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# FERTILIZER USE IN INDIAN AGRICULTURE AND ITS IMPACT ON HUMAN HEALTH AND ENVIRONMENT-

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**ABSTRACT:** Fertilizer is one of the vital inputs required for enhancing agricultural production and the farmers' income in India. India ranks second in the world and first among the South Asian Association of Regional Cooperation (SAARC) countries in terms of total fertilizer consumption. However, the average fertilizer application per hectare of about 145 -1 kg in India during 2019-20 was much below than that in the SAARC countries of about 174 kg ha. The use of fertilizer varies greatly between states and regions. The distribution and use of fertilizers have changed, and this has had a substantial effect on the nutrient utilization ratio. Reduced utilization of applied nutrients has resulted in an accumulation of fertilizer nutrients in the soil and/or leakage into the environment, which has caused environmental degradation and climate change. This can be attributed to overuse, misuse, imbalanced application of fertilizer nutrients, and simple negligence in the application of secondary and micronutrients. The compounded harmful effects of imbalanced fertilizer use are not only intensifying soil and atmospheric pollution but also impacting water bodies (eutrophication) and causing threat to biodiversity and human health. The increased use of fertilizer-N has direct bearing on higher total N O emission and low N use efficiency (15-30%). As per estimates, India emits about6.24 Tg yr of reactive nitrogen (Nr), though contribution from agricultural fields is not really alarming Fertilizer use can be reduced by 20–30% by implementing the best crop and fertilizer management techniques, such as using neem oil coated urea, cultivating genotypes that are nutrient efficient, applying nutrients in a balanced manner, implementing preventive measures, and using organic farming methods made possible by enabling policies. The Indian government's Ministry of Agriculture and Farmers Welfare is working comprehensively to guarantee that fertilizers are used in a balanced manner for all important crops, including horticultural, medicinal, and agricultural ones. India has to put in place a well-defined comprehensive system that enforces stringent policies on balanced fertilizer use, besides facilitating integrated nutrient management with locally available organic manures/crop residues and cultivation of efficient crop genotypes.

**Key words:** Fertilizer use, agriculture, soil health, environmental degradation, human health

Agriculture is the livelihood source for around 50% human population of India. With 29 states and 7nd Union Territories it is home to 2 largest (1.38 billion) human population in the world. With the current levels of about 309 million tons (Mt) of food grain production (wheat & rice among major ones), country has to produce more than 400 Mt of food grains by 2050 to feed 1.68 billion people. India is home to one of the biggest national agricultural systems in the world, with 71 Agricultural Universities, 104 ICAR Institutes, Krishi Vigyan Kendra's (KVKs), and a huge number of autonomous and non-governmental organizations. With the help of the Green Revolution in the middle of the 1960s, independent India made significant progress, multiplying its production of food grains by 5.6 times, horticulture crops by 10.5 times, fish by 16.8 times, milk by 10.4 times, and eggs by 52.9 times over the course of the previous seven decades. With current $ 2.1 trillion economy, country is the major exporter of raw cotton, wheat, rice, fruits, vegetables, spices, meat and chemicals; largest producer of milk, pulses and jute; second largest producer of rice. wheat, sugarcane, groundnut, vegetables, fruits and cotton; and is a leader in the production of spices, fish, poultry, livestock and plantation crops. Agriculture accounts for 23% of gross domestic product (GDP) and offers employment to 59% of the country's total workforce.

A fifty percent rise in the nation's food grain yield is attributed to fertilizer. Between 1970 and 2020, India's fertilizer use increased by a factor of 13 (FAI, 2020; Bijay-Singh, 2016); the country's fertilizer use remained heavily biased towards nitrogen. Reactive nitrogen (N) (Nr) loss to the environment was enhanced by approximately five times by disproportionately higher usage of fertilizer nitrogen (N). Excessive use of two key nutrients, namely, N and phosphorus (P), has led to the alteration of N cycle, amplifying annual budget of Nr compounds from atmospheric dinitrogen (N), resulting in the reduced nitrogen use efficiency (NUE) of the Indian food system (30%) (Adhya et al., 2010).

The fertilizer P use recovery is very low (15%) leading to the deposition of P unutilized by the plants in soil and loss to water bodies either through leaching down to groundwater or runoff to surface water bodies. Harmful effects associated with excessive use of N and P include soil and atmospheric pollution, eutrophication (a reduction in dissolved oxygen in water bodies caused by an increase of mineral and organic nutrients) of rivers and lakes, threat to biodiversity and the health of native plant species and natural habitats, formation and release of nitrous oxide (N O) – a highly harmful greenhouse gas (GHG),2 etc.

It is necessary to: i) adopt ecosystem-based approaches; ii) model crop management practices that reduce greenhouse gas emissions; iii) have balanced nutrient consumption; v) adopt ecosystem-based Approaches; and vi) strengthen policies that have little to no impact on the environment, animal health, or human health. Fertilizer use in food and horticultural production must be regulated and optimized.

**Fertilizer Consumption in India-** Fertilizer manufacturing industry in India is second most important core sector after steel industry in terms investment, developments, quantity and the types of fertilizers produced, the technologies used, and the feedstock employed. With ushering into the Green Revolution era in mid-1960s through the introduction of fertilizer-responsive high-yielding varieties of rice and wheat, fertilizer consumption in India witnessed a spectacular rise. For example, nutrient consumption rose in 2019-20 to 28.97 million tons (Mt) against 2.26 Mt in 1970-71 (Figure 1). However, fertilizer use exhibited inter-state and inter-region variations. The 252-1 consumption in the East and West zones was less than 80 kg ha, but the North and South zones consumed more than 100 kg N +-1 P O + K O ha. Of the main states, West Bengal (122 kg), Haryana (167 kg), Punjab (184 kg), Uttar Pradesh and Uttarakhand (127 kg), Andhra Pradesh (138 kg), and Tamil Nadu (112 kg) had per-hectare consumptions exceeding 100 kg. The consumption per hectare in the remaining states is less than the average for all of India. The overall NPK consumption in India grew 11.84 times from 1970-71 to 2018-19. Consumption of fertilizer products increased from 50.6 Mt in the year 2009 to 61.4 Mt in 2020 with compound annual growth rate of 2.0%. However, the partial factor productivity (kg food grain produced per unit of fertilizer nutrient. exhibited a decline from 28 kg kg in 1970-71 to 10 kg kg in 2019-20 (Figure 1).

While food grain output increased from 108.4 Mt to 297.5 Mt during the same period, total nutrient intake (NPK) skyrocketed from 2.26 Mt in 1970–71 to 28.97 Mt in 2019–20. With 28.97 Mt, India 252 stands second in the world for overall fertilizer nutrient consumption (N+P O + K O), only surpassed by China (52.50 Mt). Nonetheless, India's per-hectare fertilizer use is comparatively low in comparison to many other nations, especially those in our immediate neighborhood (Figure 2). The current average fertilizer nutrients (N+P O +K O) use per hectare in SAARC countries in 252 -12019-20 was much higher (~174 kg ha) than India-1(~145 kg ha) (FAI, 2020; FAO, 2020). Fertilizer use pattern is highly skewed towards N consumption. Fertilizer-N consumption in India during 1970 to 2020 increased by about 13 times, whereas the crop N uptake increased by 4 times, leading to 5 times more loss of reactive N. In addition to application through N-containing fertilizers, N inputs also accrue through the biological N-fixation (BNF) process. Conservative estimates place the N contribution through BNF in Indian agriculture between 5.20 and 5.76 Tg N, or 9.5% to 10.6% of the global agricultural BNF. Cereals make up 32% and grain legumes 43% of the total. From 0.54 Mt in 1970–71 to 1.21 Mt in 1980–81, 3.22 Mt in 1990–91, 4.80 Mt in 2000–01, 7.28 Mt in 2010–11, and 7.50 Mt in 2019–20, India's phosphorus consumption grew. Thus, P consumption recorded more than 14 times increase during 40 years (1970-71 to 2010-11). Consumption of K which was very meager at 0.24 Mt in 1970-71 increased 11-fold to 2.64 Mt in 2019-20.

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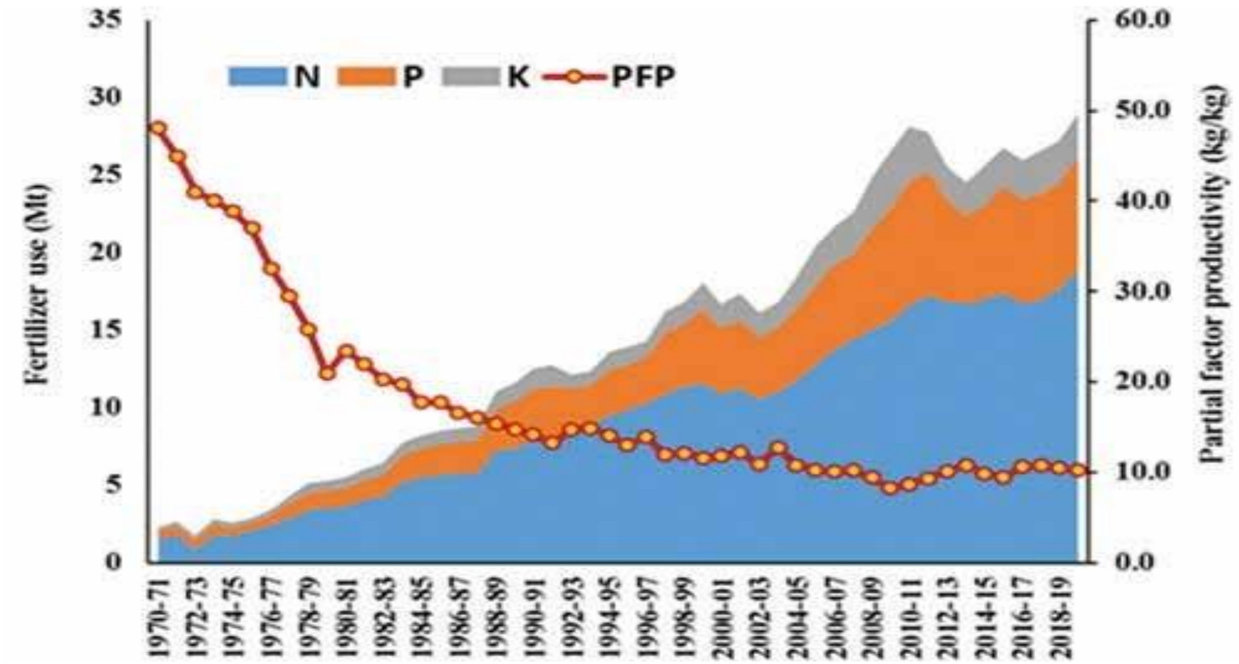


Fig.- 1. Use of NPK fertilizers and partial factor productivity after Green Revolution (Source: FAI, 2020)

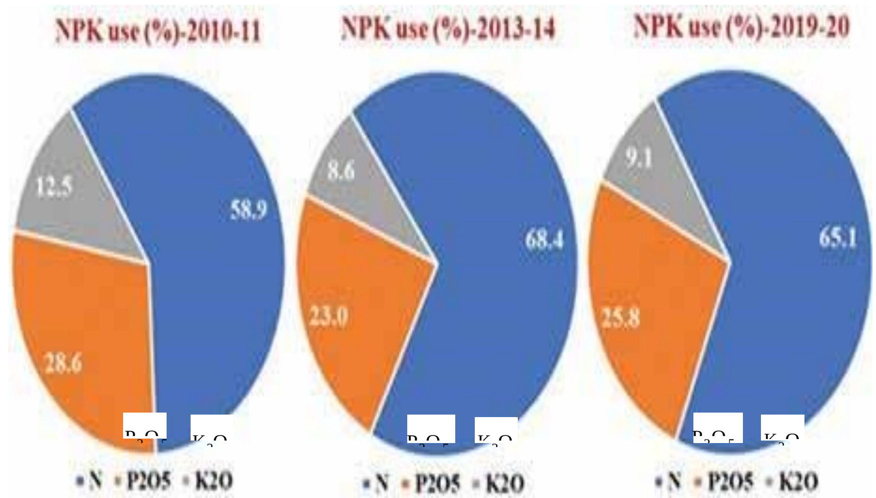


Fig. -2. Relative changes in NPK use over the years due to implementation of price decontrol and nutrient based subsidy scheme (Source: FAO, 2020)

**Policy Framework for Optimum Use of Fertilizers-**

In India, fertilizer was brought under Essential Commodities Act 1955 and Government of India (GoI) regulated the sale, price, and quality of fertilizers under Fertilizer (Control) Order (FCO) 1957, which was revised several times till 1985. Revised version is known as Fertilizer (Control) Order 1985. Urea is the only controlled fertilizer, which is sold at the statutory notified uniform sale price. The phosphatic (P) and potassic (K) fertilizes are decontrolled and are sold at indicative maximum retail prices (MRPs). The most important factors which influence fertilizer use are prevailing fertilizer price policy and various subsidy schemes implemented by GoI. Five major historical policy decisions which guided the fertilizer use in the country included: i) Retention Price Scheme (RPS) (Marathe Committee) (cost plus pricing subject to some efficiency norms)-1977; ii) Economic Reforms and Joint Parliamentary Committee (JPC) during 1991-92 and decontrol of P&K fertilizers as on 25th August 1992; iii) Expenditure Reforms Commission (Geethakrish-nan Committee)-2000 and group based new pricing scheme for urea in 2003; iv) Nutrient Based Subsidy (NBS)-for P&K fertilizers in 2010 selective implementation of the scheme on 2010; and v) Promotion of neem coated urea-2015 (Table 1). The NPK use ratios are also given in the Table. The cheaper price of fertilizer N and government subsidy have rendered fertilizer use highly skewed in favours of N across the length and breadth of the country. Abolition of retention price-cum-subsidy scheme on P&K fertilizers and their decontrol in 1992 severely distorted the NPK ratio to 9.5:3.2:1in 1992-93 as compared to 5.9:2.4:1 in 1991-92. Further, India announced the nutrient-based subsidy policy in 2010 to ensure application of fertilizers in a balanced approach; however, selective implementation of the scheme on P and K fertilizers led to a decrease in their use. The immediate effect of NBS was a sharp rise in prices of P and K fertilizers, which increased on an -1 average from 10,000 t before the introduction of NBS to Rs. 25,000 t in 2013. The immediate outcome of this was a sharp decline in the use of P and K fertilizers and disproportionately larger increase in the urea-N consumption at the cost of P&K fertilizers.

Despite the fact that urea prices stayed fixed, the increase in sales indicated that farmers were placing a greater demand on urea due to its lower MRP when compared to P&K fertilizers. NPK ratio skewed as a result, going from 4.3:2.0:1 in 2009–10 to 8.2:3.2:1 in 2012–13. The government's mandate on 100% urea coating with neem oil (NOCU) improved the efficiency of using fertilizer N; up until 2018–19, fertilizer N use stayed steady with an NPK ratio of 6.6:2.6:1 (FAI, 2020). As against the ideal ratio of 4:2:1 (approximately 57% of N, 29% of P and 14% of K), the actual ratio has always been distorted due to fluctuations in fertilizer policies. As a result, NPK use changed to 68.4, 23.0 and 8.6% in 2013-14 and 65.1, 25.8 and 9.1% in 2019-20 as against 58.9, 28.6 and 12.5% in 2010-11 (Figure 3). Inappropriate fertilizer use leads to deterioration of soil health, degradation of environmental quality, and strain on the country's economy caused by the burgeoning fertilizer subsidy bill. Biggest challenge is to change the fertilizer use pattern, which involves not only revamping and re-energizing the extension services but also changing the NBS suitably to remove the price distortion caused by it. Since fertilizer prices follow the trends of prevailing international petroleum prices, the only way to reduce the subsidy bill is to reduce the dependence on imports and increase the domestic production. While rationalizing fertilizer subsidy across nutrients may be the short-term but the need of the hour is to have a policy framework that incentivizes domestic production of fertilizers.

**Types of Fertilizers Used in Agricultural Production Systems-**

Nowadays, crops are grown using a variety of fertilizer compounds in order to generate enough food to support the world's expanding population. The most common N P and K carriers on the Indian market are urea, ammonium sulphate (AS)/ammonium chloride (ACl), diammonium phosphate (DAP), single superphosphate (SSP), muriate of potash (MoP), and NP/NPK complex fertilizers. The total amount of nutrients consumed in 2019–20 was 28.97 Mt (N + P O + K O); the individual amounts consumed were 18.86 Mt for N, 7.46 Mt for P O, and 2.64 Mt for K O (FAI, 2020).

Supply of individual nutrients has been highly skewed in favours of urea and DAP. Of the total fertilizer products consumed in Indian agriculture during 2019-20, the share of urea at 54.6% was highest followed by DAP (16.5%), NP/NPK (15.5%), SSP (6.9%), MoP (4.6 %), and AS/ACl (1.4%), respectively (FAI, 2020). Share of consumption of micronutrient-containing products to the total fertilizer products was very little (<0.50%). Urea has been the major N fertilizer consumed in India; its share to total N fertilizer supply was 82% during 2019-20 against 80% in 1990-91 (Figure 4). Diammonium phosphate has been the most preferred P source. Share of NP/NPK complex fertilizer to P nutrition increased from 22% in 1990-91 to 30% in 2019-20, while supply of P through SSP decreased from 15% to 8% during the same period.

Other straight N fertilizers, such as, and ACl account for less than emergence of secondary and micronutrient deficiencies in the country. Out of the total fertilizer nutrients applied in Indian agriculture, 67.1% goes to food crops followed by 9.6% to oilseed crops, 8.7% to cotton, 5.6% to sugarcane, 3.1% to vegetables and only 2.0% to fruit crops (Figure 5). As per recent estimates on micronutrients consumption, the use of zinc sulphate fertilizer was the highest at 1,89,579 t followed by iron sulphate (38,624 t), boric acid/borax (27,166 t), manganese sulphate (17,241 t) and copper sulphate (4,564 t) during 2020-21 (FAI, 2021). Of the total zinc (Zn) used, 70% goes to the field crops and remaining 30% finds use in vegetable and fruit crops, while the reverse is true for manganese (Mn), iron (Fe) and copper (Cu). Of the total borax fertilizer used, about 60% goes to vegetable and fruit crops and the remaining 40% is consumed by food and oilseed crops (Shukla et al., 2021).

**Best Management Practices for Fertilizers-**

The well-known 4Rs (method, rate, time, and source) of fertilizer application, in addition to weather, cultivars, spacing, crop rotation, and tillage techniques, have a direct impact on how well crops utilize the nutrients that are provided (Majumdar et al., 2014). To reduce the amount of applied nutrients that are lost or leaked into the environment from the soil-plant system, efficient nutrient management is essential. Improving the sprayed nitrogen's recovery efficiency which remains low at 30–50% by the first crop remains a significant problem. Rest of the applied N either remains in the soil, the recovery of which in the following crops is very limited, or escapes from the soil-plant system, causing serious disruptions in ecosystem functions (Ladha et al., 2005). A large number of best management practices (BMP) have been developed for optimum use of nutrients by enhancing nutrient use efficiency (NUE) and reducing the losses across the country.

**Some of the important BMPs are summarized as under:**

1. Balanced fertilization using fertilizer nutrients as per soil test and crop response function is first and foremost BMP. Agronomic efficiency parameters measured in different cropping systems are higher under balanced NPK fertilization. Such an improvement in NUE is attributed to the increased indigenous nutrient supplying capacity of soil under balanced NPK fertilization (Yadav, 2001).
2. Promotion of the micronutrient application in adequate amounts guided by the existing deficiency status. Application of micronutrients not only ensures improved use efficiency of major nutrients like NPK, but also improves the micronutrient content in the edible plant parts, which helps in combating micronutrient malnutrition in the country.
3. Integrated plant nutrient supply (IPNS) involving conjoint use of different nutrient sources is a sustainable strategy for realization of high yields, restoration of soil health, and improvement in fertilizer use efficiency as a whole (including NUE). Important ingredients of IPNS, namely fertilizers, organic manures, green manures, crop residues (CRs), industrial wastes and by-products, sewage sludge, and bio-fertilizers have to be used in balanced, judicious and effective manner.
4. In situ burning of crop residues by farmers in North-West India causes serious environmental implications besides causing loss of nutrients. Conservation agriculture (CA) has the potential to make available about 141 Mt of cereal residues for nutrient cycling and soil health improvement.
5. Site-specific and precision nutrient management refers to management strategies which encourage better utilization of applied nutrients, enhance the NUE, and minimize N losses to the environment. Use of leaf color chart (LCC), chlorophyll meter for synchronizing N application with crop N requirement, and use of micronutrients kriged maps of 640 districts prepared by ICAR-All India Coordinated Research Project on Micronutrients offer important tools to execute site-specific nutrient management and precision nutrient management at a mega scale. The NUE and grain yield of rice and wheat crops have been improved with fertilizer N application that is directed by the crucial LCC values. LCC <3 for Basmati, LCC <4 for inbred (Saket 4), and LCC <5 for hybrid (PHB 71) rice were developed as the standard values, taking into account AEN of 20 kg -1 kg N and REN of 50% as the ideal NUE for rice (Shukla et al., 2004). According to studies conducted by Bijay Singh et al. (2003) and Shukla et al. (2004), fertilizer N-scheduling based on LCC was found to be superior to the traditional method of applying 120 kg N ha in three-splits on a -1 basis. Using LCC has been shown to save fertilizer N in some circumstances—up to 30 kg N-1ha.Inclusion of legume-based crop rotation in existing cropping pattern helped in restoring atmospheric N lost through denitrification or other processes.

By using precision management in accordance with the "4R" principle—which stands for "right fertilizer source, right rate, right time, and right method of placement"—nutrient utilisation efficiency might be maximized. In contrast to the on-farm RENs of 30–40%, the application of fertilizer in accordance with the 4R concept increased the fertilizer nitrogen recovery efficiencies (RENs) in researcher-managed trials for key grain crops to the range of 46% to 65%.

Table 1. Environmental problem associated with fertilizers and mitigation strategies

| Environmental problems | Causative mechanisms | Mitigation strategies |
|---|---|---|
| Groundwater contamination | Nitrate leaching | Judicious use of fertilizers through LCC, increasing efficiency through novel fertilizers, use of nitrification inhibitors and neem coated fertilizers |
| Eutrophication | Loss of nutrients (nitrate and phosphate) through erosion and surface runoff | Reduce runoff through water harvesting and controlled irrigation |
| Methemo-globinemia | Consumption of high nitrates through drinking water and food | Reduce N leaching by adopting crop rotation with crops of different rooting zone. use balanced fertilization and neem coated urea (NOCU) |
| Acid rain and ammonia redeposition | Nitric acid originating from reaction of N oxides with moisture in atmosphere, ammonia volatilization | Reduce ammonia volatilization losses through use of novel fertilizer formulations and nitrification inhibitors |
| Stratospheric ozone depletion | Nitrous oxide emission from depletion and global warming | Use nitrification and urease inhibitors and increase the N use efficiency. Synchronize N use with crop demand. |

**Impacts of Fertilizers on Human Health and Environment**

Based on the data from large number of on-station and on-farm studies, best nutrient management strategies identified for reducing the adverse impact of fertilizers in various crops and cropping systems are summarized in the

**Promotion of Neem Oil Coated Urea-** It has been extensively demonstrated that the use of modified urea materials and nitrification inhibitors can reduce N losses (Prasad, 2013). The promotion of neem cake and oil-coated urea serves as a pesticide and fertilizer at the same time. Azadirachtin is the primary active component of neem; it offers insecticidal, nitrification retardation, immunomodulatory, and anti-cancer effects. It prevents oviposition and stops male sperm production, causing sterility in insects and acting as an antifeedant, unpleasant, and repulsive substance. Numerous studies conducted nationwide have shown that applying neem coated urea (NCU) at 200 kg of neem cake urea or neem oil coated urea (NOCU) at 0.5 kg of neem oil t urea exhibits properties that inhibit nitrification and may significantly increase crop yields and N use efficiency when compared to pilled urea. Metanalysis research showed that in approximately 30% of comparisons, crop yields and/or NUE did not rise. Because of inadequate crop management and plant protection measures, yield increases utilizing NOCU recorded at farmers' fields are typically lower than those at the researcher's plots. Farmers applying high and above optimal levels of urea-N in different crops may not observe significant improvement in yield levels due to NOCU application. In India, more than 50% of the urea is consumed in rice and wheat crops. Replacement of urea with NCU or NOCU could enhance the grain yield by 5% to 6% in plots managed by researchers. The effect of nitrification inhibitors depend on concentration of triterpenoids in neem cake/oil, soil texture, pH and also on redox status of the soils determined by irrigated or rainfed conditions. Nitrification inhibitors work better in acidic soils than in the neutral or alkaline soils, in coarse textured soils than in fine textured soils, and in irrigated crops than in rainfed crops.

Although neem is utilized as a natural substitute for synthetic pesticides, not much research has been done on the pesticidal qualities of either NCU or NOCU. A small number of research on neem-coated urea have been noted by Baboo (2014). According to Yash Roy and Gupta (2000), neem oil is applied as a cost-effective and environmentally friendly way to prevent termites from attacking crops. Farmers at Sangrur and Gurdaspur in the State of Punjab saw decreased incidences of white grub with the application of neem coated urea in the wheat crop, and farmers at Panipat in Haryana had nil incidence of leaf folder and stem borer in the rice crop. Site-specific NOCU application using LCC led to higher or similar levels of crop production vis-avis untreated urea but with lower fertilizer application rates (Shukla et al., 2004). With farmers increasingly adopting NOCU urea coupled with SNM principles for fertilizer management, demand for NOCU may exhibit a decline over the current demand for urea.

**Nutrient Efficient Genotypes**

Finding genotypes that are nutrient-efficient may be a key crop production tactic. Even in situations when native nutrient levels are low, nutrient-efficient genotypes or cultivars can extract or absorb comparatively substantial amounts of nutrients from soil (Behera et al., 2021). These cultivars keep relatively little nutrients in the stover/straw parts and yield large volumes of grain per unit of nutrients ingested.

**Preventive Strategies**

Traditional methods are being reevaluated in light of new technological alternatives for contemporary intensive agriculture that may help reduce or eliminate the requirement for unfavorable chemical inputs and build sustainable, environmentally friendly systems. There are many models that have been supported in this context. These consist of organic farming, low external input sustainable agriculture (LEISA), and integrated pest management (IPM) (Tomer et al., 2014).

♦ Identification and disposal of basket of technologies, which encompasses the principles and practices that restore/improve soil health, protect crop from insect pest and diseases, and ensure sustained high productivity while minimizing environmental footprint.

♦ It is more realistic to promote practices for increasing SOC stock and improving soil quality. The benefits accrued by small increases in SOC may not necessarily translate into the increased crop yield but improve the soil health and ensure the environment safety.

♦ Existing LTFEs (AICRP-LTFE, DA, IFS) serve as the repository of information. These need to be modified to retain their relevance, and converge with present-day farming issues, like organic inputs, tillage, and residue recycling and crop diversification.

**Challenges of Fertilizer Use in Agricultural Systems**

♦ If the NUE stays the same under the existing business as usual, then more fertilizer nutrients will need to be used in order to fulfil the increased food grains needed by 2050. If urea were to be placed under nutrient-based subsidies, its price would rise at first until BMPS adoption was also implemented, which would increase NUE. The greater use of IPNS and balanced fertilization will be the long-term benefits of urea under NBS.

♦ There is a need to intensify research on using alternative management practices beneficial to both the group of indicators i.e., use of organic fertilizers for biological soil quality as well as increase in crop yields.

♦ Despite of the known advantages of IPNS, the availability of subsidized urea fertilizers, the time and labour required to prepare farmyard manure and composts, and the higher handling costs of organic manures prevented its widespread use. grown over time under intense cropping, yet their use is still insufficient to maintain soil health and meet crop demand. All farming systems have extremely negative yearly K balances as a result of soil K being mined and used sparingly by crops. The mineralogical composition of soil has gradually changed as a result of ongoing K input neglect, indicating a decline in the soils' ability to supply K.

**REFERENCES** Abrol, Y.P. and Adhya, T.K. 2017. Technical summary. The Indian Nitrogen Assessment 1-5. http://dx.doi.org/ 10.1016/B978-0-12-811836-8.00001-X.

1. Adhikari, T., Wanjari, R.H. and Singh, M. 2019. Research Bulletin on Microbial Diversity and Heavy Metals Buildup in Soils under Long Term Fertilizer Experiments, pp. 1-53. ICAR Indian Institute of Soil Science, Bhopal.
2. Adhya, T.K., Shukla, A.K. and Panda, D. 2010. Nitrogen losses, N-use efficiency, and N-management in rice and rice-based cropping system. In Bulletin No. 2: ING Bulletins on Regional Assessment of Reactive Nitrogen.
3. Indian Nitrogen Group, Society for Conservation of Nature in Association with South Asian Nitrogen Centre, International Nitrogen Initiative.
4. Behera, S.K., Shukla, A.K., Singh, P., Trivedi, V. et al. 2021. Zinc application enhances yield and alters micronutrients concentration in pigeon pea (Cajanus cajan L. Millsp.). Nutrient Cycling in Agroecosystems 119, 423-443.
5. Bijay-Singh. 2016. Site-specific nitrogen management in cereals in India. Indian Journal of Fertilisers 12(4), 4657.
6. Bijay-Singh, Singh, Y. and Bains, J.S. 2003. Real-time nitrogen management using chlorophyll meter and leaf colour chart (LCC) in rice and wheat. In Nutrient Management for Sustainable Rice-Wheat Cropping System (Y. Singh, B. Singh and J. Singh, Eds.), pp. 115-124. NATP, Indian Council of Agricultural Research, New
7. Delhi and Punjab Agricultural University, Ludhiana.
8. Bijay-Singh, Yadvinder-Singh and Sekhon, G.S. 1995. Fertilizer use efficiency and nitrate pollution of groundwater in developing countries. Journal of Contaminant Hydrology 20, 167–184.
9. Brar, B.S., Singh, J., Singh, G. and Gurpreet-Kaur. 2015. Effects of long-term application of inorganic and organic fertilizers on soil organic carbon and physical properties in maize–wheat rotation. Agronomy 5, 220238.