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FRETILISERS IN INDIAN AGRICULTURAL SYSTEM (II): ADVERSE IMPACTS ON SOIL, ENVIRONMENT, AND HUMAN HEALTH

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ABSTRACT

Long-term fertilizer experiments (LTFE) of India, which received regularly fertilizers for many decades serve as the ideal sites for monitoring buildup of the heavy metals added through them. Soil and plant samples were monitored for the accumulation of these metals. Results presented in Figure 6 did not show any specific pattern/trends of heavy metal accumulation/status in the soils after 35 years of continuous application of fertilizers under different treatment combinations. In general, accumulation of chromium (Cr) and cadmium (Cd) was much higher than lead (Pb), nickel (Ni) and cobalt (Co) (Figure 6). Use of phosphatic fertilizers like, DAP and SSP and organic manures have been identified as the major products responsible for increase in the heavy metal contents in the soil. Phosphate rock used as raw material in manufacture of phosphatic fertilizers contain lot of impurities in the form of heavy metals. At Ludhiana, Cr was recorded in the FYM-amended plot. Since FYM is an output of animal dung which is fed on fodder probably grown on soil contaminated with Cr, this could be the route of its entry into the soil. Currently, the contents of heavy metals at all the LTFE centers are far below the safe limits reported in literature

Key Words- Heavy metals accumulation, agriculture, crop, pollution , Nitrate, Urea, Soil health

INTRODUCTION

Some mineral/chemical fertilizers contain heavy metals and even radionuclides, in low quantities, and their excessive use in agriculture has a potential of creating environmental problems. Heavy metal contents in fertilizers and FYM used in India are given in Table 2. Perusal of data shows that the heavy metal impurities are more in SSP, DAP and FYM as compared to urea and MOP. The fertilizer samples contain heavy metals as impurities, which vary in different gradesof fertilizer depending upon the raw material used for manufacturing. Organic fertilizers especially FYM contain heavy metals, found in complexes with the functional groups such as carboxylic and phenolic groups. When applied to the soils, heavy metals form complexes or chelates with different functional groups and get absorbed by the plants.

Nitrate

In India, there have been reports of a rise in nitrate-related groundwater pollution. One of the main causes of the rise in nitrate (NO3-) levels in river systems and drinking water has been linked to excessive urea use. The NO3- levels in 1,290 samples (27%) of the 4,696 water samples studied, according to the water quality assessment studies conducted in 17 Indian States by NEERI, exceeded the WHO drinking water standards.

Nitrate concentrations in the samples ranged from traces to 450 mg NO3-L-1, according to an analysis of ground water in Srikakulam, Andhra Pradesh, which is located in the Vamsadhara river basin. Nitrate concentrations rose after fertilizer applications, according to Rao (2006). The current effects of nitrate pollution in India's freshwaters are a somber reflection of the legacy of excessive fertilizer and manure application in the past and ongoing unchecked pollution now.

currently. Since 1975 (the year the samples were originally tested), the amount of nitrate-N (NO3-N) in the groundwater in Punjab has been steadily increasing (Bijay-Singh et al., 1995). The Punjab region was designated as a high-risk zone for nitrate groundwater pollution by the Central Ground Water Board of India based on data collected during reconnaissance of the nitrate content in shallow ground waters. Using data related to fertilizer use and a remote sensing and GIS methodology,

According to Chhabra et al. (2010), roughly 29% of the fertilizer N used to rice is lost as nitrate in the coarse textured soils of Punjab. This information was based on soil characteristics, rainfall at a 1 km2 grid size, and N loss coefficients. In Punjab, the weighted average nitrate-N loss due to leaching was calculated to be greater than 50 kg ha-1 year-1.

Water bodies pollutions

Because surface water flow carries applied phosphatic fertilizers, the amount of phosphate in drinking water and rivers may increase. In leafy vegetables like lettuce and spinach, an accumulation of NO3--N in the soil causes greater NO3- uptake by plants, which in turn causes the development of carcinogenic compounds such nitrosamines. The focus of future studies should be on enhancing the management of water and fertilizer in agroecosystems, which can lessen the impact of fertilizers to the nitrate contamination of water bodies (Sattar et al., 2014). The extent of pollution caused by fertilizers is, of course, also influenced by a wide range of other factors. The Bay of Bengal Large Marine Ecosystem (BOB LME) study on nutrient loads exported by rivers to coastal seas in 2000 found that rivers exported 7.1 Tg N and 1.5 Tg P to the BOB LME, with the Ganges, Godavari, and Irrawaddy accounting for 75-80% of the total river export of N and P. By 2050, it was predicted that the river export of N might reach 8.6 Tg (Pedde et al., 2017). As a result of the altered nutritional stoichiometry caused by the increased load in BOB LME (Tripathy et al., 2005), detrimental non-nutritive emissions occurred.

The damming of rivers and an increase in human water consumption are linked to a decrease in the export of particulate N and P. Nutrient exports across the rivers do, however, vary greatly. According to Pedel et al. (2017), rivers that drain into the western BOB LME typically export more N and P than rivers that drain into the eastern BOB LME.

In various inland lakes, rivers, and ponds across the nation, the concentrations of nitrates and phosphates vary significantly (Vass et al., 2015). Due to the application of high amounts of N and P fertilizers, higher concentrations of N and P (1.87 to 6.79 mg L-1) were found in lake, groundwater, and channel waters in western Uttar Pradesh and Mysuru district, Karnataka. In Karnataka, the levels of nitrate were high enough to harm the fish. According to Camargo et al. (2005), long-term exposure to the WHO-set safe limit of 50 mg NO3-L-1 for humans' drinking water can have a negative impact on freshwater invertebrates.

In comparison to the waters of eastern rivers [Brahmaputra (Tr - 0.02 mg L-1), Damodar (Tr - 0.35 mg L-1), Brahmani (Tr - 0.03 mg L-1), and Mahanadi (Tr - 0.03 mg L-1), phosphorus concentration is significantly higher in the waters of north-western rivers [Ravi (0.17 - 0.20 mg L-1), Sutlej (0.12 - 0.15 mg L-1- 0.001 mg L-1], western [Narmada (Tr - 0.10 mg L-1), or southern [Godavari (0.06 - 0.18 mg L-1), Krishna (0.04 - 0.30 mg L-1), and Cauvery (0.02 - 0.94 mg L-1)] India. According to Jindal and Sharma (2011), the inflow of Buddha Nullah at Wallipur, a point close to the industrial area of Ludhiana, which contained industrial effluents rich in nitrates and phosphates, was the cause of the higher concentrations of nitrates and phosphates in water at three points of the Sutlej River in Punjab (Table 3).

Indicating rising P contamination of the river water, phosphate contents increased throughout a 36-year period (1960–1996). The role of industrial effluents was clearly seen in the variations in phosphate content in the Ganges at Haridwar, Kanpur, Prayagraj, Varanasi, and Patna, with Kanpur having the highest levels (0.07 to 0.21, 0.01 to 2.10, and Tr - 2.50 mg L-1, respectively).

In contrast, it was zero in Haridwar, which has no significant industry, throughout 1960, 1980, and 1996, the most industrialized town on the Ganges (Vass et al., 2015). Tiwari et al. (2016) found that the nitrate and phosphate levels were both elevated in a different research.
in Varanasi were greatest (Table 4). Total phosphorus concentrations over 100 ppb (0.1 mg P L-1), the MPCA's 2007 standard, may result in eutrophication. The inland waterways of India may therefore be very eutrophic based on the information currently available on P concentration. Additionally, the N: P ratio, which is often less than 10, in Indian inland waters may affect the likelihood of forming phytoplankton "Bloomers," which could cause fish death.

GREEN HOUSE GASES- GHG

The year 2017 (Abrol and Adhya). About 18 Mt (14% of the world's total N) of fertilizer N is now consumed in India. The main consumer of fertilizer-N is the agroecosystem. The majority of nitrogen fertilizer is consumed by cereals. But because cereal crops utilise nitrogen inefficiently (35%), >65% of applied nitrogen is lost to the environment (Figure 8). Compared to agricultural crops, horticulture crops contribute less nitrogen (N) to the environment; yet, the current high intensity horticultural production methods also release a significant amount of reactive nitrogen (Nr) into the environment. The harmful effects of (N2O), a significant greenhouse gas (GHG) that is 300 times more deadly than CO2, on human health and environmental services are numerous. Ammonia (NH3) and nitrogen oxides (NOx) are significant sources that affect radiation.

The oxidation capacity of the atmosphere through the emission of hydroxyls (-OH) and nitrates, and the atmospheric CO2 budget through the creation of O3. Due to greater nitrogen losses in rice fields due to NH3 volatilization under surface broadcasting of N fertilizers, the NUE is reduced (Ladha et al., 2005). The current rate of growth for nitrogen oxide (NOx) emissions from combustion sources is 6.5% year-1. Comparatively speaking, the population growth rate is lower (2% year-1), and the increase in ammonia (NH3) emissions is even

lower (1%), both as a result of lesser changes in animal numbers. By 2055, Indian NOx emissions will outpace NH3 emissions at the current rate. In addition to nitrogen fertilizer, livestock, especially cattle (56.1%), .
The main source of nitrogen (Nr) in the form of ammonia is buffaloes. The scenario is getting increasingly worrying as the chicken business expands, with a current annual growth rate of 6% and an estimated contribution of 1.089 Mt of reactive N by 2030. India currently loses nitrogen of US$ 10 billion per year in terms of fertilizer value, while US$ 75 (38–151) billion per year is considered to be the cost of losing nitrogen to health, ecosystems, and the climate. From 8% in 1970 to 23% in 2010 (Figure 9), fertilizer N application's relative contribution to global greenhouse gas emissions rose. Due to the promotion of direct seeded rice over puddled rice during the same period, the GHG contribution from rice fields reduced from 26% to 17% (Pathak et al., 2014).

Despite being an environmentally safe source of N, BNF also produces Nr, albeit to a smaller level. Transport has significantly altered the structure and functions of nitrogen cycling during the past 50 years, in addition to economic development and societal demands for more energy. N cycling is now the most disturbed biogeochemical cycle as a result of this enormous anthropological development. Eutrophication, atmospheric N deposition, biodiversity loss, and other ecosystem services are just a few of the negative effects of a significant rise in Nr and its loss to the aero-geo-biological system on the environment and ecological balance. The main problem for India is to effectively utilize Nr as a source of fertilizer-N because its current inefficient use is placing a significant financial burden on the country's exchequer in the form of subsidies, as well as detrimental climate effects connected with environmental degradation and ramifications for animal and human health.

Soil Acidity

A large amount of ammonia in the atmosphere controls how acidic it is. It is a component of air aerosols that raindrops deposit on soil, where its oxidation releases acidic chemicals and increases soil acidity. The exchangeable cations on the clay surface affect the pH of the soil, which is an intrinsic feature that changes slowly. In addition to these air depositions, overuse of inorganic fertilizer produces Nr, a major source of environmental harm. Soil acidity is the main detrimental effect of Nr depositions on soil quality. A long-term fertilizer experiment at Punjab Agricultural University (PAU), Ludhiana, India, found that after 36 years of manuring and fertilizing a maize-wheat cropping system, soil acidity increased significantly under 100% NPK (pH 7.39) and 150% NPK (pH 7.25) treated plots as compared to non-treated control (7.90) (Brar et al., 2015). Additionally, the excessive use of N fertilizers runs the risk of degrading soil carbon and negatively impacting the structure and operation of soil biological communities.

Harmful Impacts

A vast overgrowth of algae, known as an algae bloom, which degrades water quality and affects aquatic life, is another significant effect of excessive nutrient use, particularly nitrate and phosphate, on the ecosystem. Due to water clarity issues and fish gill clogging, algal blooms make it harder for aquatic species to obtain food. A few types of algal blooms release

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toxins that can sicken or kill creatures like turtles, gulls, dolphins, fish, and shellfish. When exposed to or in contact with the algae toxins, people can suffer from a variety of health impacts, including stomachaches, rashes, and more serious issues. Agrochemical overuse is another factor in the air pollution in the area. Heart disease, lung cancer, and respiratory illnesses like emphysema are just a few of the long-term health repercussions of air pollution. The nerves, brain, kidneys, liver, and other organs of people can all suffer long-term harm from air pollution.

Micronutrients in relation to Food and Human Health

The growth and development of plants, animals, and people are significantly influenced by micronutrients. The use of micronutrients, which has expanded over the past ten years, has greatly increased the nation's production of food grains (Shukla and Behera, 2012). Poor trace element concentrations are a characteristic of food and fodder grown on micronutrient-deficient soils, and micronutrient deficiencies are caused by the ingestion of these elements.
malnutrition in people and animals. While the quantities of trace elements like Cu, Zn, Mn, Fe, Mo, Se, and Co in crops are occasionally adequate for producing optimal yields, these are insufficient to meet the demands of cattle, resulting in widespread insufficiency. Human health has been adversely impacted by widespread nutritional deficits in vitamin A, iron, zinc, and iodine (I), particularly in women and young children. Anemia is also linked to a lack of trace metals in the soil, specifically selenium (Se), copper (Cu), iron (Fe), and zinc (Zn). The health of humans and animals is negatively impacted by toxic quantities of some trace elements in soil.
In spite of the fact that most of the soils were adequate in available Fe, Mn, and Cu to support crop yields and only required Zn fertilization to get good yields, a survey conducted in the Gujarati district of Vadodara revealed that the dry fodders tested low in Fe (61%), Zn (72%), and Cu (87%) and green fodders were low in Fe (17%), Zn (5%) and Cu (23%) as well. Zn insufficiency in humans became known as a health issue for the first time in 1961 (Prasad et al., 1961, 1963). Young people from Iran and Egypt were the first to experience hypogonadism, delayed sexual development, and growth stunting as a result of human Zn deficient disorders. According to Shukla et al. (2016), there is often a significant link between soil zinc status and levels of zinc insufficiency in humans. The poor population of this country consumes a diet that is disproportionately low in Zn and rich in phytate, which results in low Zn bioavailability, and is largely considerably below the recommended limits. The average consumption of zinc across all age categories is significantly below the recommended dietary allowance (RDA) in the States of Assam, Bihar, Odisha, Tripura, and West Bengal. As a result, communities who consume just cereals and a plant-based diet are at risk for Zn insufficiency. Over 50% of households have moderate to severe levels of Zn deficiency, and a significant portion (84%) of families have inadequate Zn intakes.

Food Consumption.
The average zinc intake for pregnant women around the world is only about 82% of what is required. About 25% of the population in India has a Zn deficit. While it affects 33% of the world's population overall, nutritional stunting caused by Zn deficiency affects children under

the age of five at a rate of roughly 47.9%. In five significant Indian states, a high rate of Zn insufficiency (43.8%) was observed among children from low socioeconomic backgrounds (Table 5).

The state with the highest Zn deficiency was Odisha (51.3%), followed by Uttar Pradesh (48.1%), Gujarat (44.2%), Madhya Pradesh (38.9%), and Karnataka (36.2%). In 45% of the adolescent girls (10–16 years old) from two secondary schools in Pune, a cross-sectional study (n = 630) similarly demonstrated low plasma Zn content and subpar cognitive function. The addition of Zn-rich meals increased brain function, taste acuity, and plasma Zn status, indicating the necessity of dietary Zn intake for normal health (Kawade, 2012).

An investigation of the Zn concentration in soil, grain, straw feed, animal and human blood serum, and a case study conducted in the Mandala area of Madhya Pradesh showed high correlations between them, demonstrating the interdependence of the soil-plant-animal-human continuum (Figure 11). The determining factors (R2) between soil Zn

grain Zn concentration was 0.36 percent and there was 0.48 between the levels of zinc in human blood serum and grain. The Zn concentration in animal blood serum was not correlated with the Zn content of straw, though. It showed a highly significant link with animal blood serum Zn (R2 = 0.61) when contribution of Zn through feed and Zn content in grazing grass were combined with fodder Zn content.

Delayed Impacts On Soil Health

In India, LTFEs (long-term fertilizer experiments) on arable lands were started in 1972 in several agro-climatic zones of North and Central India under sub-humid climatic conditions. These LTFEs revealed a variety of crop responses and changes in soil C status. LTFEs, or long-term fertilizer experiments, were carried out in Palampur, Jabalpur, and sequences of maize-and-wheat farming in Ludhiana demonstrated that both NPK and NPK+FYM significantly increased grain production. The crop yields, subterranean root biomass, and therefore soil C pools in various agro-ecosystems were all improved by the long-term use of balanced fertilization and integrated plant nutrient supply (IPNS). Carbon is stabilized at greater levels via balanced fertilization and integrated plant nutrient supply (IPNS) (Table 6). At the Jabalpur, Palampur, and Ludhiana sites, respectively, application of the optimum NPK dose increased the SOC stock by 20%, 12%, and 61% over the initial SOC stocks, whereas treatment with NPK+FYM increased the SOC stocks by 46%, 30%, and 107% over the initial value, respectively (Jha et al., 2021).

LTFEs performed across the entire country revealed that consistent application of fertilizer P in proportionate amounts resulted in the accumulation of (Figure 12) The soil's readily available P. By modifying the P doses in following crops, this stored P could be put to use again. A common misconception among farmers is that "Indian soils are rich in K," which has kept them from paying much attention to the usage of K in agriculture. The ongoing lack of K from the fertilization schedule or the insufficient delivery of K has resulted in a net negative K balance in Indian soils (Figure 13). Vertisols react to K application because K from the non-exchangeable pool is released more slowly and the K material accessible. Due to the fact that all potassic fertilizers are imported from overseas, applying K fertilizers to maintain soil K fertility status is quite expensive.

Technologies and Methods to Track and Manage Fertilizer's Effects on Human Health and the Environment best nutrient management solutions have been found for decreasing the negative impact based on data from numerous on-station and on-farm investigations.
Table 7 provides an overview of the use of fertilizers in various crops and cropping methods.

Encouragement Of Neem Oil-Coated Urea

It has been well established that the use of modified urea materials and nitrification inhibitors can reduce N losses (Prasad, 2013). The promotion of neem cake/oil coated urea has the dual benefit of serving as both a pesticide and a fertilizer. The primary active component of neem is azadirachtin, which has anti-cancer, insecticidal, immune-modulatory, and nitrification-retarding activities. Inducing sterility in insects by stopping oviposition and halting sperm production in males, it functions as an antifeedant, repellant, and unpleasant chemical. Numerous studies conducted all over the nation have shown that applying neem coated urea, (NCU) @ 200 kg neem cake t-1 urea or neem oil coated urea (NOCU) @ 0.5 kg neem oil t-1 urea, which exhibits nitrification inhibition properties, could result in significant improvements in crop yields and N use efficiency as compared to prilled urea. According to meta-analysis research, 30% of comparisons did not show an increase in agricultural yields or NUE. Due to inadequate crop management and plant protection strategies, yield increases utilizing NOCU recorded at farmers' fields are typically lower than the researcher's plots. Farmers that apply urea-N at high and above-optimal amounts to various crops may not notice a noticeable increase in yield levels as a result of NOCU application. More than 50% of the urea used in India is used in the production of wheat and rice. In research plots under the control of the researchers, replacing urea with NCU or NOCU could increase grain yield by 5% to 6%. The action of nitrification inhibitors is influenced by the triterpenoids included in neem cake or oil, the soil's texture and pH, as well as the soils' redox status, which is affected by whether or not they receive irrigation or rainfall. Nitrification inhibitors function better in acidic soils than in neutral or alkaline soils, in soils with coarser texture than in soils with finer texture, and in crops that are irrigated rather than those that are rainfed.
Neem is employed as a natural alternative to synthetic pesticides, although little research has been done on the NCU or NOCU-related pesticidal activities. Few studies relating to neem coated urea have been cited by Baboo (2014). Neem oil is reportedly employed as an affordable and cost-effective method to stop termite attacks in the field, according to Yash Roy and Gupta (2000). The blue bull (Boselaphus tragocamelus) threat was lessened in one area of the state of Uttar Pradesh by farmers applying neem-coated urea to rice fields. Farmers in Panipat in Haryana reported no instances of leaf folder and stem borer in the rice crop, while at Sangrur and Gurdaspur in the Punjabi State, they reported decreased instances of white grub with the application of neem coated urea in the rice crop.
crop of wheat. In comparison to untreated urea, site-specific NOCU application via LCC resulted in higher or equal levels of crop output, but with lower fertilizer application rates (Shukla et al., 2004). The demand for NOCU may fall relative to the existing urea demand as farmers progressively embrace NOCU urea along with SNM methods for fertilizer management.

Preventive Measures

Traditional methods are being reevaluated as modern, intensive agriculture's technological alternatives that could assist reduce or eliminate the need for unfavorable chemical inputs and develop environmentally benign, long-lasting systems. There are several of models out there that have been promoted in this regard. IPM (integrated pest management), LEISA (low external input sustainable agriculture), and organic agriculture are a few of these (Tomer et al., 2014).

Organic Farming

The practice of organic farming is not a recent development in India; it dates back to ancient times. Its main goal is to cultivate the land and grow crops in a way that maintains the soil's life and health by using organic wastes (such as crop, animal, and farm wastes, and aquatic wastes), other biological materials, and helpful microbes (also known as "biofertilizers"), and releases nutrients to crops for increased sustainable production in a clean, pollution-free environment. According to Willer et al. (2020), India is the world's top producer overall and has the eighth-largest area dedicated to organic farming. The total area registered under the National Program for Organic Production as of March 31, 2020 that was undergoing the organic certification procedure was 3.67 Mha (2019–20). A total of 2.75 Mt of certified organic products were produced in the nation in 2019–20, including all types of food products such as oilseeds, sugarcane, cereals & millets, cotton, pulses, aromatic & medicinal plants, tea, coffee, fruits, spices, dry fruits, vegetables, processed foods, etc.

Farmers Views

Farmers believe that fertilizer N and P use is the cause of the exponential increase in N and P consumption.In order to increase crop productivity more quickly, crop growth should be encouraged. Because urea is available at a lower price under the program, for example, they ignore the benefits of fertilizer application that is balanced. The first victim is the preservation of the beneficial N:P2O5:K2O consumption ratio at 4:2:1. High production regions like Punjab, Haryana, and Uttar Pradesh have a fairly wide ratio.

Diagnostic studies carried out in heavily farmed areas of the Indo-Gangetic plains revealed that farmers' fertilizer practices were skewed toward N due to N being relatively cheaper than P and K, with optimal to suboptimal use of P and complete neglect of K, S, and micronutrients (Singh et al., 2013). Due to farmers applying fertilizers in an unbalanced manner, the situation in intensively farmed areas has gotten worse. Farmers exclusively apply Zn to rice crops, and they do it at an inefficient rate. By encouraging nutrient imbalances in the soil-plant system, lowering NUE, enhancing groundwater pollution through NO3 leaching, and increasing costs for production inputs, the indiscriminate use of N not only widens the fertilizer consumption ratio but also intensifies non-sustainability.

Mohanty et al. (2013) reported significant observations on farmers' understanding of pesticide use procedures. According to their study, 70% of farmers believed that a person's health was impacted by pesticide spraying. Only 40% of people were aware of the environmental impact. Only 62% of farmers were aware that pesticides enter the body through the nose and harm the lungs, whereas knowledge of other entry points was lower.

Comprehensive Research, Extension, and Farmer-Farmer Links in Fertilizer Use in Agriculture and the Spread of Best Management Practices

Through the Krishi Vigyan Kendras (KVKs) run by the Indian Council of Agricultural Research and National Agricultural Research and Extension System (NARES), the Government of India has established an effective network of scientists, extensionists, and farmers who interact with each other. KVKs' primary objectives are to evaluate location-specific technology modules in agricultural and related businesses through technology assessment, refinement, and demonstrations. More than 700 KVKs serve as information and resource hubs for agricultural technologies.

Activities from the public, private, and nonprofit sectors are fostering connections between farmers, the NARES, and the extension system to improve the district's agricultural economy. Each KVK is equipped to offer recommendations on the application of agrochemicals (fertilizer nutrient management and plant protection measures) through soil scientists/agronomists and plant protection scientists located all throughout the nation.

In 2015, the Indian government launched the Soil Health Card Scheme. With an aim to raising knowledge about the balanced fertilizer application in accordance with soil test requirements, the Department of Agriculture & Co-operation within the Ministry of Agriculture and Farmers Welfare supports it. A soil health card is used to determine the current state of the soil's health and, over time, to identify changes brought on by changes in land management. The soil health card shows the indications of soil health and the descriptive adjectives that go with them. It gives every farmer information on the nutrient state of the soil on his property and gives him recommendations on the amount of fertilizer and necessary soil amendments that should be maintained for good soil health.

The soil health card program thoroughly inspects the farmers' soils and provides them with a structured report so they may choose the crops to cultivate for more income while using a balanced amount of fertilizers and manures in accordance with the results of the soil test and the needs of the crops.

Research and development requirements, as well as stakeholder capacity building, are needed to minimize negative effects and maximize the use of fertilizers.

• In addition to FYM, more focus should be placed on the utilization of organics (enriched composts, crop diversity with legumes, recycling of crop residue and waste, industrial byproducts) in order to optimize fertilizer application. This will aid in the creation or improvement of nutrient management techniques and customs for CA, RA, and integrated farming systems (IFS) with efficient nutrient fluxes and flows.

• Encouraging the creation of highly mechanized composting facilities in rural regions, which will help to increase the accessibility of high-quality manure and create fertilizer prescriptions tailored to specific cropping systems that use organic resources that are readily available in the area.

• The identification of nutrient smart farmers (farmers following superior fertilizer management methods or nutrient smart communities) and the implementation of incentive programs for such farmers/village. This will facilitate the development of stakeholders' capacities and promote field-based efforts to restore soil health.

demonstrations of agricultural chemical management technologies and informal education/skill building to increase farmers' awareness of nutrient recycling and safe pesticide use.

The best management practices for revitalizing agriculture should be linked with GOI initiatives such as the National Mission on Sustainable Agriculture (NMSA), Doubling of Farmers' Income (DFI), National Food Security Mission (NFSM), Pradhanmatri Krishi Vikas Yojna (PKVY), Soil Health Card Scheme (SHC), and Mission for Integrated Development of Horticulture (MIDH) in order to ensure a reduction in the negative effects of agrochemical use and promote the optimum

• The identification and disposal of a basket of technologies, which includes the ideas and methods used to improve and restore the health of the soil, safeguard crops from insects and diseases, and maintain sustained high productivity while minimizing environmental impact.

• It is more practical to promote actions that will boost SOC stock and enhance soil quality. Although small increases in SOC may not always result in higher crop yields, they have positive effects on soil health and environmental safety.

• The repository for the information is an existing LTFE (AICRP-LTFE, DA, IFS). To stay relevant, these must be changed to align with modern farming challenges such organic inputs, tillage, residue recycling, and crop diversification.

CHALLANGES

• If the NUE stays constant under the existing business as usual, more fertilizer nutrients will need to be used in order to produce the increased foodgrains needed by 2050. If BMPS adoption is not concurrent with bringing urea under nutrient-based subsidies, the cost of urea will initially increase. The greater adoption of balanced fertilization and IPNS will result in long-term benefits from the introduction of urea under NBS.

• More research is needed on alternative management techniques that will benefit both the set of indicators (e.g., use of organic fertilizers for biological soil quality and growth in crop yields).

• Despite the known advantages of IPNS, its widespread implementation was not feasible due to the lack of readily available, affordably priced urea fertilizers, the time and labor required to prepare

Composts from farms and the costlier treatment of organic manures are examples.

• SOC and yield drop when organic matter or fertilizer are used alone. Given this and the government of India's emphasis on the soil health program, there is a need for a resurgence of interest in IPNS and for its efficient implementation in mission mode to improve the soil's native capacity to supply nutrients, optimize nutrient input, increase fertilizer use efficiency, and restore soil health.

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• By utilizing the native nutrients at a variable rate and diverse depths, crop rotations play a significant role in restoring soil fertility. Due to the reduced yield of legumes and uncertainty around MSPs for new crops, farmers are hesitant to alter their cropping strategy.

• Crop sensitivity to K, S, and micronutrients under intensive cropping has improved over time, but their utilization is still insufficient to meet crop demand and maintain soil health. The yearly K balances have generally been extremely negative across all cropping systems due to soil K mining and its limited usage in crops. The gradual alteration of the soil's mineralogical composition as a result of ongoing K input neglect suggests a decline in the capacity of soils to supply K.

TO MOVE AHED

• India has a fantastic potential to take advantage of the N problem by working together to improve institutional and public awareness among stakeholders of the perceived threat of rising Nr in the environment. By adopting optimum crop and fertilizer management methods in tandem with efficient policy execution, India can achieve a 20–30% reduction in the use of fertilizers, notably N and P.

• To increase NUE, BMPs must be developed for various soil-crop contexts that take into account techniques like balanced fertilization, IPNS, the use of legumes, precision N management, and CA technologies.

• There is a need to encourage research on the creation of new fertilizer products and the evaluation of their effectiveness in various soil-crop scenarios.

• Policies should be streamlined or coordinated to increase knowledge on the use of secondary and micronutrients to address the problem of nutritional security/malnutrition and improve macronutrient usage and crop quality.

• Encouragement of multidisciplinary research is needed to create ways for increased NUE, increased crop productivity, and less environmental damage.

• A national action plan could be created and put into effect to improve fertilizer quality control, strengthen international regulations regarding the responsible and safe use of fertilizer materials, increase training for key players, and make sure farmers have access to quality fertilizers at reasonable prices.

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