Innovative Fertilizers for Enhanced Nutrient Use Efficiency and Sustainable Agriculture

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Fertilizers are feeding the world. There has been rapid increase in use of fertilizers during last 50 years. Increased access to mineral fertilizers has helped immensely in reducing hunger and malnutrition globally including India. Fertilizers, being one of key inputs, contribute 50% to growth in global food-grain production. However, these gains in food production have come at a cost in terms of exploitation of natural resources and environment. In addition, there are sustainability issues both for fertilizer and agriculture sectors. The imbalanced and inefficient use of fertilizers has resulted in lowering of nutrient use efficiencies, declining crop response to fertilizers, reduced farm profits, degradation of soil health, and accentuation of environmental pollution. This is a challenge to agricultural sustainability and future food security.

The biggest challenge facing nutrient management today is the abysmally low nutrient use efficiency of applied fertilizers. Utilization of fertilizer nitrogen (N) by crops in India seldom exceeds 35% under lowland and 50% under upland conditions. Use efficiency of other nutrients is: 15-25% of phosphorus (P), 50-60% of potassium (K), 8-12% of sulphur (S) and 2-5% of most of the micronutrients under the best managed conditions. Fertilizer-N not consumed by the crops leaks to the environment through processes like ammonia volatilization, nitrate leaching, surface run off and N_2O emissions. All these factors affect the environment adversely. Nutrients other than N upon addition remain essentially in the soil but get locked/ fixed/ difficultly available/ unavailable making them inaccessible for absorption by the growing crops.

To alleviate the problem of low fertilizer use efficiency, research institutions and fertilizer industry world over are working relentlessly on the development of innovative fertilizer products, technologies, and practices. Being both universally deficient nutrient and reactive pollutant, fertilizer N has drawn maximum attention. Too little external input of N or no N means poor crop productivity, but too much of it leads to environmental pollution. Both these extremities threaten the agricultural productivity, food security, and farm income at one end and health of environment and human on the other end. Enhanced efficiency nitrogenous fertilizers, abbreviated as EENFs, are defined as the fertilizer products with characteristics that allow increased plant N uptake and reduce the potential of N losses to the environment via atmospheric losses, leaching, or runoff when compared to an appropriate reference product. These are being developed using principles of controlled N release, slowed N release, and controlled enzymatic and /or bacterial activity.

Innovation in the conventional bulk nitrogenous fertilizers, especially in prilled urea, has been introduced by way of condensation, polymerization, coating, encapsulation, and addition of inhibitors to increase the crop N-use efficiency. Objective here is to keep the added N in plant utilizable forms for extended periods, thus reducing leaching potential, and minimizing the gaseous loss of N to the atmosphere. A number of controlled release fertilizers, slow release fertilizers, sulphur coated urea, and stabilized nitrogen fertilizers have been developed to bring about significant improvement in nitrogen use efficiency (NUE). These products have proven their superiority in enhancing the recovery efficiencies of applied N and cutting down on the N_2O emissions. However, very high cost of these products (4-6 times of the conventional fertilizers) have restricted their use to the low volume-high value crops and turfs, and lawns and ornamental plants grown in the regions having stringent environmental regulations. These products are largely used in developed countries and their use is practically nil in our country due to very high cost *vis-à-vis* highly subsidized urea.

Among the innovative fertilizers, water soluble fertilizers (WSFs) have witnessed rapid growth worldwide including India. Water-soluble fertilizers segment accounted for about 63% of the global specialty fertilizers market in 2018. International Fertilizer Association (IFA) estimated the global WSFs demand at 3.6 Mt in 2018 and was mainly driven by the fast development of greenhouse and drip irrigation cropping systems to produce vegetables and fruits. South Asia is emerging as a significant market pursuant to Indian Government's incentives for drip

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irrigation and the spread of low-cost greenhouse equipment. Consumption of WSFs in India witnessed 6-fold increase, from 50,000 t in 2010-11 to 3,00,000 t in 2020-21. However, share of WSFs in total fertilizer consumption in India is less than 0.5% against 5-6% achieved globally. It means that there is a vast scope/ potential to increase consumption of WSFs. Rising societal demand for micronutrient-fortified staple diets has also triggered the demand for micronutrient-containing WSFs in foliar fertilization. Spiraling demand on account of consumers' preference for the low volume-high value horticultural crops including flowers and medicinal plants grown with protective cultivation technologies will further stimulate the growth of this segment.

Liquid fertilizers is another category of innovative fertilizers with good potential due to attractive monetary returns and minimum environment footprints. Global liquid fertilizers market size was valued at US$ 2.4 billion in 2020 and is projected to reach US$ 3.0 billion by 2025, registering a compound annual growth rate of 4.4%. Liquid fertilizers have been introduced recently and ten products have been included in the Fertiliser (Control) Order 1985 in India during last 2 years. Commercial success of these products remains to be evaluated in our country as fertilizers in the liquid form require distinctive handling and storage facilities.

With assurance of smart delivery to the targeted site, nano fertilizer has a potential of enhancing many-fold the use efficiency of the nutrient(s) and reducing the environmental footprints. A number of nano products have been developed in India and globally, particularly in the last two decades. However, these were not commercialized for various reasons. India has become the first country in the world to start the commercial production and use of nano fertilizer. Based on the results from a large number of multi-locational experiments conducted across the length and breadth of the country, Nano Urea (liquid) fertilizer has shown a potential of reducing the use of prilled urea by 25-50% and increasing the crop yields by 10-15% over the farmers' fertilizer practice.

Extensive work has been done globally on identification and evaluation of beneficial micro-organisms that help in the fixation of atmospheric N in soil and solublization/mobilization of nutrients fixed in soil. Based on nature and role of these microorganisms, different types of biofertilizers have been developed and are being used to supplement to the bulk fertilizers. A number of fertilizer companies in India are in the business of production and sale of biofertilizers. These biofertilizers have potential to supplement 15-20% nutrient demand of the crop, increase the crop yields, and improve the biological soil health.

Soil organic carbon content in India is very low (<0.5%) and it is also one of the major reasons of poor nutrient use efficiency. Organic carbon of soil can be increased by use of organic manure. Farmers should be educated to use crop residues / farm wastes and animal wastes in fields. Further, conversion of rural, urban and peri-urban wastes into manurial wealth for its use in soil should be encouraged under Swachh Bharat Abhiyan of Government of India. Higher organic carbon content in soil will result in higher use efficiency of fertilizers.

It is a hard fact that the innovative fertilizers cannot completely replace/substitute bulk fertilizers in the near future. However, considering the limited availability, increasing cost and poor nutrient use efficiency of conventional fertilizers, gradual shift towards innovative fertilizers is going to become a reality. Prohibitive cost of innovative fertilizers is acting against their adoption by the farmers. A lot of research and development work is needed to develop the protocols for cost-effective and efficient innovative fertilizers. The government and industry will have to make concerted efforts to convince the farmers that despite their high cost, the net gains in terms of improvement in crop yields, produce quality, reducing impact on human health and environment realized with application of innovative fertilizers are much higher compared to the conventional fertilizers. Production and use of innovative fertilizers on large scale will increase the affordability of the fertilizers.

Large scale adoption of innovative products requires reforms in the present fertilizer policy and regulatory environment to provide level playing field to all those engaged in development of sustainable plant nutrition systems. To sum up, development and introduction of new fertilizer products or the customization/ modification of the existing ones are required for meeting challenges of food, conservation of natural resources, protection of environment and prevention of ill effects of climate change. ■