O; Wu, Guo, Fend, *et al*. 2014). The study conducted by Kumar, Nayak, Mohanty, *et al*. (2016) in eastern India found that smart irrigation strategies that ensure soil water potential (-40 to -60 kPa) with low irrigation water result in 49% less N_2O emissions compared to continuous flooding irrigation systems which account to 103,951 and 121,519 Gg of N_2O emissions for 2030 and 2050, respectively (Case 4). In a study conducted by Li, Dong, Oenema, *et al*. (2019) at Luancheng Agro-Ecosystem Experimental Station in the North China Plain in Hebei (37°53′ N, 114°41′ E; elevation 50 m above sea level), it was found that low-volume irrigation results in 12% reduced N_2O emissions, which translates to the projection of 134,525 and 157,260 Gg of N_2O for 2030 and 2050, respectively (Case 5).

N losses have been resulting in undesirable emissions that are at times governed by the nitrogen use efficiency of the crop. Various practices under site-specific nitrogen management (SSNM) involve field-specific N management strategies that include quantitative knowledge of field-specific variability in crop N requirement and expected soil N supplying power (Yadav, Kumar, Parihar, *et al*., 2017). This is to establish an optimum harmonization between supply and demand of N for a plant's growth (Giller, Chalk, Dobermann 2004; Dobermann and Cassman 2004). Such practices with better diagnostics including SPAD (soil plant analysis development) and LCC (Leaf colour chart) have resulted in the detection of approximately 12% reduction in direct N_2O emissions, which translates to be 134,525 and 157,260 Gg of N_2O emission for 2030 and 2050, respectively (Case 1; Figure 1C) compared to the BAU scenario (Base Case, FAO). Secondly, smart approaches including Integrated Nitrogen Management involve optimum use of indigenous N components, i.e., crop residues, organic manure, biological N fixation, chemical fertilizer, and their complementary interactions to increases N recovery (Olesen, Sørensen, Thomsen, *et al*. 2004). The complementary interaction of N with secondary and other micronutrients directly improves NUE. This approach with the application of slow-release fertilizers and nitrification inhibitors can potentially result up to approximately 22% decrease in direct N_2O emissions (Dobermann, Witt, & Dawe 2004), which accounts to a projection of 119,238 and 139,389 Gg of N_2O emissions for 2030 and 2050 (Case 2). However, high cost is a limitation in such cases.

Table 1. Calculations for the base case for N_2O-related direct emissions from agricultural lands in India

S. No.	Attributes	Value	Units	Sources
1	Total agricultural area	44.12	MH	https://www.statista.com/statistics/
2	N_20 flux	2100	üg/m²/h	https://www.pnas.org/content/pnas/115/39/9720.full.pdf
3	N_20 seasonal emissions	10	kg N_20/ha/season	https://www.pnas.org/content/pnas/115/39/9720.full.pdf
4	Annual N_20 emissions	20	kg N_20/ha	
5	Emission factor	0.3	--	https://www.sciencedirect.com/science/article/pii/S0048969718345819
6	Net emissions	264,720,000	kg N_20/annum	
7	Net direct emissions ($C0_2$ equivalent)	82,063,200,000	k$C0_2$eq./annum	
8	Net direct emissions (Mt$C0_2$ equivalent)	82.0632	Mt$C0_2$eq./annum	
9	Net direct emissions (Gg)	82,063.2	Gg/annum	

Ecological fertilization approaches forgo using synthetic N and apply an array of methods for incorporating available N into soils (legumes, manures, composts, agro waste, etc.). Such interventions can cut off approximately 50% of the GHG emissions (Tirado 2009). Also, reduced N loads can lead to an offset of approximately 30% of the direct N_2O emissions. A combination of ecological fertigation practices and reduced N loads aids in improved NUE that is realizable to offset up to 30% of N_2O emissions (Tirado, Gopikrishna, Krishnan, *et al.* 2010). In this context, Case 3 deals with ecological fertigation with reduced N loads scenario that individually reduces direct N_2O emissions to 96,307 and 112,584 Gg of projection for 2030 and 2050, respectively.

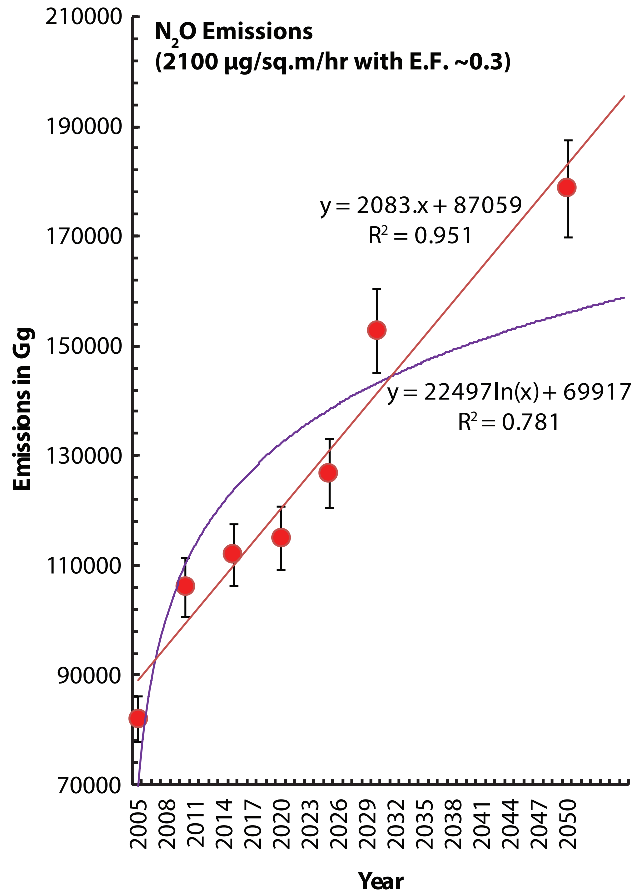

Figure 1A: Trend and curve fitting for emissions (direct emissions as per FAO data, 2005 till 2017), (projected emissions for 2020 to 2050 as per literature)

Transgenic/genome-editing approaches by genetic engineering of rice crop is a suitable method for improving NUE. Studies conducted by Shrawat, Carroll, DePauw, *et al.* (2008) elucidated the development of nitrogen-efficient plants, for example, rice *(Oryza sativa L.)* which was genetically engineered by introducing a barley AlaAT (alanine aminotransferase) cDNA driven by a rice tissue-specific promoter OsAnt1. This resulted in increased biomass and grain yields w.r.t. control. There was approximately 60% NUE increase that corresponds to almost half of the total N_2O (178,704 Gg) emission reduction. If all the rice varieties are replaced with these kinds of rice cultivars with similar efficient NUE, ideally the N_2O emission projections would be 126,117 and 147,431 for 2030 and 2050, respectively. Similarly, a long-term study conducted by Bingham, Karley, White,

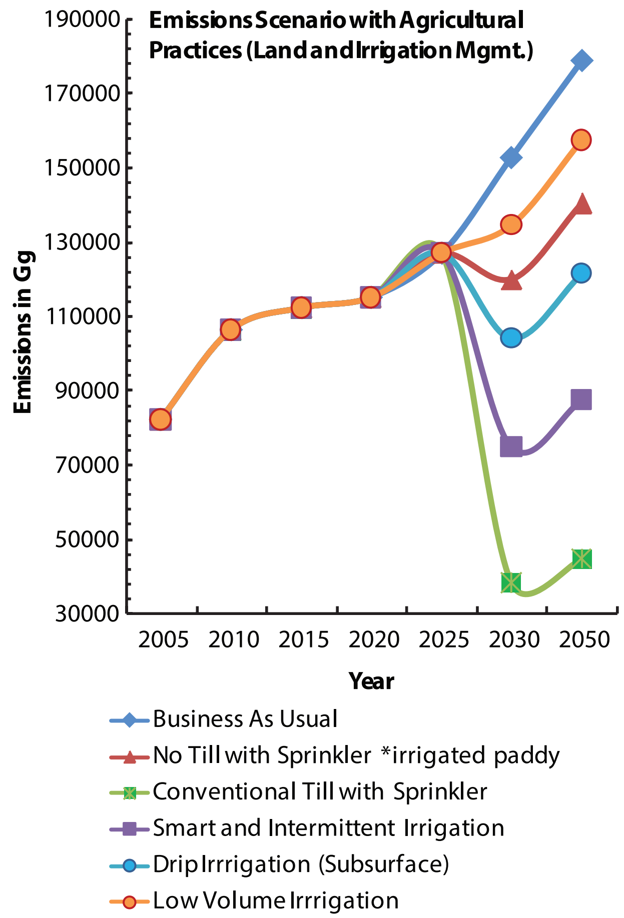

Figure 1B. Scenarios in GHG emissions - N_2O (direct emissions) due to improved Land management and Irrigation practices

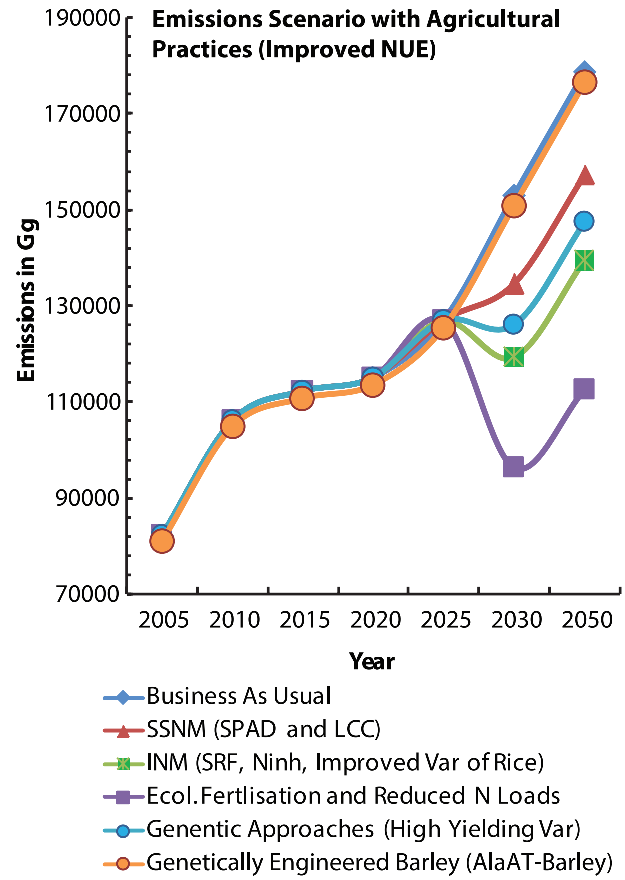

Figure 1C: Scenarios in GHG emissions - N_2O (direct emissions) due to improved NUE using various strategies

et al. (2012) for the last 75 years showed a consistent decreasing trend in the direct N_2O emissions by 1.25% every year due to genetic improvements in NUE through conventional breeding. Cumulating this number from 2005 onwards and projecting it for the next three decades, the average reduction of GHG emission would be 4.96%. Therefore, this meagerly influences the trends when compared to the base case, and negligibly brings down the direct emission as compared to other scenarios with emissions as 151,517 and 176,810 Gg for 2030 and 2050, respectively. Thus, the integration of improved packages and practices of crop cultivation has a significant potential for offsetting current trends in GHG emissions towards achieving sustainable developmental goals.

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