Agricultural Nitrogen Use & Its Environmental Implications

Agricultural Nitrogen Use & Its Environmental Implications provides a comprehensive, interdisciplinary description of problems related to the efficient use of nitrogen in agriculture, in the overall context of the nitrogen cycle, its environmental and human health implications, as well as various approaches to improve N use efficiency. The book has been divided into six sections and targets graduates, postgraduates, research scholars and policy makers in Agricultural and Environmental Sciences.

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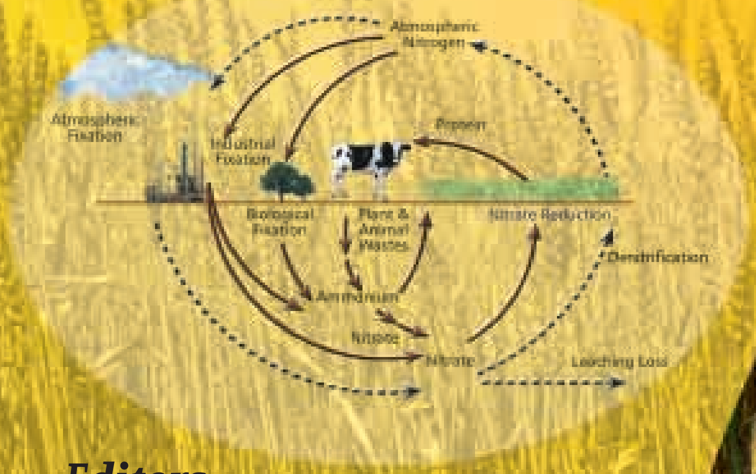

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AGRICULTURAL NITROGEN USE & ITS ENVIRONMENTAL IMPLICATIONS

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Towards an Integrative Understanding of Reactive Nitrogen

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Summary: Nitrogen is an essential input to meet our ever growing needs for food, feed and fiber, but it can be used only in its reactive forms, which include inorganic forms such as NH_3, NH_4^+, NO_x, HNO_3, N_2O, NO_3^-, and organic forms like urea, amines, proteins and nucleic acids, that constitute the global N cycle. While their natural formation is too little to meet our needs, their natural removal is too little for our comfort. Anthropogenic perturbations of the natural N

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cycle over the last several decades have led to the increasing accumulation of inorganic forms of reactive N in the soil, water and air, intentionally through agriculture and unintentionally through fossil fuel consumption and other activities, adversely affecting human health, biodiversity, environment and climate change. Fertilizers, whether chemical, biological or organic, constitute a major source of reactive N in areas of input-intensive agriculture, primarily due to low N-use efficiency of most crops. One of the major challenges facing us is to ensure adequate availability and rational use of appropriate fertilizers for agriculture, while preventing the unwanted accumulation of reactive N from agricultural and industrial sources. This article provides an overview of the emerging issues related to reactive N in the Indian context, and underscores the need for an integrated approach to research and policy in order to tackle them in a timely and effective manner.

1. INTRODUCTION

Nitrogen (N) has a great impact on our food security, economy, development and environment. It is necessary for all forms of life. In many ecosystems on land and sea, the supply of nitrogen controls the nature and diversity of plant life, the population dynamics of both grazing animals and their predators, and vital ecological processes such as plant productivity and the cycling of carbon and soil minerals. This is true not only in wild or unmanaged systems, but also in most croplands and forestry plantations as well.

2. NITROGEN PARADOX

We live in a world surrounded by gaseous nitrogen (N_2), but more than 99% of this nitrogen is not available to more than 99% of the living organisms, due to its relatively unreactive nature. Therefore, barring a few N_2-fixing microorganisms and legume crops that harbour them as symbionts, the entire living world depends on reactive forms of N compounds. While plants are capable of utilizing inorganic N compounds such as nitrate and ammonium ions, animals acquire them through the food chain in readily usable organic forms (amino acids, nucleotides etc.). The natural processes of producing reactive N compounds from atmospheric N_2 gas by lightning or N_2-fixing microorganisms cannot meet the agricultural demands for food, feed and fiber production for the continuously increasing human population. Artificial or anthropogenic production by any means, whether chemical fertilizers, biofertilizers, or organic N manures must ensure their adequate utilization, failing which reactive N compounds tend to accumulate in the environment, as the natural processes of their denitrification (back to inert N_2) cannot cope with the scale of their accumulation. In addition to the N compounds produced deliberately for use as fertilizers, reactive N species are also formed as by-products of anthropogenic domestic sewage, dairy effluents, as well as fossil fuel-consuming industries and vehicles. In the last 150 years, the annual inputs of reactive nitrogen primarily from anthropogenic sources to the earth's soil and water bodies have nearly doubled. In some places, excessive pollution of the ground, water, and air with reactive N compounds has already begun to adversely affect the public health and ecology. While some of these concerns may be regional or national in nature, the ozone depleting and greenhouse effects of NO_x gases are an issue of global concern. This is sum and substance of the nitrogen paradox: We can't use what exists naturally in abundance (N_2). What we produce in abundance either deliberately (N fertilizers) or as by-products (of other industries) is not fully usable or available for agriculture, and we can't get rid of the unused excess to avoid adverse consequences.

3. AGRICULTURAL NITROGEN USE

Nitrogen fertilizers give large economic gains in modern farming systems, and therefore, their application has been steadily increased to meet the increasing food demand. The dramatic increase in food production during the era of green revolution was accomplished mainly by using improved seed varieties and hybrids with better responsiveness to water and fertilizers, particularly nitrogenous fertilizers. Nitrogen fertilizers constitute nearly 70% of the total fertilizer material used for this purpose. It is currently estimated that as much as 40% of the world's food production has become possible because of the application of fertilizers produced using the Haber-Bosch process of converting N_2 and H_2 to NH_3. In India, the increase in fertilizer N use in the last 3-4 decades has resulted in unprecedented increase in agricultural production in the northwestern India leading to food security of the country. With 6 million tonnes N-fertilizer in 1989-90 to 10.4 million tonnes in 1998-99, every million tonnes N-fertilizer used resulted in 10 million tonnes of cereal production. The per hectare use of nutrients from fertilizers increased from less than a kilogram in the 1950's to more than 100 kg per hectare of gross cropped area by 2000. Accordingly, the all India annual consumption of fertilizers increased from 70,000 tonnes in 1950-51 to nearly 18 million tonnes at present. India is currently the third largest producer and consumer of fertilizers (after China and USA), and fertilizer usage is bound to increase with further intensification of agriculture. In the process, agricultural N use has become the primary source of injecting excessive amounts of reactive N into different ecosystems.

However, the expansion of fertilizer use has not been uniform. While chronic N-deficiency continues to be a problem in majority of the Indian soils, the fertilizer N use may be as high as 300 kg ha^{-1} yr^{-1} in the intensively cropped regions of northwestern India. This has led to a peculiar situation in which demands for the expansion of fertilizer N-use in some areas coexist with the concerns over the environmental hazards of excessive and inefficient N fertilizers use in other areas. While the interest in organic manures and biofertilizers is increasing (and rightly so), these can at best meet only a fraction of the total demand for fertilizers, at least in the next few decades. In any case, the environmental consequences of the accumulation of reactive N are the same, regardless of its chemical or biological origin.

4. NITROGEN USE EFFICIENCY IN AGRICULTURE

Worldwide, NUE for cereal production (wheat, rice, maize, barley, sorghum, millet, oat and rye) is as low as 33%. The unaccounted 67% represents an annual waste of upto Rs. 72,000 crores. The manufacture of N fertilizers involves huge investments, import dependence, and foreign exchange and also consumes large quantities of non-renewable energy resources such as naptha, natural gas, coal etc. Waste of N fertilizers due to their poor utilization by plants also adds to the pressure on these finite resources. Low NUE for crops also implies higher costs to producers and consumers and therefore reduced competitiveness. Loss of N from soil plant system results from gaseous plant emission, nitrification, denitrification, surface runoff, volatilization and leaching and beyond rooting zones of crops. Many ^{15}N recovery experiments conducted in the country on different crops have reported unaccounted losses of fertilizer N from 20 to 50% depending on the local conditions. Therefore, the losses/ leakages of the reactive N from the agricultural systems are a cause of serious concern for both economic and environmental reasons.

The problems of N-use efficiency are often compounded in Indian agriculture due to the neglect or insufficiency of other nutrients, water, and other critical inputs including better crop varieties and protection from biotic/abiotic stresses. Harvesting high yields with N-fertilizer (especially urea) alone as the major input is at best a short-lived phenomenon. It has been clearly shown that "N-driven systems" are not sustainable, as N becomes a "shovel" to mine the soil of other nutrients, with the result that soils initially well supplied in other nutrients become deficient in them and productivity declines. Scientists have been working at different levels to improve N-use efficiency: improving fertilizer formulations for more balanced plant nutrition and/or prolonged retention of N in the plant rhizosphere, better N management practices such as localized placement, foliar sprays, repeated split doses, integrated nutrient and water management, as well as selection/breeding cultivars for better N-use efficiency, either by conventional or marker-assisted breeding, molecular breeding, or transgenic crops for better N response. The current state of development in each of these aspects has been reviewed in separate chapters of this book.

5. OTHER ANTHROPOGENIC SOURCES OF REACTIVE NITROGEN

Animal husbandry effluents also contribute significantly to the loading of local environments with reactive N compounds. Depending on the local conditions, they may spread to both surface waters and ground waters, as well as contribute to gaseous emissions due to volatilization. Other industrial effluents and domestic sewage also contribute widely to the anthropogenic N-loading to varying degrees, while natural geodeposits rich in nitrogenous compounds contribute to some local concerns. The contribution of gaseous emissions of reactive N compounds from fossil fuel consuming industries and automobile exhausts is becoming an increasingly significant factor not only in the developed countries but also in the rapidly developing countries such as China and India. The burning of fossil fuels such as coal and oil releases previously fixed nitrogen from long-term storage in geological formations back to the atmosphere in the form of nitrogen-based trace gases such as nitric oxide. High-temperature combustion also fixes a small amount of atmospheric nitrogen directly. It is also estimated that by 2020, India alone will be contributing NO_x to the tune of 7.1 million tons annually from road and rail transport sectors.

6. ENVIRONMENTAL CONCERNS

Since the beginning of the last century, mankind has injected increasing amounts of reactive nitrogen into the environment, intentionally as fertilizer and unintentionally as a by-product of combusting fossil fuels. As a result, the global nitrogen cycle is being altered, perhaps more than any other basic element cycle, with grave impacts on biodiversity, global warming, water quality and human health in several parts of the world. Accumulation of reactive N adversely affects the soil, water, as well as air quality. On the surface, they include, soil acidification, widespread N pollution of groundwater and eutrophication of surface waters (including potable water), posing a public health problem and the ecosystem imbalance. The transport of surface reactive N from unused fertilizers, animal wastes and other domestic and industrial sources into streams and rivers and eventually into estuaries and coastal waters is becoming a matter of great concern, as reports are already pouring in regarding O_2 deficiency in Indian coastal waters due to enhanced nitrogen loading from the land.

Human activities are also responsible for affecting air quality due to the accumulation of nitrogen-containing trace gases, including 40% of the nitrous oxide, 80% or more of nitric oxide, and 70% of ammonia releases on a global basis. According to an estimate, out of total emission of NO_x in Asia, China and India accounted for 42% and 17% of the emissions during the year 2000, respectively. In addition to the health impacts of N-loaded air, the ozone depleting and greenhouse effects of NO_x gases from various farm and non-farm sources may pose new concerns for N-C balance, especially for environment and sustainable agriculture. Moreover, while the global C cycle is being perturbed by less than 10% due to anthropogenic activities, the global reactive N cycle is being perturbed by over 90%. The accumulation of NO_x gases has global consequences that cannot be constrained by political boundaries or explained away by local policies.

7. INTEGRATIVE APPROACH

The global nitrogen cycle is now attracting increased attention from scientists, environmentalists, governments, and industry. Industrial emissions of nitric oxide to the atmosphere must be reduced as soon as possible. The problem of excess nitrogen can be addressed by more judicious and efficient applications of nitrogen fertilizers in agriculture, and by the better management of wetland ecosystems that return nitrogen to the atmosphere in its nearly inert or unreactive form—N_2. In fact, it is the ultimate goal of the scientific community to provide policy-makers with reliable estimates of reactive nitrogen transfers to different ecosystems, and to describe balanced, cost-effective, and feasible strategies and policies to reduce the amount of reactive nitrogen where it is not wanted.

In order to prepare ourselves for this challenge, we need a precise understanding of the scale of nitrogen use/misuse/release through various agricultural, industrial, vehicular and other activities and their contribution to the pollution of water and air, with special reference to various point and non-point sources and the biogeochemical N cycle. While well-coordinated nationwide surveys on N in our environment are lacking in India, indications from a few sample studies point to the alarmingly high levels of nitrates in some areas of the country, especially in ground/surface waters. The rise of NO_x levels in the polluted air of our cities often makes eye-catching graphics in the media. We need to clearly integrate the information from various studies, account for their methodological differences, and identify the underlying issues/sources of concern, options for mitigation, and areas that need further study.

One of the most important realizations that emerged from an integrative view of the various aspects of reactive N in the broader developmental context is that the problems of reactive N in agriculture, industry and environment are multidimensional and interconnected. The sheer diversity of research areas/expertise/approaches it encompasses, and the various levels at which the problems need to be identified/tackled calls for an integrated network approach to harness our intellectual, financial, and infrastructural resources effectively.

8. RESEARCH AND POLICY

Considering that N is an essential part of our developmental paradigm, the options for reduction of the accumulation of reactive N in our environment will have to be addressed at many different levels, such as establishing/updating national N information systems; improvements in fertilizer formulations; promotion of biofertilizers while improving the strains for biological N fixation, enhancement of the N use efficiency of our crops and farming systems/practices; reduced dependence on non-renewable energy sources; improvements in fossil fuel quality, fuel-use efficiency and reduction of fossil fuel use/abuse; reduction in NO_x emissions from farming, industrial and vehicular sources, minimizing anthropogenic (including agri-industrial) reactive N load in naturally overloaded areas (e.g., geodeposits) and fragile ecosystems, etc. Many chapters in this book are devoted to reviewing the current level of understanding on various aspects of the nitrogen cycle, with special reference to reactive N in the Indian context in order to highlight the importance of this field, as well as identify the gaps in our knowledge for informed decisions on further research and policy. For example, while many groups are working on biofertilizers, there is a very little understanding of the biology of the nitrogen cycle in the Indian environment. Similarly, emerging research trends abroad to find an environmentally benign alternative to the Haber-Bosch process by developing suitable catalysts from transition metals has not yet been explored in India. In some other areas such as leaf colour sensors, the prohibitive cost of imported equipment makes them unaffordable even for research labs, let alone for farmers. Indigenous development of simple and cost-effective optical sensors can go a long way to inculcate the habit of rational and demand-driven use of N fertilizers. Only an integrative and interdisciplinary understanding of our strengths and weaknesses in tackling the tricky problem of reactive N of our environment would enable us to think of such "out of the box" approaches for research and policy.

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