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Targeted Nitrogen Management to Increase Cereal Production while Reducing Nitrogen Consumption in India

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Abstract

Nitrogen is the most essential nutrient in crop production but a substantial portion of applied N to the cropland is lost into the environment by means of volatilization, leaching, or emissions causing multiple adverse effects on terrestrial and aquatic systems and on human health. Consumption of Fertilizer-N in India, the second largest consumer of N fertilizer in the world, has increased steadily since 1960s and is expected to further increase in the future to produce more food to meet the projected food demand. However, inequality is the core of the problem with some regions applying more N fertilizer than required leading to negative environmental externalities and other regions applying far less N leading to lower yields and soil mining adding to the vicious cycle of food insecurity. A data-based approach to identify areas of N surplus/N deficit, the magnitude of nitrogen-use-efficiency (NUE) and N harvest gaps helps develop location-specific fertilizer management strategies. Here, we developed a global NUE atlas using various sources of data on N input and N output to show the priority areas of N management work to address the issues of over- and under-fertilization. Adopting this data-based approach and using examples from field and national level analyses, we suggest spatially tailored agronomic, economic, and policy strategies of N management to address food, fertilizer, and climate crisis in India.

Keywords: Nitrogen, Rice, Maize, Wheat, Nitrogen-Use-Efficiency, Food Security, India

Introduction

India is the second largest consumer of nitrogen (N) fertilizer in the world after China. With the increasing share of consumption and imports of fertilizer, India has emerged as the dominant player in the world fertilizer market since the late 1970s. Over the last 50 years, N consumption in India has increased by over 800% but the average NUE has not increased since the 1980s. Projections indicate that cereal production will have to increase by about 1-2% per annum, respectively, over the next four decades to meet the food demand in India. This means that the consumption of N fertilizer in India will continue to grow in the future. At the same time, nutrient-use-efficiency (NUE) in India is one of the lowest in the world (Farnworth *et al.*, 2017) suggesting that opportunities exist to increase crop production while reducing N consumption by improving NUE. This implies that although increased N input has had tremendous positive benefits concerning food security, a significant amount of applied N is lost into the environment, leading to increased production cost, decreased profit from agricultural production, and numerous negative environmental externalities. Fertilizer recommendations in India are based on the response trials conducted to represent wide geography but in reality, India has such a diverse agro-ecological and socio-political environment that such blanket recommendation leads to over-fertilization in some fields and under-fertilization in others, even within an agro--ecological zone. Given the situation, we need to find ways to eliminate over-fertilization in some places and soil mining in others to meet food security and environmental goals. For this, we need a data-based approach to identify areas of fertilizer surplus and fertilizer deficit in order to develop location-specific fertilizer management strategies. Using various sources of data on N input and N output, we developed a high-resolution gridded database of NUE and N surplus showing the priority areas of work to address the issue of over- and under-fertilization and recommend differentiated approaches (technological, market and policy instruments) across over- and under-fertilized agricultural landscapes.

Using crop N input and output data and information potential N harvest, we classified rice, maize and wheat areas based on NUE, N surplus/deficit, and N harvest gap (Fig. 1). For this, we considered all source of N inputs into the production areas i.e. synthetic N input inputs (Lu and Tian, 2017), manure N (Zhang *et al*., 2017) residue N (IPCC, 2019) atmospheric N-deposition (Eyring *et al*., 2013), N mineralization (IPCC, 2019). We used harvested crop area and crop yield from Spatial Production Allocation Model (SPAM) and their corresponding N content (Feliciano *et al*., 2017) to calculate N output. For each crop, the yield gap was calculated as the difference between SPAM and potential yield obtained from the FAO Global Agro-Ecological Zones (GAEZ) v4 data portal (https://gaez.fao.org/). N surplus or deficit was determined as the difference between N input and output, NUE as ratio of N output to N input and N harvest gap as the difference between potential N removal (i.e. potential yield x N content) and actual N removal (SPAM yield x N content). We suggest spatially targeted N management strategies based N status-quo in maize, rice, and wheat fields across India.

Results

Our data-based analysis shows that maize field in the transact of the Indo-Gangetic Plains (IGP) and Northeastern India has high N surplus, low NUE and high removal gap (**Figure 1**). Low removal gap in western arid area and eastern tip is mainly driven by lower potential yield. In wheat field, central river basin and eastern coast of India experience high N surplus, low NUE and low to high N harvest gap while western semi-arid region experiences medium NUE and low removal gap. Western most semi-arid region of India is characterized with N deficit, medium NUE and low N removal gap because of low input and low productive area. Most of the rice growing areas in India has high N surplus, low NUE and low (central river basin

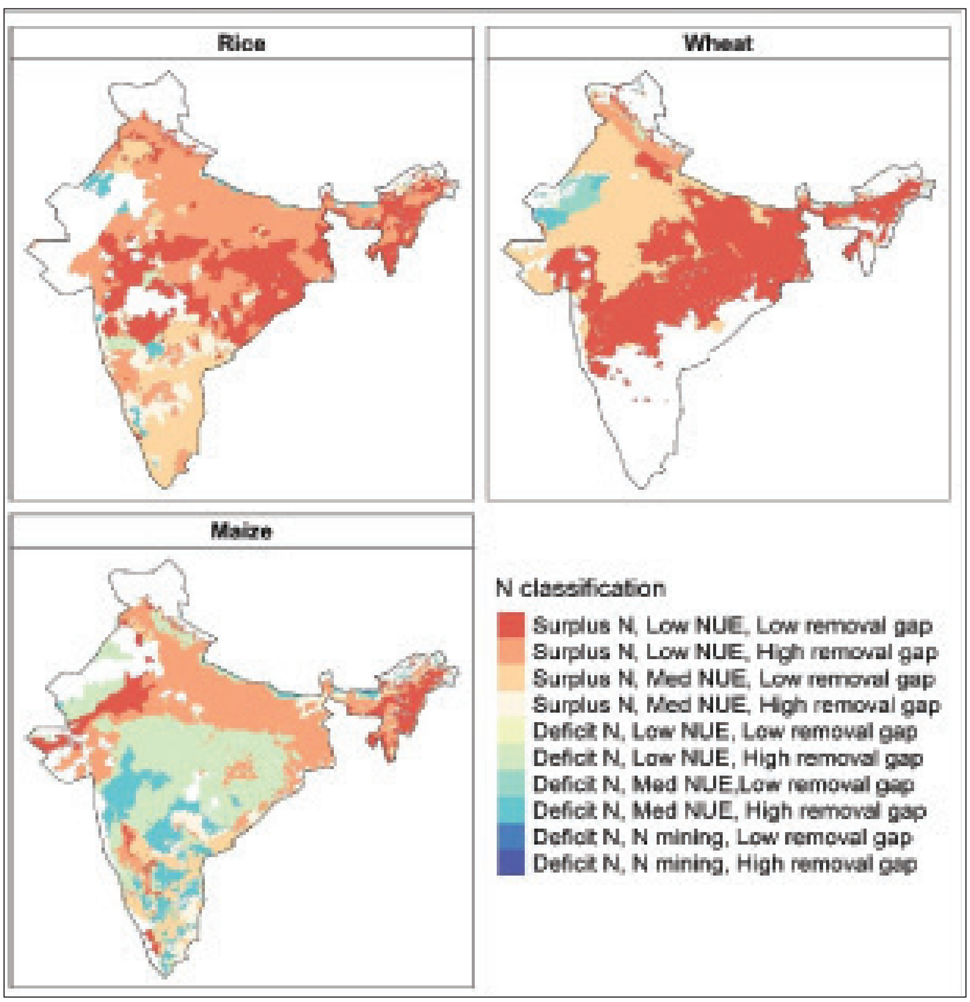

Figure 1: Rice, Wheat, and Maize production area in India classified based on N surplus/deficit, nitrogen-use-efficiency and N removal gap.

and eastern region) to high (transact of IGP) N removal gaps except in southern region where rice fields show medium NUE and low N removal gap. Low N removal gaps in central river basin and eastern region of India is mainly due to low production potential in this region.

Based on these analyses, we identified areas with excessive N use i.e. pollution hotspots and emerging pollution hotspots, areas with inadequate N use i.e. N mining hotspots and emerging production hotspots and areas with minimum N use concern i.e. minor or non-hotspots and improvements in such hotspots. Inspired by the apparent success of Green Revolution and due to availability of subsidized N fertilizer, farmers applied N fertilizer in quantities in excess of the crop's requirement leading to persistent or worsening potential N surplus across the countries. In such areas, efforts should be placed in increasing NUE to secure yield gains while minimizing fertilizer consumption through systematic implementation of best fertilizer management practices. A number of technologies (e.g. 4R nutrient stewardship, precision agriculture, fertigation etc), tools (e.g. Leaf color chart, GreenSeeker etc) and decision support systems (e.g., Agvisely, GreenSat, Nutrient Expert, Crop manager etc) have been developed to help farmers implement integrated soil fertility management based on crop requirement thereby increasing NUE and minimizing N surplus. Federal and state governments should focus their efforts on contextualizing and scaling such tools, techniques and DSS through digital extension, citizen science, ICT, decision support systems and partnership. Increasing NUE by diversifying cropping systems could also help increasing food production while reducing fertilizer N consumption in such areas. Areas characterized by N mining and emerging production hotspots require increasing N supply through increased access to fertilizer and increasing farmers' awareness on field-level optimization through organic (e.g. use of farm-yard-manure, producing compost, growing/integrating legumes etc) and inorganic fertilization. Promoting integrated organic and inorganic N management is a 'no regrets' fertilizer-N management strategy. While government should continue research on cutting-edge nature-based solutions for managing nitrogen, carbon and greenhouse gas simultaneously for net zero farming (e.g. BNF, BNI, ISFM), emphasis should also be given to repurposing fertilizer subsidy and connect farmers with carbon market as well as private sectors for responsible sourcing.

Conclusion

While India is second largest consumer of fertilizer N in the world, N fertilizer use in India is going to further increase in future necessitated by increased food demand. Opportunities exist to increase NUE to increase food production yet reducing fertilizer N consumption but differentiated responses are needed based on the status-quo of N surplus/deficit, NUE and N harvest gap. Based on the trajectory of N status across rice, wheat and maize areas in India, we suggest relevant N management strategies to address food security, climate change and number of other sustainable development goals.

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