Stakeholders Dialogue on
Enhancing Fertilizer Use Efficiency for Sustainable Soil Health

PROCEEDINGS AND RECOMMENDATIONS

taas
Progress Through Science

Trust for Advancement of Agricultural Sciences (TAAS)

GOAL

Harnessing the potential of agricultural sciences for the welfare of the people.

MISSION

Promoting growth and advancement of agriculture through scientific partnerships, policy advocacy and public awareness.

OBJECTIVES

- To act as a 'Think Tank' to deliberate on key issues relating to agricultural research and innovation for development (ARI4D) and influence policy decisions
- To organize workshops, conferences, brainstorming sessions, policy dialogues seminars and special lectures on emerging issues and new developments in agricultural sciences
- To disseminate knowledge among stakeholders through publication of proceedings, strategy papers and policy papers
- To confer awards to the scientists of Indian and foreign origin for their outstanding contributions having impact on Indian agriculture
- To facilitate scientific interactions and partnership building of non-resident Indian agricultural scientists

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Organizers

Trust for Advancement in Agricultural Sciences (TAAS)
International Fertilizer Development Center (IFDC)
Indian Council of Agricultural Research (ICAR)

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Acronyms and Abbreviations

ADG	Assistant Director General
ADG (AA&CC)	Assistant Director General (Agronomy, Agro-forestry and Climate Change)
AI	Artificial Intelligence
AICRP	All India Coordinated Research Project
APG	Agricultural Productivity Growth
ASRB	Agricultural Scientists' Recruitment Board
BMP	Best Management Practices
BNF	Biological Nitrogen Fixation
BNI	Biological Nitrification Inhibition
BRC	Biodegradable Reaction Coating
CA	Conservation Agriculture
CAFT	Centre for Advanced Faculty Training
CASI	Conservation Agriculture-Based Sustainable Intensification
CAZRI	Central Arid Zone Research Institute
CCS HAU	Chaudhary Charan Singh Hisar Agricultural University
CF	Customized fertilizers
CFAES	College of Food, Agricultural, and Environmental Sciences
CIMMYT	International Maize and Wheat Improvement Center
CISH	Central Institute of Sub-tropical Horticulture
CoEF	Centre of Excellence on Fertilizers
CRA	Canada Revenue Agency
CRAFS	Climate Resilient Agri-Food Systems
CRIDA	Central Research Institute on Dryland Agriculture
CSE	Centre for Science and Environment
CSISA	Cereal Systems Initiative for South Asia
CSKHPKV	Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidyalaya
CSR	Corporate Social Responsibility
CSSRI	Central Soil Salinity Research Institute
CWANA	Central and West Asia and North Africa
DA	Digital Agriculture
DAN	Desensitize Ammonium Nitrate, Directly Available Nitrogen
DAP	Diammonium Phosphate
DARE	Department of Agricultural Research and Education

DBD	Dielectric Barrier Discharge
DBT	Direct Benefit Transfer
DDG	Deputy Director General
DDR	Day Dissolution Rate
DG	Director General
DSR	Direct Seeded Rice
DSS	Decision Support Systems
EEF	Enhanced Efficiency Fertilizers
ESS	Environmental Services Section
F2F	Factory to Fork
FAI	Fertilizer Association of India
FAO	Food and Agriculture Organization of the United Nations
FCO	Fertilizer Control Order
FDP	Fertilizer Deep Placement
FIC	Fertilize Innovation Centre
FN	Fertilizer Nitrogen
FUE	Fertilizer Use Efficiency
GAP	Good Agronomic Practices
GBPUA&T	Govind Ballabh Pant University of Agricultural and Technology
GCA	Gross Cropped Areas
GCS	Green Credit Scheme
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHM	Green Hydrogen Mission
GIS	Geographic Information Systems
GM	Genetically Modified
GoI	Government of India
GR	Green Revolution
GST	Goods and Services Tax
HYVs	High Yielding Varieties
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
ICL	Israel Chemicals Ltd
ICRIER	Indian Council for Research on International Economic Relations
ICSF	Innovative Climate-Smart Fertilizers
NIAP	National Institute of Agricultural Economics and Policy Research
ICRISAT	International Crop Research Institute for Semi Arid Tropics
ICT	Information and Communications Technology

IFA	International Fertilizer Association
IFDC	International Fertilizer Development Center
IFFCO	Indian Farmers' Fertilizer Cooperative Limited
IGFRI	Indian Grassland and Fodder Research Institute
IIFSR	Indian Institute of Farming Systems Research
IIMR	Indian institute of Maize Research
IISR	Indian Institute of Soil Science
INM	Integrated Nutrient Management
INR	Indian Rupees
IoT	Internet of Things
IPNM	Integrated Plant Nutrient Management
JVs	Joint Ventures
KVKs	*Krishi Vigyan Kendras*
LCC	Leaf Color Charts
LNG	Liquefied Natural Gas
MERVs	Minimum Efficiency Reporting Value
MoC&F	Ministry of Chemicals and Fertilizers
MoEF&CC	Ministry of Environment, Forest and Climate Change
MOP	Muriate of Potash
MRVs	Measurement, Reporting and Verification
NBMMP	National Biogas and Manure Management Program
NBPGR	National Bureau of Plant Genetic Resources
NBS	Nutrient-Based Subsidy
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NCB	Nano Clay Biopolymers
NCPCs	Nano Polymer Composites
NDC	Nationally Determined Contributions
NF	Natural Farming
NFP	Neutral Fertilizer Platform
NGOs	Non-Government Organization
NMSA	National Mission for Sustainable Agriculture
NP	Nitrogen Phosphorus
NPK	Nitrogen Phosphorus and Potash
NPMCR	National Policy for Management of Crop Residue
NRM	Natural Resource Management
NUE	Nitrogen Use Efficiency
OUAT	Orissa University of Agricultural and Technology
P&K	Phosphorus and Potash

PA	Precision Agriculture, Protective Agriculture
PAU	Punjab Agricultural University
PF	Precision Farming
PFP	Partial Factor Productivity
PIO	Public International Organization
PM PRANAM	Pradhan Mantri-Program for Restoration, Awareness Generation, Nourishment and Amelioration of Mother Earth
PNM	Precision Nutrient Management
PPL	Paradeep Phosphates Ltd
PPP	Public-Private Partnership
PPPP	Public-Private-Producer-Partnership
PUE	Phosphorus Use Efficiency
R&D	Research and Development
RA	Regenerative Agriculture
RDF	Recycling-derived Fertilizers
RVSKVV	Rajmata Vajayaraje Scindia Krishi Vishwa Vidyalaya
SAUs	State Agricultural Universities
SBNA	Sensor-based Nutrient Application
SCC	Soil Carbon Content
SCF	Soil Conservation Fund
SDGs	Sustainable Development Goals
SFS	Soil Fertility Status
SHC	Soil Health Card
SMCA	Soil Management-Based Climate Adaptation
SNMI	Soil Nutrient Mining Index
SOC	Soil Organic Carbon
SSNM	Site- specific Nutrient Management
SSP	Single Superphosphate
STCR	Soil Test Crop Response
TAAS	Trust for Advancement of Agricultural Sciences
TFP	Total Factor Productivity
TNAU	Tamil Nadu Agricultural University
TSP	Triple Super Phosphate
USD	United States Dollars
UT	Union Territories
VC	Vice Chancellor
WUE	Water Use Efficiency

Stakeholders Dialogue on
Enhancing Fertilizer Use Efficiency for Sustainable Soil Health

BACKGROUND

Fertilizers have a crucial role in sustainability of global agriculture as they provide necessary nutrients for crops for optimum growth and yield. The ultimate food security for this ever-increasing global population necessitates a rising demand for fertilizers. India became the world's most populous country in 2023, with increase in population by 4.33 times (from 330 million to 1,432 million) since its independence (1947), though simultaneously, there is rise in foodgrain production (6.61 times, from 50 mt to 330.5 mt) and fertilizer use (464 times, from 0.07 to almost 32.51 mt). The technology-based high yielding varieties (HYVs), fertilizer use, and investment-led irrigation infrastructure played an important role in transforming Indian agriculture from net importer to self-sufficiency and even exporter. The country became the second largest consumer and importer of fertilizers with more than 6 per cent average annual increase from 1970s and currently accounts for 16.1 per cent of global fertilizer use. Over the years, Government of India (GoI) has been ensuring fertilizer availability to the farmers at subsidized price resulting in huge burden of subsidy, which increased almost 1.5 times from US$ 20 billion in 2021-22 to US$ 28 billion in 2022-23.

CONSTRAINTS AND FUTURE POTENTIAL

The GoI has allocated a subsidy of Rs 1.08 lakh crore for 2023-24 *kharif* including Rs 70,000 crore subsidy for urea and Rs 38,000 crore for diammonium phosphate (DAP) and other fertilizers. Existing subsidy provisions do favor nitrogen (N) fertilizer use, causing overuse of N at the cost of requisite dose of phosphorus (P), potash (K), and micronutrients. Observing the recent trends in international prices of DAP, MOP and S, the GoI approved the nutrient base subsidy (NBS) rates for *rabi* 2023-24 effective from 1 October 2023 to ensure the availability of P and K fertilizers to farmers at affordable prices. Among the essential plant nutrients, the use of N fertilizer has increased significantly (around 67 per cent of the total fertilizer nutrient consumption) in the country.

The N partial factor productivity declined from 32 kg foodgrain per kg of N applied in 1970s to 12 kg in 2020, reducing the nitrogen use efficiency (NUE) as low as 30 per cent and phosphorus by 20 per cent. Low NUE and energy intensive urea production emits around 119 mt CO_2 equivalent emissions annually in the country. Technology-led growth has increased food production, but also enhanced the agro-eco-environmental challenges by over-exploitation of natural resources such as soil, water, and biodiversity, decreased NUE and factor productivity, depleted soil health and increased climate aberrations. Hence, low efficiency results in considerable waste of resources and a drain on foreign exchange as the country imports almost 25, 90 and 100 per cent of N, P and K as finished products or as raw material. These problems are of utmost concern for industry, farmers, researchers, and policy makers.

The projections do suggest that India may have to double its fertilizer use by 2050 to feed its ever-bulging population. Since India depends extensively on fertilizer imports, the sky-high fertilizer prices during Russia–Ukraine war have adversely impacted the fertilizer subsidy and agriculture sector. Now the prices have largely receded to pre-war levels, but as was the case with previous disruptions (1978, 2008), the fertilizer prices on average will probably remain somewhat higher than those in the decade before the war. The Indian fertilizer industry achieved a high energy efficiency comparable to the best in the world, which has been possible through continuous modernization of old processing plants and addition of state-of-the-art infrastructures. It is felt that now fertilizer industry needs to be given realistic time schedule and obligations to switch from grey ammonia to green ammonia.

These multi-faceted challenges of inter-connections between energy, fertilizer prices and availability, food insecurity, nutrition, and its environmental implications as well as the health impacts of the increasing environmental losses due to fertilizers have become a subject of growing scientific concern – both biophysical and socioeconomic. It is also evident that exclusive dependence on inorganic fertilizers, particularly, if misused, can have serious environmental consequences. Therefore, the Government of India (GoI) is promoting alternative sources of plant nutrition, organic and biofertilizers on a large scale through several sponsored schemes. But currently, the total area under organic farming is only about 2.7 per cent and production of biofertilizers (soil and liquid) is less than 0.15 mt in 2020-21, despite a growth of around 500 per cent in the past one decade. There are several barriers in widespread use of biofertilizers and organic fertilizers, relating to subsidies, and support for promotion of biofertilizers and organic fertilizers, quality control, data collection and reporting.

Combining fertilizers with natural and organic sources (organo-minerals), therefore, is a kind of assurance to minimize adverse economic and environmental

impacts. Global scientific innovations on improving NUE by 20 per cent reportedly reduced carbon footprints by 21.0 mt of CO_2 equivalent annually in India. The annual reduction in carbon footprints may provide an additional carbon trading/ green credits income to farmers and industry to the tune of around US$ 213 million annually, save around US$ 4 billion subsidy, and achieve the targeted Nationally Determined Contributions (NDCs) under Paris Agreement by 2030 at the country level. Pragmatic reforms are urgently required for the soil health and plant nutrient sources and technologies in India since the inaction cost would be far greater than that of action.

The GoI, to address these issues, has to focus more on incentivizing efficient use of fertilizers. The fertilizer industry must change the way it produces and do marketing of fertilizers. Competitiveness and innovation are vital for its survival and growth. Innovation to develop, test and manufacture high-quality improved fertilizer blends, coatings, compounds, organo-minerals at different production scales are needed to replace/modify the traditional fertilizer formulations, especially urea. Moreover, the sustainable agriculture production systems demand innovations in new organic, inorganic, and mixed products and integrated nutrient management (INM) technologies including mechanization of fertilizer deep placement (FDP) and use of artificial intelligence and machine learning tools.

THE STAKEHOLDERS' DIALOGUE

In view of above, the Trust for Advancement of Agricultural Sciences (TAAS), New Delhi, a neutral 'Think Tank', and the Indian Council of Agricultural Research (ICAR) in collaboration with International Fertilizer Development Center (IFDC), Alabama, USA organized a ***Stakeholders' Dialogue on Enhancing Fertilizer Use Efficiency for Sustainable Soil Health,*** in New Delhi on 28-29 September 2023. A total of over 100 diverse stakeholders representing researchers, policy planners, development officials, representatives of the private sector and progressive farmers participated. The objectives of the Dialogue were to: (i) understand the interdependence between energy, fertilizers, soil, and environmental health for developing innovative pathways to achieve food and nutritional security, (ii) suggest innovative options for enhancing holistic nutrient use efficiency (factory-to-field) through novel products, management practices, and science of scaling, and iii) recommend the Way Forward for promoting science-led incentive-based policies and strategies for improving nutrient use efficiency and restoring soil health.

INAUGURAL SESSION

Dr RS Paroda, *Padma Bhushan* awardee, Chairman, Trust for Advancement of Agricultural Sciences (TAAS), and Former Secretary, Department of Agricultural

Research & Education (DARE) and Director General, Indian Council of Agricultural Research (ICAR) inaugurated the Stakeholders' Dialogue.

In setting the context of the program, **Dr VK Singh,** ICAR-Central Research Institute on Dryland Agriculture (CRIDA), welcomed the Chief Guest Dr RS Paroda, Mr Harshdeep Singh, and Dr Upendra Singh, distinguished invitees and eminent experts to this important Stakeholders' Dialogue who assembled here to discuss the challenges and the way forward for the fertilizer sector and thereby sustainable agricultural production in the country. He thanked all the participants attending the Dialogue and felt that the large turnout from the public, private and cooperative sector reflected the importance attached to fertilizer sector, in general, and the sincere efforts of the TAAS in particular. He highlighted on the declining soil fertility and the emergence of multi-nutrient deficiencies in Indian soils, which are serious productivity constraints in targeting higher crop productivity. He further proposed integrated plant nutrient management as the way forward' for the sustainability of agriculture in India. He echoed for site-specific nutrient management, sensor-based nutrient application (SBNA), slow-release N fertilizers, neem-coated urea, placement technologies, customized fertilizers (CF), fertigation, foliar sprays of water-soluble nutrients and nano-fertilizers, use of hydrogel (super absorbent polymer), briquets along with soil management-based climate adaptation (SMCA) to improve the use efficiency of nutrient and help both adaptation and mitigation of climate change.

In his special remarks, **Mr Harshdeep Singh,** representing Chairman Fertilizer Association of India (FAI) highlighted on the strategies for enhancing nutrient use efficiency (NUE) for sustainable soil health and shared existing problems of declining fertilizer response, imbalanced fertilizer use, deteriorating soil and environmental consequences of fertilizer use leading to climate unpredictability. He emphasized the importance of soil carbon for better soil health. He also echoed for continuous monitoring of soil physical, chemical and biological parameters, improving soil organic carbon (SOC), integrated nutrient management (INM) and integration of legume crops in the crop rotation. Representing the fertilizer industry, his key message was that it needs to be proactive to engage with research organizations more intensively for the development of new innovative products and technologies for enabling improvement in NUE for sustainable soil health.

Dr Upendra Singh, Vice President, International Fertilizer Development Center (IFDC) in his special remarks suggested that a vast country like India needs to enhance nutrient use efficiency with adoption of innovative climate-smart fertilizers (ICSF). The country needs to revisit deep placement of the fertilizer with mechanized planting and fertilization. He further highlighted that India has

tremendous potential of nutrient and waste recycling and value-addition with organo-mineral fertilizers, which IFDC has championed in the past few years. For the industry, he echoed for revamping existing urea plants with cleaner fuels and more efficient processes and tap the opportunities for decarbonization and decentralization.

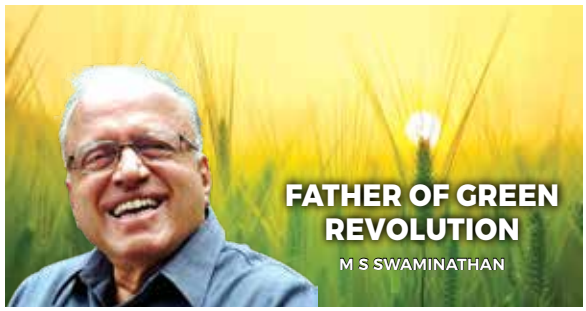
In his address as Chief Guest, **Dr RS Paroda,** Chairman, TAAS, suggested that the future of fertilizers, plant nutrition, sustainable production and healthier environment demands for improving efficiencies using Factory to Fork (F2F) approach**.** He shared that in the past five decades, fertilizers and agriculture at large have benefited from scientific innovations and technology. He highlighted the importance of innovation like Haber Bosch process starting in 1918, which made the production of ammonia fertilizer economically feasible to enhance productivity and role of IFDC in delivering those innovations in the developing and under-developed world. He also shared that this Stakeholders' Dialogue is exclusive and important in the current context as the industry, research, extension, and policy stakeholders are at one platform to devise a 'way forward' for increasing farmers' income and reducing the environmental impacts of fertilizers. He shared that from 1950s to 2020s, the global fertilizer use increased six- times, whereas in India the increase is by 471-times. During the same period, foodgrain production increased by 6 times and therefore, over the years, partial factor productivity (PFP) has declined from 32 kg foodgrain per kg of N applied in 1970s to 12 kg in 2020 in India. He also raised his concerns on the ever-rising fertilizer subsidy of Government of India (GoI), which has increased to more than US$ 25 billion annually leading to imbalanced use of fertilizer due to inclination towards urea fertilizers. India imports equivalent to 25, 90 and 100 per cent of N, P and K fertilizers. He also shared that India being one of the largest importers of fertilizers, the global geo-political situations play a vital role on the fertilizer prices. He informed that while technology-led growth and subsidy-based fertilizer use resulted in increased food production, it has promoted over-exploitation of natural resources such as soil, water, and biodiversity. The fertilizer sector faces multi-faceted challenges, including volatile fertilizer prices, soil health and environmental concerns, depleting nutrient use efficiency (NUE), imbalanced fertilizer uses due to subsidy and urea favoring policies, increasing fertilizer subsidy, import dependence, and supply-chain disruptions. The impact of climate change also affects NUE adversely as well as low NUE causes global warming by high GHG emission (119 mt annually from urea alone). The long-term studies confirm a 40-50 per cent increase in foodgrain production attributed to fertilizers, which saved around 5 giga ha land from deforestation, but contrary to it, there is ample evidence that indiscriminate and imbalanced use of chemical fertilizers and other inputs are the major cause

of deteriorating soil health, environmental quality, biodiversity sustainability, and human health as well as adversely impacting economics and climate change fallouts and drain on foreign exchange. He also shared Government schemes and programs, viz., Soil Health Card (SHC), Neem-coated Urea, National Mission for Sustainable Agriculture (NMSA), National Policy for Management of Crop Residue (NPMCR), Customized Fertilizers (CF), National Biogas and Manure Management Program (NBMMP), *Pradhan Mantri*-Program for Restoration, Awareness, Generation, Nourishment and Amelioration of Mother Earth (PM PRANAM) are effective towards improving soil health and nutrient use efficiency. He also stressed on the urgent need for pragmatic reforms in the soil health and plant nutrient sources and technologies in India since the cost of inaction is far greater than the cost of action. To address these issues, he suggested to – transform fertilizer sector from subsidy to incentives system, allocating 5 per cent of subsidy amount on fertilizer innovations, enhanced corporate social responsibility (CSR) funding to fertilizer research, judicious use of organic and inorganics, initiate new research through development of a Fertilizer Innovation Centre (FIC) in India, emphasize on circular economy by converting industry waste into plant nutrition products, and include cutting edge information and communications technology (ICT), drones and artificial intelligence (AI) in the fertilizer sector. He emphasized that the fertilizer industry should innovate for being competitive in the global market and cater to the needs of fertilizers and contribute to One Health, starting from soil to environment to livestock and to human beings.

Dr Bhag Mal, Secretary TAAS, expressed gratefulness and profuse thanks to Dr RS Paroda, Chairman, TAAS for his thought-provoking address in the Inaugural Session as well as continued guidance and meticulous planning of the program and catalyzing the various co-organizers for their kind support. He expressed heartfelt thanks to both Mr Harshdeep Singh and Dr Upendra Singh for their insightful special remarks and assuring the support for both the research and development (R&D) of the sector. He also thanked Dr VK Singh for his welcome remarks, setting the context, and also the ICAR and IFDC for the help and support provided for organizing the Dialogue. Finally, he thanked all the distinguished guests, eminent experts, invitees, and participants for their kind presence and all those who helped in organizing the Stakeholders' Dialogue.

TECHNICAL SESSION I: FERTILIZER SCENARIO- NATIONAL AND INTERNATIONAL ISSUES

The first Technical Session was co-chaired by **Dr AK Singh,** Vice President National Academy of Agricultural Sciences (NAAS) and **Dr Ramendra Singh,** Expert Fertilizer Sector. Presentations were made on national and international issues of



Homage to Prof MS Swaminathan

The Dialogue participants led by Dr RS Paroda observed one-minute silence to pay homage to Prof MS Swaminathan, Former Secretary, DARE & Director General, ICAR- the father of Green Revolution (GR) in India.

the fertilizer sector by **Dr JC Katyal,** Former Vice Chancellor, Chaudhary Charan Singh Hisar Agricultural University (CCS HAU), Hisar (Haryana); **Dr Achim Dobermann**, International Fertilizer Association (IFA); and **Dr Kuldeep Sati**, Fertilizer Association of India (FAI). **Dr Alison Laing**, International Maize and Wheat Improvement Center (CIMMYT) was the rapporteur for the Session.

Dr JC Katyal made a presentation on "Rationalizing chemical fertilizer use for maintaining ecological sustainability and containing subsidy budget". He mentioned that as fertilizer is essential to farmers and India, it needs to be affordable and economic. The GoI subsidies supported agricultural production and paid dividends across India; and now the country is self-sufficient and an exporter of agricultural commodities. He shared that in future liquid and tailor-made fertilizers will dominate, and growth in uptake and use of complex fertilizers is increasing. Global studies showed that urea production and its use in soils are the major sources of soil health decline and global warming (P & K do not do much). The Indian fertilizer subsidy policy was initiated in 1957 and last revised in 2021. The current plant nutrient subsidized prices are ₹ 5.33 urea, DAP 27, MOP 34 (2022). It means that farmers pay significantly below the market rates for fertilizers. Since 1957, fertilizer subsidy has been increasing. In 2022-23, it was ₹ 2.25 lakh crore. Urea, DAP, MOP dominate subsidy policy (64, 26, 10% respectively). There is a strong relationship between fertilizer

consumption (NPK) and subsidy budget. While the fertilizer subsidy scheme made NPK affordable for farmers, it has also promoted over and imbalanced use, misuse leading to deterioration in soil health, GHG emission, etc. The soil nutrient mining index (SNMI) shows that N is building up, P also building up, but K is depleting in Indian soils. Therefore, the costs of fertilizer import are increasing and returns are decreasing over time. He also emphasized that Fertilizer N (FN) is significantly related to global warming – in production and after application in field and contributing up to 22 per cent of total agriculture emissions. The reduction in N consumption will reduce GHG emissions both in the field and in production and transport; and enhanced fertilizer use efficiency is in a win-win situation to mitigate both climate change and the subsidy budget. He exhorted that fertilizer overuse has significant adverse effects on human health in both adults and children.

There is a need to streamline the fertilizer subsidy bill in the country either by decreasing NPK consumption or reducing global market price. But it is easier to manage consumption than international prices. Hence, there is a need to enhance fertilizer use efficiency (FUE), especially in FN because FN consumption dominates and offers the maximum prospect to effect savings. Also, over applied P & K stay in soil but N volatilizes/leaches if not taken up by plants. There is an urgent need for innovations and R&D to improve FUE. Goal-oriented approach is required to enhance fertilizer subsidy financing efficiency i.e. containing growth in subsidy budget by reducing NPK use without affecting farm productivity/ profitability, introducing good agronomic practices (GAP) and best management practices (BMP). Another option may be complementary and supplementary sources of fertilizer to inorganic and synthetic fertilizers. He also shared that developed world has almost double the NUE than India and China. The agronomic efficiency (kg foodgrain/kg) of NPK has decreased from 12 in 1960-69 to 3.5 in 2020-22 in the country and this trend is continuing from 1960s. He suggested several strategies to elevate the FUE including raising the NUE by appropriate technology targeting for GAPs-specific but holistic across all agricultural management practices, complementary sources that replace part of synthetic fertilizer and synergize yield, air and soil health and human health and alternative farming methods that harmonize tradition and technology (natural farming (NF) + conservation agriculture-CA, regenerative agriculture-RA, etc.). He also emphasized on 4Rs nutrient management concept, i.e. use the right source, right rate, right time, and right placement integrated with standard agronomic practices. He shared examples of ecological sustainability research at ICAR-CRIDA, which suggested replacing some inorganic fertilizer with organic manure (up to 25% of total required fertilizer) and this leads to economic savings and enhanced

productivity. He shared several examples on different tools for reducing N use including leaf color charts, delayed basal application in maize, applying top dress urea before irrigation, etc. He also emphasized on K-rich mineral glauconite and shared that India has around 1,900 mt of glauconite, which can be effectively utilized for this purpose. It is an effective soil conditioner and acid ameliorant, effective organic fertilizer for plantation crops and can be used as customized fertilizers. Glauconite could be included in the schedule of minor minerals for better exploitation of its value, but it requires enabling policy.

On the policy aspects, he emphasized new policies to facilitate utilization of glauconite to reduce imports equal to 1 mt K, saving USD 590 million/year and Rs 1,518 million in subsidy expenses. He also voiced for incentive and rewards scheme for production of quality organic manures, which should be extended to cultivators. There is a need to support financial practitioner groups who undertake professional production of organic manures for efficient FN management. He exhorted science-driven recommendations on efficient fertilizer management, educate extension workers and provide them with training in NUE-based site-specific nutrient management. He further proposed replacing blanket recommendations for fertilizer use with crop-specific soil test-based site- specific nutrient management (SSNM) recommendations; with good agricultural practices, this can help in enhancing NUE by 20 per cent and save around 15 per cent of the urea use. There is no need to broadcast fertilizers; only deep placement needs to be done in a mechanized way and skill enhancement of farmers to use these technologies be ensured.

Dr A Dobermann from International Fertilizer Association (IFA) presented on the global supply and demand of the fertilizers. He shared that foodgrains, and food and fertilizer prices are strongly connected (increasing overtime 1960-2023). He exhorted that global food and nutrition in future is not possible without fertilizers. The global fertilizer market is driven by supply (costs, logistics, technology), demand (global food demand, crop prices, forex) and also weather, planting progress, trade disruption, domestic policy, geopolitics and conflicts, etc. and complexity of these are increasing over time and also hard to project in the future. The fertilizer prices were corrected after the Russia-Ukraine war caused trade disruptions for urea, DAP and potash, etc. But in 2021 and 2022, several countries decreased their fertilizer use; and East and South Asia are the largest contributors to global decline. Central and West Asia, and North Africa (CWANA) region; and central Europe declined by at least 15 per cent in fertilizer use during this period. There were two major supply-chain disruptions i.e. COVID-19 pandemic and Russia-Ukraine war. Now the global fertilizer use of plant nutrients is back to 2019 status for all the NPK fertilizers, but long-term

predictions of demand-supply are still uncertain. There are several other new factors that may significantly influence the future demand and supply including public voices as urban consumers, media, influencers, activists, politicians, and investors advising how to live–especially healthy diets, diverse production, and environmental concerns of soil-biota, fair, sustainable, renewable, zero carbon, nature positive, no GM, no chemicals– as per the new mainstreaming popular opinions. But still the real-world drives on demand, supply, farming markets, and risks. Disruptive technologies lead to population growth, income growth, social changes, climate, environment, energy, water, minerals, technologies, conflicts, pandemic, regulation which are unlikely to change much before 2050.

He shared that IFA has done long-term projections for fertilizer demand and supply but limited to cropland only up to 2030 and 2050. There are several assumptions in these projections including no disruptive changes in food demand, pillars of global food system do not change significantly, organic farming remains small (< 20% yield). Incremental improvement of crop NUE over time, improvement of nutrient recycling from manure and no disruptive technology may lead to a quantum leap. Since, there is a large contribution of cereal to global nutrition which is not only providing carbohydrates but many other key elements, minerals, amino acid and vitamins as well. He shared that cereals supply for over 40 per cent of these nutrients to humans globally. Also, cereals consume more than half of the global supply of fertilizers. Cereals may remain the basis of the world food supply for years to come. Therefore, cereals may be taken as basis for the fertilizer demand-supply scenario. Four possible nutrient management scenarios were taken into consideration for the projections, i.e., no change in NUE, medium improvement, high improvement, and customized ambition in NUE. Global projections indicated that NPK applications to cropland will be 900-120 mt N applied by 2050 i.e., about 1 per cent growth per year, and similarly 1 per cent for P but 1.5 to 2.0 per cent for K by 2050. The regions contributing to increase NPK use are Africa and China for nitrogen (N); Latin America and Africa for phosphorus (P) and Latin America and East Asia for potash (K). The projections for India are a small increase in N consumption to increase yields, little change in P, and doubling of K use from 2017 to 2050. He also shared that IFA projections are comparable to other forecasts in past and medium term. He shared that there is increasing N and P surplus in Indian soils and the NUE and phosphorus use efficiency (PUE) are decreasing, whereas most of Indian soils are K deficient and further increasing, other emerging limitations of India soils are S and Zn. He exhorted that Indian researchers need to work on innovations that help farmers to adopt better technologies and transform subsidy to incentive system. He also mentioned fertilizers to shift towards renewable, decentralized,

and green ammonia. He further advised to shift towards smarter fertilizers with AI driven crop advices, more closed-nutrient cycles, and tailored micronutrient enrichment of fertilizers. Lastly, he predicted that in the next two decades, the average fertilizer use in Africa is going to increase by 3x or 4x as compared to that today. Globally, there is a need for more innovations and fewer/smarter subsidies in the fertilizer sector including at the production level.

Dr Kuldeep Sati, also from International Fertilizer Association (FAI**)** presented on the Indian fertilizer supply and demand scenario. He stated that food security is important for India, which would require around 400 mt of foodgrains by 2050 i.e. around 100 mt more than current 330.5 mt in 2022-23. Chemical fertilizers will continue to play a major role in ensuring food security in spite of increasing emphasis on organic and biological sources of nutrients. India is the second largest consumer and producer of fertilizers in the world and the largest fertilizer importer also. The higher imports are increasing the international prices, but he shared that India is capable of producing urea at competitive prices. This will help with a high degree of self-reliance and avoid exposure to price volatility in global market. He also mentioned that the per ha use of fertilizers in India is lower than the neighboring countries. Since 1970, the 50 per cent increase in foodgrain production has been attributed to fertilizer use. In India, production of urea increased significantly in 2022-23 due to the commissioning of new urea plants and also with enhanced capacity. There is scope to increase domestic production capacity further for P & K production. India depends on import of more than 90 per cent of rock phosphate and 40 per cent of S. About 12 per cent of ammonia, 60 per cent of phosphoric acid and 84 per cent of liquefied natural gas (LNG) is also import dependent (the intermediate materials needed to manufacture NPK fertilizers in India). There has been a significant decline in imports of urea due to increased domestic production. Whereas DAP production is static, and imports increased due to demand and muriate of potash (MOP) import reduced due to high prices and low subsidies. The NP and NPK complex fertilizer production is constant, imports increased due to increasing demand. There is a scope to increase domestic production of single superphosphate (SSP), however, the domestic P fertilizers are uncompetitive against imports due to relative quality issues. The recent and upcoming support means an additional 7.6 mt urea capacity will come online shortly. He encouraged that India is very close to self-sufficiency in urea production. He shared that supplementing products to urea and DAP are being produced and promoted by GoI e.g. nano-urea produced by the Indian Farmers' Fertilizer Cooperative Limited (IFFCO) and nano-DAP by Coromandel. Overall, the demand for N and P fertilizers is on the increase in India. Since the consumption of fertilizer is seasonal, production is year-round,

therefore, stocking of supply near consumption points is important to ensure that demand can be readily met. He highlighted that there are many factors- climate, prices, etc. and global as well as domestic factors- that influence fertilizer demand. India would require 10 lakh mt N, 4 lakh mt P_2O_5, and 3 lakh mt K_2O by 2025-26 to meet projected requirements in fertilizer nutrients. The likely demand of N from all sources would be 36.7 mt by the end of 2025-26. The anticipated domestic production will leave a gap of 5.2 mt urea to be met through imports or alternative sources. He also highlighted that fixed cost of urea needs revision as it has not been revised since 2002-03. The tightening of energy norms without recognizing investments in energy saving projects has squeezed the profit margins of the urea industry. The declining share of domestic gas results in import of LNG at high cost and rise in subsidy bill (2.25 lakh crore in 2022-23). This requires an increase in working capital due to rise in LNG for sustained domestic production and consumption. The challenges related to P fertilizer are that likely demand of P will be 11.1 mt by the end of 2025-26 with a gap of 2.8 mt P /5.3 mt DAP. The production of P and K depends on import of raw materials, so the import of sufficient DAP depends on global availability, market price, forex, etc. The addition of customs duties means imports are uncompetitive. The GST has been levied on the full value of raw materials (input service), whereas GST on imported fertilizer is not part of the subsidy – the tax paid on the GST is not refunded. The challenges related to K fertilizer are that likely demand of K will be 2 mt by 2025-26 and entire potash is imported. In the last 2 years, some K_2O was generated from domestic production of molasses and potash: further growth is expected in coming years that will reduce imports to some extent. The imports depend on global availability, market price, forex, potash subsidy rates, etc. There is a limited availability of potash internationally. The GoI should support joint ventures abroad needed to ensure smooth import of fertilizers and components necessary to produce fertilizers domestically. The joint ventures (JVs) ensure timely availability of raw materials and end products at competitive prices.

The gap between consumption and production has been increasing since 2005 and was growing for both N and P. Now even crude oil and urea price track similar fluctuations and correlated. India has witnessed, steep increase in import price of fertilizers since Q4 2021 in urea, DAP and MOP as well as there is depreciation of INR against USD since 2011. The monsoon also plays a vital role in fertilizer consumption in the country. The sales of major fertilizers between April and August 2023, were 8.4 per cent higher than that during the same period last year. Overall consumption of fertilizer nutrients is expected to be above that of the previous year. In future, it is projected that fertilizer consumption will grow

in India and will largely depend on imports. There is a need to strike the right balance between domestic production and imports, which would require significant rationalization of policies to support access. So, India needs to emphasize on innovations and R&D and collaborate with international organizations like IFDC for alternate fertilizers and sources of plant nutrients. The scientific evidence-based balanced nutrient use with enabling scientific policy frameworks and education of farmers is the need of hour. This will reduce the dependence on conventional products and management methods and improve NUE and innovating direct benefit transfer (DBT) to the farmers in future.

During the discussion session, several questions were asked from Dr JC Katyal, which ranged from urea application timing, manures to replace 25 per cent N and its impact on P&K, strategy for fertilizer use in North-eastern states of India, ceiling on manure application, etc. It was suggested that TAAS in collaboration with IFDC should publish a 'Strategy Paper on Fertilizers', which can provide the status and the way forward for the fertilizer sector in India. The speakers also highlighted that there is a lot of published scientific information available in the ICAR and SAUs, which the state governments should take up to frame their policy recommendations based on current cutting-edge science. They also highlighted the maintenance of P doses of future fertilizer applications, which must be science driven, not by anecdotes. It was further stressed that there is a need to prove the results of active research at farmers' fields so that the proven technologies could be adopted by them.

While concluding the session, the co-chairs. **Dr Ramendra Singh** highlighted that relative FUE and recycling-derived fertilizers (RDF) and those which are based on integrated nutrient supply are very important but there is a need for determining the modality of application. The key tools/technologies include leaf color charts (LCC) guiding applications; delayed application of N fertilizer; and investigation on the role of glauconite which are very important to include into integrated planning and alongside imported fertilizers. The International and Indian scenarios of future fertilizer use project on higher FUE, substantially decreased domestic demand for application of fertilizers. There is a need to quantify this and expand into calculating subsidy savings. **Dr AK Singh** another co-chair highlighted that 25 per cent organic fertilizer is a scientifically-proven and long-standing recommendation as well as inclusion of pulses in the system, but the implementation is pending, hence we need to devise ways for better implementation of these recommendations. He stressed that nutrient-based subsidies (NBS) should be based on element percentages and then subsidized; this will reduce imports. There is an urgent need to look for urea alternatives, which is one of the key recommendations. New avenues of NPK sources should

be explored and encouraged in countries or through joint ventures (JVs). The green credits and soil health is now a new GoI initiative but their economic evaluation is still to be conducted, and incentives need to be passed on to farmers/ NGOs/ those earning green credits. He exhibited SSNM as the first step for improving NUE and it should be integrated with new technologies like ICT, drones, and AI but with proper skill development. He highlighted the fertilizer deep placement (FDP) example from Bangladesh as propagated by IFDC, where Government of Bangladesh does not subsidize fertilizer; farmers actively work to make it more efficient and have saved 40 per cent through mechanized deep placement with crop establishment, which offsets the costs of the machines. He also shared that use of neem coated urea is now making a comeback because of high fertilizer prices. He stressed to get away from broadcasting and propagate fertigation, fertilizer deep placement in mechanized system and it would require incentivization of farmers who adopt these innovative technologies. He concluded by stressing on the need for improving NUE to reduce climate change impacts.

The key points emerged are as follows:

- Strategies need to be developed to improve FUE; raise NUE by adoption of GAPs site specific; complementary sources; organics, biofertilizers, K-rich mineral glauconite; alternative farming methods that harmonize tradition and technology (natural farming-NF + CA, regenerative agriculture-RA, etc.), 4Rs approach, and broadcasting to STCR, INM, SSNM, DSS, drones etc.
- Likely demand of N from all sources may be 36.7 mt by the end of 2025-26 despite uncertainty in projections.
- Chemical fertilizers will continue to play a major role in ensuring food security despite increasing emphasis on organic and biological sources of nutrients.
- Government support for joint ventures (JVs) abroad is needed to ensure smooth import of fertilizers and components necessary to produce fertilizers domestically. JVs ensure timely availability of raw materials and end products at competitive prices.
- Fertilizer consumption is likely to grow in India and will depend on imports. There is a need to strike the right balance between domestic production and imports- R&D, policy framework.
- TAAS should publish a 'Strategy Paper on Fertilizers' in India.
- Long-term research is needed for developing innovative fertilizer technologies.

TECHNICAL SESSION II: INNOVATION IN FERTILIZERS AND ITS SCALING

The second Technical Session was co-chaired by **Dr JC Katyal**, Former Vice Chancellor, CCS HAU, Hisar and **Dr ML Jat,** Global Director, ICRISAT. Four presentations were made on the innovations in fertilizers and its scaling to the farming community by **Dr Upendra Singh**, Vice President, IFDC; **Dr ML Jat**, ICRISAT; **Dr VK Singh**, ICAR-CRIDA and **Dr (Ms) Vaishali Chopra**, Yara Fertilizers. **Dr (Ms) Padma Shanthi**, GrowIndigo was the rapporteur for the Session.

Dr Upendra Singh in his presentation on 'Global Perspective of Innovations in Fertilizers Research', gave a brief background on the origin of IFDC, and goal of improving the efficiency of fertilizers and soil health. He shared that IFDC was designated as Public International Organization (PIO) in 1977 and briefed about the pilot plant and research facilities with the only global non-profit organization in the fertilizer research. He highlighted that less than 0.5 per cent of fertilizer trade money is devoted to research globally, which is far lower than that in pharmaceutical, seed or chemical industry. The spending on fertilizer is much lower than this due to the existing subsidy policy and non-existence of dedicated R&D facilities in the country. He shared about the global advances in the N research including controlled-release with biodegradable-reactive coatings (BRC), desensitize ammonium nitrate (DAN), less soluble N forms, integrated synthetic-natural products (organo-mineral), biofertilizers, and alternative N fertilizer production technologies. He shared that all these interventions are aimed at improving NUE and reducing the adverse environmental and health impacts of N fertilizers. He further shared the details of R&D on enhanced efficiency fertilizers (EEF) that are climate smart and mitigate weather and climate risks. But still globally, the EEFs are not much adopted and only 14 to 18 per cent fertilizers are coated. He further mentioned that the IFDC study on EEFs showed that nitrification inhibitors reduced N_2O emissions by 24 per cent, a double inhibitor (nitrification and urease) reduced N_2O emissions by 30 per cent and slow release using a polymer coated urea reduced losses for both ammonia (NH_3) and nitrous oxide (N_2O) by 81 and 55 per cent, respectively, as compared to urea. He stated about the IFDC innovation on organo-minerals in the recent couple of years, where natural materials such as plant or animal by products can be mixed with synthetic fertilizers as an organic + inorganic fertilizer product, which can help in developing a circular economy, improve soil and environmental health and propagate the Waste-to-Wealth concept in the fertilizer sector, e.g., ammonium sulphate synthesis recycled waste can be processed into amino acids and organic compounds, and other nutrients can also be added. The initial scientific studies

revealed that these organo-minerals are slow and steady in release of nutrients, improve soil structure and water holding capacity, enhance microbial activity, and improve the taste and quality of fruits and vegetables. The organo-minerals can be developed by mixing synthetic fertilizers with compost, biochar, manure, green manure, bone meal, fish emulsions, lime, plant residues, wood ash, etc. This helps in value-addition (waste to wealth), 10-15 per cent higher yield, reduced N loss and added carbon and micronutrients.

The second technology was the mechanization of fertilizer deep placement (FDP), which is one of the promising technologies to get away from the broadcasting of fertilizer i.e., reduce the volatilization and leaching losses of N and improve NUE. IFDC in collaboration with Punjab Agricultural University (PAU), Ludhiana has modified the existing paddy transplanter and zero-till drill into fertilizer deep placement drill and planters. IFDC successfully demonstrated the Fertilizer Deep Placement (FDP) technology at farmers' fields in Assam. Around 1,000 demonstrations in different crops showed encouraging results of yield increase by 33 to 124 per cent and improved the FUE from 28 to 54 per cent. Farmers experienced a yield enhancement of INR 25,322 per hectare in rice to INR 1,60,000 in tomato. He further emphasized that mechanized FDP reduces GHG emissions by 61–80 per cent and ammonia emissions by 52-70 per cent, leading to improved air quality. It also reduces losses of nutrients caused by leaching and volatilization and promotes balanced fertilizer use and reduces labor through mechanization. This technology can help to reduce the urea use by 20 to 25 per cent and save the exchequer's money in subsidy up to a tune of 5-6 billion USD annually. He also shared the new technologies, which can be the future of the fertilizer industry including the directly available nitrogen (DAN), decarbonization/decentralization of fertilizers through electrolysis and plasma arc technologies. For India, he suggested for new R&D and scaling of enhanced efficiency climate-smart fertilizers, revisiting fertilizer deep placement (FDP) with mechanized planting and fertilization, focus on nutrient and waste recycling – value additions with organo-mineral fertilizers and revamping existing urea plants with cleaner fuels and more efficient process – opportunities for decarbonization and decentralization. He also exhorted to create infrastructure for fertilizer R&D and skills within the country, keeping in view the extent of fertilizer demand in India to feed its increasing population.

Dr ML Jat presented interesting information on innovations in fertilizers and carbon farming. He highlighted the impacts of nexus between agriculture-industry-climate that revealed that anthropogenic climate change has reduced global agricultural total factor productivity (TFP) by about 21 per cent since 1961, a

slowdown that is equivalent to losing the last 7 years of productivity growth. He also highlighted that of the 18 Gt CO_2e annually, Agri-Food Systems are responsible for one - third of global GHG emissions and every ton of carbon dioxide emission to cost USD 86 to Indian economy on agricultural productivity growth (APG). One of the environmental impacts of food systems is that the nitrogen use has crossed planetary boundaries particularly in South Asia leading to adverse environment having bad impact on food systems. He exhorted that we have no time to lose, the last seven years have been the hottest ever recorded and earth is rapidly approaching dangerous tipping points for human health and safety, ecosystems, and infrastructure. He highlighted that fertilizer use has significant role in GHG emissions in agriculture. He cautioned that emissions from fertilizers need to reduce, but this must be balanced against global food security. The fertilizers are critical for achieving zero hunger and about 48 per cent of the global population is fed with crops grown with synthetic fertilizers, and the world's population is expected to grow by 20 per cent by 2050. The food system "from factory to fork (F2F)" is responsible for net 17 Gt CO_2e/year, 31 per cent of human-caused greenhouse gas (GHG) emissions. He shared the IFA report on high level scenario for cumulative emission reductions and also CIMMYT's study on the technologies to reduce GHG emissions from the agriculture sector with special reference to South Asia. He further stressed that increasing nitrogen use efficiency (NUE) through best management practices is the key to address greenhouse gas (GHG) emissions from mineral fertilizer use. He suggested a 5-pronged approach for improving NUE including innovations in fertilizers/nutrients (new molecules/products), soil biology (biological nitrogen fixation -BNF, biological nitrification inhibition- BNI, biological consortium/stimulants/enhancers and soil health); innovation in system design (system thinking and plot to landscape approach); innovation in delivery (customized recommendation, digital advisory, non-linear extension); and innovation in policy (mechanism for incentives for ecosystem services and policy bundling). He also highlighted on innovation in new fertilizer molecules – FDP can also improve NUE, and reduce emissions. He shared that through biological nitrogen fixation (BNF), the grain legumes alone can harness 35Tg of N globally. This would require landscape specific nutrient management bundled with system solutions to harness the power of soil biology, and digital tools and next generation climate services. He emphasized a holistic and integrated approach at the farm and landscape level, working in partnership with all users/stakeholders. The three levels for making the shift towards Climate Resilient Agri-Food Systems (CRAFS) are: (i) farm, (ii) landscape, and (iii) entire food system. He shared examples of ICRISAT's work on watershed-based landscape for such innovations. In the end, he suggested for a resilient agriculture-vibrant industry for synergy for climate action through cropping

carbon with commitments of carbon neutrality where agriculture can provide larger carbon offsets and industry can benefit farmers through carbon credits and ecosystem services (ESS). There is growing carbon market (300 billion USD/year) but it requires a pull factor through incentive mechanism for low emission farming practices. Carbon farming still needs valuation of ecosystem services and designing payment for ESS. This would require new approaches, tools, protocols, tracking, verification and enabling policies for mainstreaming regenerative agriculture (RA) in investment plans and innovations in policy/policy bundling.

Dr VK Singh spoke on the role of fertilizers in smart climate agriculture and shared that fertilizers drive agricultural intensification, feeding more than half of the world's population. Declining soil fertility and the emergence of multi-nutrient deficiencies in Indian soils are serious productivity constraints in targeting higher crop productivity. Over the last five decades of crop intensification, the amount of fertilizer application has increased tremendously, and the corresponding partial-factor productivity of fertilizer inputs has declined gradually. During this period, the dependency of plant nutrition systems moved from traditional organic manure application to the use of chemical fertilizers alone. This led to negative ecological and environmental consequences such as higher input costs and loss of nutrients or higher GHG emissions. In addition, fertilizer management should be based on cropping systems rather than sole crops for higher nutrient use efficiency and economics. Hence, the integrated plant nutrient management (IPNM) system has emerged as a necessity for the sustainability of agriculture in India. Involvement of all the stakeholders, viz., farmers, frontline workers, private organizations, government policy makers is crucial to facilitate sustainability in current production system in India. Developing awareness among farmers through extension activities about deteriorating soil health, unsustainable production, and environmental pollution due to reduced or no use of organics in overall soil health management coupled with conservation agriculture (CA) practices, replication of climate-resilient villages, and intensive implementation of district contingency plans in the country will result in evolving resilient production systems. At the same time, policy implementation in support of sustainable soil health management and incentive support will be crucial for successful village-level adoption of these technologies. He suggested to use geographic information system (GIS) and soil test based nutrient applications; and development of rapid soil testing facilities for quantitative analysis and recommendation through soil health cards. He emphasized for real-time monitoring of plant nutrient status and use of decision support systems (DSS), precision nutrient management (PNM); and development of novel materials/ nano-fertilizers for higher use efficiency and reduction of transport cost. Soil and crop-specific recommendations need to be developed for

nano-fertilizers. Development of location-specific customized fertilizers, micro-irrigation and fertigation should be made affordable to improve both fertilizer and water use efficiency (WUE). Development of more water-soluble materials for drone application is required to reduce application cost. He stressed on authentic research trials on large scale to evaluate the performance of INM with respect to economic and environmental sustenance. Lastly, he highlighted that manufacturing of biofertilizers should be encouraged to balance with chemical fertilizers.

Dr (Ms) Vaishali Chopra from Yara Fertilizers, reaffirmed Yara's dedication to advocating the use of best practices and products aligned with a healthy and sustainable soil health ecosystem. She shared several recommendations and initiatives aimed at advancing the cause of soil health and bolstering environmental sustainability. She further highlighted that fertilizers remain one of the key factors in maintaining the right soil health and assuring food security for the growing population. There is an increased need to maintain a balance between soil health and crop yields. Therefore, the effective knowledge of the right use and right type of fertilizers becomes more important for all the stakeholders. The key challenges in the fertilizer industry include limited farmer awareness, slow R&D, and regulatory hurdles. She shared that currently, India is amongst the slowest to register new fertilizers as per World Bank 2019 Report (https://eba.worldbank.org/en/data/exploretopics/fertilizer). This needs to be improved by introducing a dynamic Fertilizer Control Order (FCO), setting general guidelines by complying with minimum nutrient content and maximum contaminant content levels for any new fertilizer product registration. She revealed that GoI can address sustainability concerns by allowing the introduction of low-emission fertilizers without field trials to mitigate environmental impact. The existing mandate for field trials hinders the uptake of environment-friendly fertilizer alternatives, exacerbating environmental issues. It is essential for the GoI to simplify the approval criteria for micronutrient-based products and help farmers access essential crop-nutrient solutions more efficiently. Complex approval criteria for these products result in lengthy registration processes, limiting farmers' access to micronutrient-based products, which are crucial for soil health. She also shared that currently the soil health information accessibility is very limited across the nation, which hinders farmers' ability to make informed decisions and improve soil quality. It is crucial for the government to establish and upgrade soil testing centres at various levels (national, state and *tehsil*/*taluka*), allowing farmers to send soil samples through local post offices and receive the reports on a digital platform (e.g. mobile) within a week. This will empower farmers with vital soil health information and promote informed decision-making for improved soil quality. As the current complex and

lengthy registration procedures lead to delays in introducing new agricultural products to the market, the government should consider simplifying and streamlining the registration process of the products to prevent market distortions and encourage fair competition.

The discussion session included the questions on studies on organic manure quality, its adoption, and its effects on yields. Carbon farming and net zero emission across all the sectors and reducing the time of new product registration in India through FCO changes.

The key suggestions emerged are given below:

- There is a need to invest in fertilizer sector which is relatively lower (0.5%) than that spent on fertilizer research at global level. Hence, the investment in fertilizers in India needs to be enhanced to 1.0 per cent of the subsidy.
- India needs to put dedicated research for innovations on EEFs development as global data available on efficiency and environmental footprints. Dedicated R&D is needed for organo-mineral fertilizers to nutrient recycling.
- There is need to revisit FDP with mechanized planting a reality now; also, multiple use of machines and revamping of old urea plants in targeted and time bound manner need priority attention.
- Innovation is needed in systems thinking and in delivery- digital advisories.
- BNF- grain legumes alone can harness 35Tg of N globally.
- For Green credits/carbon farming, the minimum efficiency reporting value (MERV) needs to be developed taking into account the Indian farmers' scenario and NDCs and with emphasis on growing carbon markets.
- Block level agromet advisories need to be enhanced.
- Atlas for package of technologies for climate resilient technologies needs to be developed for the whole country.
- Nutrient management and soil health management are key components for devising the climate resilient advisory.
- Dynamic nutrient prescriptions-based soil health card (SHC) specific to geographies, and precision nutrient prescription using low-cost sensor, internet of things (IoT) and AI/Machine learning technologies are needed.

TECHNICAL SESSION III: FERTILIZER PRODUCTION AND ENERGY EFFICIENCY

The third Technical Session was co-chaired by **Dr HS Gupta**, Chairman, Farmer Commission, Assam and **Dr (Ms) V Geethalakshmi,** VC TNAU. Two presentations

were made on fertilizer production and energy efficiency by **Dr S Nand**, FAI; and **Dr Matt Miller**, IFDC. **Ms Shivalika Gupta**, IFDC was the rapporteur for the Session.

Dr HS Gupta introduced the presenters and shared that by 2050, India might have to double the production of fertilizer. Yet, there are concerns about sustainability of agriculture due to synthetic fertilizer use. **Dr (Ms) V Geethalakshmi** shared that the area under agricultural production is reducing and the country's need is to produce more food from less land and reduced inputs.

Dr S Nand shared that more than 60 per cent of the fertilizer consumed is urea in the country. The nitrogen fertilizer production is more energy intensive than phosphates and more than 80 per cent of the energy of urea production goes to producing ammonia itself. He underscored that industrial scale fixation of nitrogen has saved the mankind and explained multiple stages of ammonia production and pointed out that improvements to the designs have been made in terms of optimizing pressure, temperature, and steam generation. He shared that there was no new plant for 20 years after 1999. The capacity at the time was increased by debottlenecking old plants. There was a policy for debottlenecking in India. He also revealed that 12 plants were closed in the 1990s and 2000s due to their viability problems. Now the new plants are gas based and India is improving the energy efficiency through: feedstock change to gas-based plants from fuel oil and naphtha, introducing large single stream plants, using high activity catalysts, innovating in process technologies, changing materials of construction for improved reliability + debottlenecking of capacity with implications to save energy, and going for high efficiency machines. He appreciated the GoI for change to gas-based steam and power generation nudged by supportive policy but still 3 to 4 plants are coal-based (efficiency of 34%) and being asked to change. Now better designed reactors with the ability to push more gas with improved efficiency from 17 to 21 per cent are working along with automation in process control. There is improvement in recovery of waste heat and most plants use 110–130°C heat. There are favorable trends of energy consumption for ammonia production and urea production in India that includes improvement of new and old plants. The benchmarking shows that the best Indian plants (25 percentile) are at par with plants across the world in the same quartile in terms of energy efficiency. He shared that there has been a reduction in CO_2 emission from ammonia plants as well. He highlighted that we are discussing benchmarks of ammonia because international benchmarking is available only for ammonia. Different countries produce different end products from it. He shared the Indian vision for shifting plants to renewable energy/green ammonia. He appreciated the policy structure of Green Hydrogen Mission (GHM) by Government of India (GoI) that incentives the stakeholders in

production. He shared that the GoI has developed a 'Road Map 2030' on green ammonia/hydrogen mission. In the 'Way Forward' he suggested that that remaining plants with low efficiency should catch up fast and then efficiency gains will only be incremental. Green ammonia will need supporting policy environment. There is a gap in the value chain.

Dr Matt Miller highlighted on the scale-up of fertilizer technologies utilizing lab and pilot plant capabilities. He shared that the current situation with growing world population and limited resources and environmental energy concerns iterate that we need fertilizer technology that is more efficient, more climate smart. Globally, some major fertilizer producers are talking about increasing the R&D budget from 0.5 to 4 per cent. Limited/scarce budget is a big reason for no major technological breakthrough in fertilizers. He shared that laboratories are a good place to start to screen technological options. It is easy to manipulate things in the lab to have successful results. Pilot plants are useful to test at commercial scale. But he cautioned that one still has to be mindful for the scale up factor; correct data collection for temperature, pressure, flow rates; mimicking full scale equipment setup, etc. He suggested a scale-up factor of 1:10 but it will also depend on the kind of technology to be scaled-up. He revealed that IFDC has three main granulation plants – small (especially when technology is new and to test without too much risk); medium (significant, but still small and low cost), and large (capacity of up to one ton an hour). There have been several commercial scale plants throughout the world that have been designed based on data generated in those regulation plans. IFDC also has environmental pollution control equipment when customers are interested in learning how new things that they are trying are going to affect their emissions into the atmosphere. Third party vendors are also engaged sometimes to learn about emissions. He emphasized that granulation is not always the answer, so we need briquetting, tabletizing, and pelletizing in the pilot plant for testing. To analyze/measure whether or not we are making what we want to make, we have several instruments such as combustion analyzers (measure items like right rate, nutrient ratios, and form of nutrients). Physical properties also need to be evaluated for storage, bagging, distribution, application, humidity etc. of fertilizers. IFDC has innovated new methods and technologies to produce organo-minerals from different waste products to promote circular economy and utilize the industry waste in agricultural productivity enhancement. For the 'way forward', he suggested to develop similar capacity for India – new innovative lab facilities in public-private-producer-partnership (4Ps) mode for innovations in fertilizer molecules. He exhibited using IFDC engineering capabilities as many countries benefitted by using these facilities.

The discussion session included the queries on direct application of ammonia in the field. It was highlighted that direct application of ammonia is feasible and being used on large scale in the developed world, but logistics is a problem for small farms as well as safe storage and handling is a challenge with small farms. Another question included on the inclusion of urea under NBS, which is a policy matter. The participants highlighted innovations like briquetting, pellets, etc. but scaling needs investment and there are applicability issues at farmers' end. For FDP, we need innovations with multi-crop, multi-utility functionality of machines and understand these from a business perspective. For example, in Odisha and Tamil Nadu, multiutility machines are used for different operations. The stakeholders also highlighted the importance of 4Ps and it needs to be a comprehensive program supported by policy.

The highlights and recommendations of this Session are as follows:

- Innovation is the key to success and having a business model is key to operationalizing.
- There is a need for a favorable policy environment for green ammonia to fill in the gaps in its value chain.
- Clarity is needed on operational modalities, especially whether investment gaps will be filled by subsidies or GoI's green hydrogen mission (GHM).
- Mechanization of fertilizer deep placement is needed to enhance efficiency and be scaled out on a large scale.
- Innovations for multi-crop, multi-utility functionality of machines are required, especially for issues of application of fertilizer products with agroecological implications.
- New agri-business model-oriented approach is needed to understand the fertilizer-based innovations from a business perspective with scalable adoption and markets.
- Public-private-producer-partnership (4Ps) approach is needed for a comprehensive program supported by policy at various stages of innovations - from ideation to implementation.
- There is a need to augment India's fertilizer research through "Centre of Excellence" approach integrated- pilot plant, agriculture, and fertilizer research. Potential of 4Ps model needs to be exploited.

SPECIAL SESSION: EVENING LECTURE

The special evening session was co-chaired by **Dr RS Paroda**, Chairman TAAS and **Dr Himanshu Pathak,** Secretary DARE and DG ICAR. The special lecture was

delivered by **Prof Rattan Lal,** the World Food Prize Laureate and Director, College of Food, Agricultural, and Environmental Sciences (CFAES)- Rattan Lal Center for Carbon Management and Sequestration, Ohio State University, USA.

Prof Rattan Lal, in his special lecture, on "Soil Health and Fertilizer Use Efficiency" highlighted that with geographical land area of 2.4 per cent and water resources of 4 per cent, India supports world's human population of 18 per cent and cattle population of 31 per cent. Indeed, India's agricultural production is a global success story. Between 1947 and 2023, India's population increased by a factor of 4.33 (from 330 to 1432 million) but its foodgrain production increased by a factor of 6.61 (from 50 mt to 330.5 mt). Thus, its per capita foodgrain production increased by a factor of 1.53 over the same time-period. Whereas the effects of improved crop varieties can never be over-estimated, use of fertilizers and irrigation also played an important role. Between 1950 and 2020, fertilizer ($N+P_2O_5+K_2O$) use in India increased from 0.07 mt to 32.51 mt. India's fertilizer uses in 2020 was 16.1 per cent of the global fertilizer use and is still increasing. Nutrient requirement for rice-wheat systems with 10 t/ha production is estimated at 640 kg/ha for macro-nutrients ($N+P_2O_5+K_2O$) and 138 kg/ha for micronutrients (S+ Ca+ Mg).

He further highlighted that fertilizer use in India increased 460 times over 70-year period from 1950 to 2020 but the fertilizer uses efficiency (FUE) decreased. Along with the increase in fertilizer use, there has also been an increase in the land area equipped for irrigation. Between 1961 and 2023, irrigated land area in India increased from 25 m ha to 73 m ha or 52 per cent of 141 m ha of gross sown area. These practices have adversely impacted quality of soil, water, air and other natural resources in India. Soil health is adversely affected by a range of factors such as water erosion (64 m ha), wind erosion (9 m ha), water logging (14 m ha), salinity/alkalinity (7 m ha), soil acidity (16 m ha) and complex problems (7 m ha). Most crop lands are severely depleted of the soil organic matter content, which can be as low as 0.25 per cent in the surface layer compared with an optimal range of 2 to 3 per cent. Consequently, the fertilizer use efficiency is rather low. He emphasized that restoring soil health, controlling accelerated erosion and enhancing soil organic matter content, can drastically improve the use efficiency of fertilizer and irrigation. Rather than broadcasting of fertilizers in the standing water of rice paddies, drip sub fertigation, use of aerobic and direct seeded rice (DSR) and adoption of conservation agriculture (CA) with retention of crop residue mulch can improve the use efficiency of fertilizers and decrease the rate of application.

He recommended that carbon farming, increasing soil carbon content (SCC) and creating another income stream for farmers through payments for ecosystem

services at the rate of Rs 5,000 per ha per year, may lead to a rapid transformation of food systems and improve the quality of natural resources in India. There is a strong need for developing and implementing policies which are pro-nature, pro-agriculture and pro-farmers. In addition to creating and implementing "Soil Health Act", subsidies in agriculture must be replaced by programs which reward farmers through payments for ecosystem services.

Dr Himanshu Pathak, in his remarks as Co-Chair highlighted the significance and crucial role of soil health in raising crop productivity and production. He mentioned that for promoting application of the best fertilizer management practices for maximizing efficient fertilizer use, a comprehensive awareness and educational program for extension/ field workers is needed. There is need to promote the use of alternative sources of fertilizers such as NPK, single super phosphate (SSP), triple super phosphate (TSP), nano-urea/DAP to bring down demand for imported fertilizers. Also, the soil health testing facility should be revised and made available across the country to have an effective database management of soil health to pave the way for sustainable agriculture. The public sector needs emphasized fertilizer product research and assured funding. Research on fertilizers is needed jointly by different research organizations in public-private partnership (PPP) mode is needed. One Health concept should be researched and devised based upon Indian agricultural and social conditions.

In his remarks as Co-Chair, **Dr RS Paroda** appreciated Prof Rattan Lal for his excellent lecture which was very informative, and useful giving clear way forward for soil health and fertilizer use efficiency. He mentioned about the enormous contribution of fertilizers in enhancing production and productivity of crops contributing around 40 to 60 per cent in yield enhancement. He suggested to transform fertilizer sector from subsidy to incentives system, allocating 5 per cent of subsidy amount on fertilizer innovations, enhance corporate social responsibility (CSR) funding to fertilizer research, use organic and inorganics judiciously, and include cutting edge information and communications technology (ICT), drones and artificial intelligence (AI) in the fertilizer sector. He emphasized that the fertilizer industry should innovate for being competitive in the global market and cater to the needs of fertilizers and contribute to One Health, starting from soil to environment to livestock and to human beings. He also highlighted that various Government schemes currently in operation are also very effective towards improving soil health and nutrient use efficiency. He emphasized that the fertilizer/nutrient use efficiency needs to be doubled by 2030 in a mission mode in fertilizer technology, innovation, research, and extension.

TECHNICAL SESSION IV: NEW AVENUES OF PLANT NUTRITION AND ONE HEALTH

The fourth technical Session was co-chaired by **Dr BS Dwivedi**, Member, ASRB and **Dr Upendra Singh,** Vice President, IFDC. Three presentations were made on new avenues of plant nutrition and 'One Health' by **Dr SP Datta**, ICAR-Indian Institute of Soil Science (IISS); **Dr Tarunendu Singh**, IFFCO; and **Dr Shailendra P Singh**, Israel Chemicals Ltd (ICL). Dr **CM Parihar**, ICAR-Indian Agricultural Research Institute (IARI) was the rapporteur for the Session.

Dr BS Dwivedi introduced the presenters and highlighted the need for analyzing the long-term trials data and link with new fertilizers research based upon different ecologies. He highlighted that India needs to innovate for science-based policies to improve soil health and NUE, reduce environmental pollution and skill farmers on new technologies and concepts for incentivization of the fertilizer sector. He also exhorted the private sector to work with the public sector for new R&D in fertilizers. Dr Upendra Singh also highlighted the importance of 'One Health' concept and mentioned that all out efforts need to made to enhance crop productivity and production.

Dr SP Datta presented novel fertilizers research updates and scaling options. He revealed that in nutrient use efficiency a parallel trend was observed with significant implications for the economy, environment, soil health, and climate change. Notably, nitrogen fertilizer (urea) consumption accounts for approximately 67 per cent of total fertilizer nutrient consumption. However, the partial factor productivity (PFP) of nitrogen declined over the years, indicating a pressing need for improved utilization strategies. He also highlighted that current subsidy policies disproportionately favor nitrogen use at the expense of other essential nutrients like phosphorus, potassium, and micronutrients. This inefficiency leads to resource wastage and strains foreign exchange reserves. He exhorted for urgent research on novel fertilizer molecules and delivery systems, such as Nano Polymer Composites (NCPCs), Nano Clay Biopolymers, Zeolite-N supplementation, and Chitosan. However, there is a gap in understanding the mechanisms of nano particle-based molecules, necessitating further study on their utilization and translocation. He also highlighted on scaling up the production of these novel fertilizers in collaboration with industries is imperative. Cost-effectiveness and the impact of these novel fertilizers on natural resources must also be assessed.

Dr Tarunendu Singh presented information on nano-fertilizer for precision and sustainable agriculture. He shared the nitrogen supply as per nano-urea bottle specifications- it contains 4% (w/v) solution of nano-urea and a market price of INR 240 per bottle (half litre). So as per specification, half liter nano-urea solution

contains 20 g nano-urea i.e. 9.2 g N (46%). IFFCO claims half litre solution of nano-urea is equal to 45 kg normal urea. Dr Singh emphasized the significance of nano-fertilizers in achieving precision and sustainable agriculture. He stressed the need for more efficient fertilizer formulations for foliar spray and seed treatment to mitigate environmental impact caused by overuse. He shared several examples including wheat N requirement and supply from urea and nano-urea. He shared that on an average, the nitrogen use efficiency of wheat crop in India is 60 per cent. The nitrogen content in wheat and straw is around 2 per cent and 0.46 per cent, respectively. Therefore, to produce one-ton wheat grain, the nitrogen uptake will be 25 kg (20 kg by grain and 5 kg by straw). Therefore, a wheat crop yielding 5 tons per hectare grain will remove 125 kg N. He shared that the soil application of 45 kg normal urea will produce 496.8 kg wheat grain at 60 per cent nitrogen use efficiency (NUE) as compared to 0.37 kg grain by half liter solution of 4 per cent (w/v) solution of nano-urea at 100 per cent nitrogen use efficiency. As per recommendation, if 50 per cent nitrogen (60 kg/ha) is applied as basal (DAP+ Urea), then two splits of nano-urea need to supply 60 kg N/ha, whereas at 100 per cent efficiency too it will supply only 18.2 g N. He shared that the second major issue with nano-urea is the cost of labor for applications which vary from ₹ 300 to 500 in different states for one-time application. For the two-time application with nano-urea bottle, the cost is around ₹ 1,000-1,300 per ha and with foliar application by drone, the cost increase is more than ₹ 2,000. The third issue is rainfall event just after spray will wash off the foliar spray of nano-urea. The fourth issue is the high cost of drones for the foliar application of nano-urea. The fifth issue is how to apply nano-urea in crops with heights more than 4 feet if drones are not available in the remote areas for smallholder farmers. Therefore, there is a need for a comparative study on foliar spray of normal urea, nano-urea, nitrogen deep placement and broadcasting of urea as well as physiological study on the leaf absorption of nano-urea. But nano-urea can be an excellent option to reduce N use in high N using areas like Punjab, Haryana and Telangana and also in rainfed areas where there is dependency on rainfall for fertilizer application.

Dr Shailendra P Singh made a presentation on specialty fertilizers for climate smart agriculture. He highlighted the role of specialty fertilizers as supplements to bulky fertilizers. Their controlled release mechanisms lead to a reduction in nitrogen losses and greenhouse gas emissions by approximately 11 per cent. Additionally, he emphasized the potential of biodegradable controlled-release fertilizers, like polyphosphate, in enhancing nitrogen use efficiency (NUE). Subsidies for these specialty fertilizer products are recommended to promote their adoption.

After due discussion and queries from stakeholders, the co-chairs summarized the outcomes of the session as below:

- Indian fertilizer sector (cooperative) was based on bulk fertilizers but with disruptive technologies (nano and specialty fertilizers) provide new avenues for new science, products, and markets.
- Nano- and specialty- fertilizer research especially in the public sector should move from lab to field, linked with industry and conducted with an aim of commercialization (nano-rock phosphate).
- There is an urgent need to understand and document the mechanism of nano particles in soil/leaf/plant in a trans-disciplinary manner addressing one health concerns (impact on environment, natural resources).
- There is a need to formulate protocols for nano-urea in view of 'One Health' concept.
- Package is needed for climate smart fertilizer – specialty fertilizers (slow release, water soluble fertilizers, controlled release fertilizers).
- Dedicated research is needed by National Agricultural Research System (NARS), especially SAUs before large scale roll out and marketing of nano-urea and be added in package of practices (20-50% replacement claims, niche agro-ecologies).
- Tagging of nano-urea is counter-productive to the farming community and recommended to product purchase by willingness.
- The public sector needs emphasis on fertilizer product research and assured funding.
- Research on fertilizers is needed jointly by different research organizations in public-private partnership (PPP) mode is needed.
- One Health concept should be researched and devised based upon Indian agricultural and social conditions.

TECHNICAL SESSION V: ENABLING POLICIES FOR FERTILIZER SECTOR

The fifth Technical Session was co-chaired by **Dr Ashok Gulati**, Chair Professor, Agriculture, Indian Council for Research on International Economic Relations (ICRIER) and **Dr PS Birthal,** Director, ICAR-National Institute of Agricultural Economics and Policy Research (NIAP). Presentations were made on the enabling policies for fertilizer sector by **Dr Amit Rastogi**, Coromandel; **Dr KV Praveen**, ICAR-IARI; and **Dr Prem Chand**, NIAP. **Dr Shankar Lal**, ICAR-Indian institute of Maize Research (IIMR) was the rapporteur for the Session.

Dr Ashok Gulati, Co-chair introducing the speakers and highlighted that fertilizor production, distribution and trade needs to be dealt with a holistic approach supported by enabling policies. Fertilizer sector has been given attention which needs to be done on priority so that both the farmers as well as the industry are benefitted. **Dr PS Birthal,** Co-chair emphasized that there is an urgent need to transform the fertilizer subsidy program. He also mentioned that redirection of subsidies and linkage with green credits and ecosystem services is urgently required and direct benefit transfer should be linked to soil health cards, crops and farms.

Dr Amit Rastogi from Coromandel highlighted on policy interventions for efficient fertilizer value-chains. The presentation focused on policy interventions at each stage of the value-chain for phosphates consumed in India, starting with mining of rock phosphate, and ending with application of phosphatic fertilizers. The proposed policy interventions will give India greater control over the supply of phosphate raw materials and bring improved efficiency in the consumption of phosphatic fertilizers. The data from Food and Agriculture Organization (FAO) and FAI were presented to understand the consumption and supply patterns for phosphate nutrients in India. Based on the analysis of the data, the key areas identified for policy interventions include securitizing supplies of rock phosphate and phosphoric acid, improving P_2O_5 FUE to > 60 per cent, increasing share of organic nutrients in P_2O_5 consumption to 25 per cent and promoting low analysis fertilizers as alternatives to imported DAP. He highlighted four key areas: (i) securitization- Government to Government dealings to allow access to foreign rock phosphate mines for Indian companies and creation of sovereign fund of USD 5 billion for enabling investment in foreign mines. Around 50 per cent of India's P_2O_5 requirement needs to be securitized through investments in mines and JV phosphoric acid plants: (ii) P_2O_5 use efficiency to be increased by creation of Soil Conservation Fund (SCF) of ₹ 1,000 crore for monitoring the condition of soil at district level. Incentives/grants to be given to farmers for increasing soil organic carbon (SOC), purchase of instruments and sensors for precision agriculture (PA), and purchase of fertilizer applicators; (iii) organic nutrient- target of 1.0 mt/y of recycled P_2O_5 to be achieved through industrial processing of waste such as sewage, poultry manure, distillery effluent and increasing availability of compost and allow organo-mineral fertilizers with 10 per cent organic matter in Fertilizer Control Order (FCO); and (iv) there is a need to look for alternatives to imported DAP such as low analysis NPKs, SSP, urea SSP, nano DAP to bring down demand for imported DAP. Promote crop specific grades in place of generic grades such as DAP and support the development of slow release phosphatic fertilizers which can replace DAP.

Dr KV Praveen spoke on transforming Indian fertilizer subsidy program to meet future challenges. He highlighted that Indian fertilizer subsidy program, a crucial component of the country's agricultural policy for decades, plays a pivotal role in ensuring the availability of affordable fertilizers to farmers. This in turn, supports agricultural productivity and food security. However, as India faces evolving challenges in the agricultural sector and seeks to meet sustainability goals, there is a pressing need to transform the fertilizer subsidy program. The current subsidy model primarily involves providing subsidies to fertilizer then they sell fertilizers to farmers at reduced prices. The current subsidy model does not discriminate among farmers' based on operational holdings, crops cultivated, soil fertility or any other factors. However, this model has several drawbacks. The subsidy system has traditionally favored urea, leading to imbalanced nutrient use. This resulted in soil degradation and reduced crop yields in the long run. It has also been plagued by inefficiencies and leakages, with some fertilizers meant for farmers being diverted to other sectors. However, with DBT scheme, this will be taken care. Further, the excessive use of fertilizers especially urea has adverse environmental effects, including soil degradation and water pollution. Finally, the subsidy program places a significant financial burden on the government, affecting fiscal sustainability. To address these challenges and prepare the Indian fertilizer subsidy program for the future, several transformative strategies were suggested including – incentivizing farmers to use chemical fertilizers optimally, paying farmers for their contribution in reducing environmental burden, tapping the future potential of carbon market, paying farmers for use of sustainable fertilizers, diverting subsidies from chemical to the sustainable fertilizers like organic and biofertilizers, expanding DBT to realize its full potential, promoting soil health management using Soil Health Cards (SHC) and enhancing farmers' awareness and training. He exhorted that transforming the Indian fertilizer subsidy program to meet future challenges is imperative for the sustainability of agriculture, food security, and environmental protection. Some of the possible strategies to transform the subsidy system are listed above. However, overcoming challenges such as political resistance and ensuring widespread education and technological access are equally crucial. By addressing these challenges and embracing these transformative strategies, India can pave the way for a more sustainable and productive agricultural future.

Dr Prem Chand in his presentation highlighted on enabling policies for sustainable use of fertilizers and reiterated that fertilizers have undeniably played a crucial role in achieving global food self-sufficiency, with India being no exception to this trend. He shared studies, which showed that judicious fertilizer uses accounts for a significant portion, ranging from 40 to 60 per cent, of crop yields. However, this success story is not without challenges. The increasing

burden of fertilizer subsidies and growing concerns about soil health are the pressing issues. In India, nitrogen use efficiency (NUE) remains dishearteningly low, remained below 50 per cent and is declining continuously. This inefficiency results in the overuse of nitrogen, driven by the desire to achieve targeted crop yields, leading to economic and environmental concerns worldwide. Addressing these challenges necessitates emphasizing the importance of applying nutrients at the right rate, time, and using the correct method. Policy corrections and adjustments can significantly improve nutrient use efficiency and rectify imbalances in fertilizer application through promoting sustainable and efficient agricultural practices. There is a need to have enabling policies in place for enhancing nutrient use efficiency and sustainability in Indian agriculture. The Government implemented various strategies to enhance agriculture, including the introduction of neem-coated urea in 2015, aimed at increasing nutrient efficiency, crop yield, and soil health while curbing the diversion of agricultural urea for non-agricultural purposes. Neem-coated urea showed potential in boosting crop yields and offering environmental benefits. However, a significant challenge persists, with reports indicating that subsidized urea is still being diverted for non-agricultural uses, resulting in a subsidy leakage. The nutrient-based subsidy (NBS), initiated in April 2010, focuses on decontrolled fertilizers like phosphorus (P), potassium (K), and sulphur (S) to promote balanced soil fertilization, affordable access to these nutrients for farmers, and equitable soil nutrient application. Additionally, the Soil Health Card (SHC) Scheme aims to improve fertilizer use and soil health but faces issues such as limited infrastructure, farmers' awareness, and concerns about the grid approach for soil testing.

Recent initiatives like the Program for Restoration, Awareness, Nourishment, and Amelioration of Mother Earth (PM PRANAM) aims to promote balanced fertilizer use, including chemical and alternative fertilizers, while raising awareness about regenerative agriculture (RA). These initiatives incentivize states and union territories (UTs) to encourage the use of alternative fertilizers and balanced chemical fertilizer application. States and UTs can benefit from 50 per cent subsidy savings, with 70 per cent allocated for asset creation related to technological adoption of alternative fertilizers and production units, and 30 per cent for incentivizing farmers, panchayats, farmer producer organizations (FPOs), self-help groups (SHGs), and others. There is also potential for cooperatives involved in bio-fertilizer production to participate, along with the Green Credit Scheme (GCS) designed to incentivize regenerative agriculture (RA). However, it is essential to intensively emphasize the social benefits of sustainable agricultural practices to fully realize the potential of these schemes. Currently, the adoption of biofertilizers and organic fertilizers remains at a nascent stage, with less than one per cent of

cultivated areas treated with biofertilizers. The quality of alternative fertilizers, particularly organic ones, needs significant improvement.

He suggested that the first and the foremost step should be to identify districts with high fertilizer use and imbalanced NPK ratios to adopt a targeted approach. He also suggested minimizing price gaps per unit of nutrients. Additionally, linking subsidies to soil health card (SHC) recommendations and crop response equations can improve targeted fertilizer application. He further highlighted the importance of crop planning and diversification, potentially through incentive-driven volumetric water pricing reforms. Increasing investments in research and development (R&D) for higher-quality alternative fertilizers is also crucial. Allocating subsidies to states, based on a multi-criteria approach that considers factors like gross cropped areas (GCA), food production contributions, soil fertility status (SFS), and policy reforms could enhance effectiveness. Recognizing that 48 per cent of land holdings in the country are less than 0.5 ha, he recommended rationalizing packaging sizes to avoid unnecessary urea wastage.

Based on the presentations and further discussion in this Session, the following key recommendations emerged:

- Redirection of subsidies and linkage with green credit and ecosystem services is required and DBD should be linked to SHC, farms, crops, etc. Farmers need to be paid for optimal use of chemical fertilizers, sustainable growth, and reduced emissions. Promotion of start-up innovations in agriculture is needed to test soil health and soil testing facilities need to be revamped. A mechanism for transferring financial benefits as incentives needs to be devised and put in place. Farmers who use less chemical fertilizer per unit area should be incentivized, while the reverse should not be the case. Such savings can be estimated at the eco-regional level and such regions can be encouraged with the establishment of alternative fertilizer facilities (organic fertilizers, biofertilizers, etc.), with a portion transferred to farmers as DBT.
- The current scheme does not discriminate between farmers and farming practices. The land registry should be linked to a soil health map and a set of farming practices for each agro-ecological sub-region to effectively channel fertilizer subsidies. Also, the soil health testing facility should be revised and made available across the country to have an effective database management of soil health to pave the way for sustainable agriculture.
- India has reduced poverty from >50 to <15 per cent and still follows the same policy and thus needs serious relook. Like China, all subsidies can be put together and paid based on per unit area. Let the market price of input and output choose to use it as per choice. However, no subsidy could help

increase MSP which eventually led to an increase in food price that consumers suffer. The reorientation and all production and consumption subsidies can save ₹ 50,000 crore/year. The inequality between crops and states needs to be addressed. The per hectare consumption data and the cost of cultivation data have mismatch which needs to be collated. Policy cocktails are required in this area with better fertilizer awareness among the farmers and responsible retailers by public extension agencies.

- Research into the development of new fertilizer products will be strengthened through consortia to increase the efficiency of fertilizer use. Public-private linkages in this regard should be strengthened and corporate social responsibility (CSR) funds should be utilized for this initiative. A well-equipped laboratory system may be developed for the development of various macro and micro-nutrient fertilizers and customized fertilizers. Establish a center of excellence under public-private partnership (PPP) for developing new products and effective linkages with industry. Sustainable fertilizer use, with 10 per cent of the subsidy amount for fertilizer research and development being used to develop breakthrough technologies. Research and innovation in plant breeding to increase nutrient utilization, nitrogen fixation in leaves and nodulation of non-legume crops need to be strengthened to improve NUE.
- Affordability of P and K fertilizers is a key issue and the NPK use ratio is rather skewed in northern India, leading to depletion of these nutrients from the soil. Potash and phosphorus fertilizers are imported and are a burden not only on government subsidies but also on farmers and consumers, leading to lower consumption and unbalanced crop nutrition. In this scenario, the government needs to explore offshore mining as a strategic initiative to be supported by the government. Mining other micronutrient fertilizers can also be initiated in this direction.
- The Fertilizer Control Order (FCO) should have provision for the different organic fertilizers in the market. The quality of alternative fertilizers should be improved. Rationalizing packaging size is also needed. Alternative instruments to have biological and organic as bio-fertilizer outside FCO may be explored.
- At present, 2/3rd fertilizer is used for paddy, wheat and sugarcane crop. State-wise differences are there in fertilizer subsidy like Bihar vs Punjab having more than thrice differences. Crop planning and diversification to be done across agroecology. The ratio of 4:2 also to be revisited as per the soil type and crop wise.
- A soil conservation fund with ₹ 1,000 crore need to be established for incentivization of the growers having >0.5 per cent soil organic carbon.

PANEL DISCUSSION ON WAY FORWARD

Dr RS Paroda moderated the Panel Discussion and **Dr PK Singh**, Agriculture Commissioner GoI; **Dr BS Dwivedi**, Member ASRB; **Dr Ramendra Singh**, Fertilizer Expert; **Dr KK Singh**, Zuari Foundation; **Mr Harbir Singh**, Rural Voice; and **Dr YS Saharawat**, IFDC made their interventions as panelists keeping in view the challenges faced for their specific vertical for the overall development of fertilizer sector in India.

Initiating the panel discussion, **Dr RS Paroda** highlighted the importance of fertilizers for enhancing the agricultural production in India, which is needed for sustainability to feed the ever-increasing population of the country. He shared that India needs to double its fertilizer consumption by 2050 to ensure food security. He commended the technology-based high yielding varieties (HYVs) and fertilizer use, investment-led irrigation infrastructure and role of skilled human resource including researchers and farmers along with enabling policies for transforming Indian agriculture from net importer to self-sufficiency. He also cautioned on the second-generation soil, environmental and human health problems arising due to imbalanced and injudicious use of fertilizers and exhorted the fertilizer industry to be proactive and innovative to tackle the current soil and environmental problems and enhance investments in R&D. He also highlighted the ever-increasing fertilizer subsidy bill and asked the panelists to provide their expert views on these aspects.

Dr PK Singh highlighted the challenges faced by the farmers and Government over the decreasing FUE, increasing fertilizer subsidy and secondary challenges of soil health and environmental problems. He shared that over the decades, agricultural success is linked with increased fertilizer use but decreasing partial-factor productivity of fertilizer inputs. The traditional fertilizers and blanket application recommendations are leading to negative ecological and environmental consequences. He emphasized customized fertilizers based on cropping systems rather than sole crops for higher nutrient use efficiency and economics. Site-specific nutrient management (SSNM), sensor-based nutrient application, neem-coated urea, placement technologies, fertigation, foliar sprays of water-soluble nutrients and nano-fertilizers, along with soil management-based climate adaptation will improve the efficiency of nutrient and help both adaptation and mitigation of climate change. He highlighted different Government schemes and programs, viz., Soil Health Card (SHC), neem-coated urea, NMSA, NPMCR, customized fertilizers (CF), NBMMP are effective towards improving soil health and nutrient use efficiency. However, involvement of all the stakeholders, viz., farmers, frontline workers, private organizations, government policy makers is crucial to facilitate sustainability in current production system in India. He also exhorted that policy

implementation in support of sustainable soil health management and incentive support is crucial for successful village-level adoption of these technologies. He stressed the newly launched 'PM PRANAM' scheme which opens new avenues for the fertilizer R&D.

Dr BS Dwivedi mentioned that fertilizer research from the public sector institutes/ laboratories has not reached to the farmer's field. This demands for a newer collaboration and agribusiness model between the public and private sector industries to deliver the new innovations at farmers' field in a public-private-producer-partnership (4Ps) approach. He also highlighted that a lot of research has been conducted at the ICAR institutes and SAUs but the data repository and its curation for further country level analysis and recommendations has not been attempted due to unavailability of the data for general use. There is a need to streamline the data repository and its usage for better recommendation and linked with PM PRANAM scheme to enhance R&D investments. He also cautioned that industry promotes scientific research-based fertilizer products and take the ownership of their product research. He suggested that Department of Fertilizers, MoC&F, GoI and the ICAR may consider bringing out a White Paper on Fertilizers in India involving Think Tanks like the Trust for Advancement of Agricultural Sciences (TAAS), National Academy of Agricultural Sciences (NAAS) and other International Organizations. He also emphasized on including the innovative and climate smart fertilizer products in the SAUs package of practices along with best bet practices for maximizing efficient fertilizer use along with a comprehensive awareness and educational program for extension/ field workers.

Dr Ramendra Singh shared that in pursuit of securing food and nutritional security possibly by 2047, several challenges must be surmounted within the purview of UN-Sustainable Development Goals (SDGs) where an essential goal is zero hunger. He emphasized that agri-input management, and to ascertain which fertilizer is a major contributor to crop productivity and production requires major attention for higher use efficiency. For India, the dependence on imports of fertilizers can pose serious threat to our national food security. Constant efforts are needed to avoid supply disruptions by maintaining good trade relations with countries where from imports are made. For achieving higher FUE, he stressed on adoption of 4Rs stewardship along with robust system of monitoring impact of fertilizer uses at regional and national level. Social aspects such as farmers' knowledge of efficient fertilizer use and higher nutritional quality of farm produce and food security due to fertilizer use can be tracked. He cautioned that environmental impact of fertilizer use is a major concern. He shared that air and water pollution linked to fertilizer use are traceable but difficult to quantify. He shared that farmers often use overdose of N fertilizers

in a zeal to get more yields, but imbalanced fertilizer use is both uneconomical and detrimental to environment. By 2070, we have a goal to achieve net zero emissions. For mitigating emissions from agriculture sector, we must evolve a suitable strategy for achieving complete food and nutrition security by 2047. Lastly, he suggested that to maintain soil health, responsible plant nutrition is the need of hour. We need to feed a burgeoning population with adequate food calories and nutrition. The plant nutrition research must focus on sustainable food and nutrition production goals. Our natural resources must be conserved and used with utmost care. In this era of scientific advancement e.g., conservation agriculture (CA), digital agriculture (DA), protective agriculture (PA), and precision farming (PF), there is hope for meeting self-sufficiency in food and nutrition by 2047 and beyond.

Dr KK Singh recommended dedicated research on agro-economic evaluation of specialty fertilizers by strengthening cooperation between public sector institutions and the fertilizer industry to move forward the innovations to the end users. For efficient soil testing facilities, he suggested for creation of accredited private laboratories managed by well-trained young entrepreneurs under the Government Scheme on Soil Health Cards (SHCs). He also stressed specific research on inventing slow/controlled release sulphur-coated urea variable dissolution rates i.e., 1DDR (1 Day Dissolution Rate) or 7 DDR. While such developments must pass the test of use efficiency, these also have to be economically favorable and ecologically benign. He exhorted the role of KVKs for promoting the science-driven efficient fertilizer management along with knowledge and skill development of different stakeholders. He also advocated for basic research on nano-products.

Dr Mahesh Gathala raised his concerns on the intensification of acid soils in eastern India and increasing use of fertilizers. He highlighted that there is an urgent need for new research to understand the impact of increased mineral fertilizers use on soil acidity in and align with their contemporary need for alternative fertilizer sources and application technology. There is a necessity to disseminate technical advice on lime treatment by SAUs and ICAR institutes. This will help in sustaining acid soil and increase productivity by 0.5 t/ha in around 25 mha, and an additional food production of 12.5 mt worth ₹ 2,500 crore. He also shared that since acid soils suffer more from sulphur (S), boron (B) and molybdenum (Mo) deficiencies, there is a need to strengthen strategy on integrated nutrient supply and management and enhance availability of custom-made fertilizers to assure balanced management of these nutrient deficiencies.

Mr Harbir Singh appreciated TAAS, ICAR and IFDC for facilitating this timely discussion on the future pathway of fertilizer sector in India. He acclaimed this

exclusive event where industry, public and private sector, farmers, and other stakeholders are at one platform. He emphasized on the role of fertilizers for the agricultural sustainability in Indian agriculture. He elaborated through examples the increasing role of media in technology propagation and adoption and for enabling policies in the agricultural sector. He shared that rural voice is a platform for all stakeholders to raise voice as well as knowledge dissemination among farming stakeholders especially farmers. He shared Rural Voice's willingness on disseminating knowledge on scientific research and innovative products to the farmers.

Dr YS Saharawat proposed the idea of establishing a Centre of Excellence on Fertilizers (CoEF) in public-private-producer partnership (4Ps) along with a pilot plant with innovative laboratory facilities to promote innovations in fertilizer technologies including efficient production, and improved NUE efficiency with support of international organizations like IFDC, which will cater skill and knowledge development needs of different stakeholders, especially the youth of India. The CoEF may be established through strategic involvement of the Ministry of Chemicals and Fertilizers (MoC&F) with technical backstopping of the Indian Council of Agricultural Research (ICAR), and the State Agricultural Universities (SAUs). He also stressed on the need to establish a 'Neutral Fertilizer Platform-A Think Tank' involving public-private sector and technical experts for better exchange of information and knowledge among stakeholders, and suggesting country's future needs and possible pathways including research, innovations, and policy advocacy, etc.

PLENARY SESSION

Dr RS Paroda, Chairman, TAAS and Former Secretary DARE and DG ICAR chaired the Plenary Session. **Dr Upendra Singh,** Vice President International Fertilizer Development Center (IFDC) delivered the special remarks; **Dr Yashpal S Saharawat,** Principal Scientist and Country Program Manager International Fertilizer Development Center (IFDC) provided the summary of technical sessions and a 'Way Forward' for the fertilizer sector; and **Dr Rajbir Singh,** ADG (Agronomy, Agroforestry & Climate Change), ICAR extended vote of thanks.

Dr Yashpal S Saharawat presented the salient recommendations and way forward emerged from the technical sessions and panel discussion. He emphasized that there is need for doubling the fertilizer use efficiency by 2030, but this would require scientific innovation in fertilizer and fertilizer technology, investments, and collaborations from ideation to product development through varies kind technical backstopping at several fora and empowering youth with new skill and knowledge to cater fertilizer sector needs. He mentioned for adopting Factory-

to-Fork (F2F) approach and creating a Centre of Excellence on Fertilizers in a public-private-producer partnership (4Ps) mode. The key take-aways of the Dialogue included: (i) targeted approach for doubling the FUE (30 to 60%) by 2030; (ii) need for R&D, policy support and investment for customized, EEFs, organo-mineral fertilizers, etc.; (iii) need for favorable policies for Green Ammonia, rock phosphate mines procurement through Government-to-Government collaborations or joint ventures; (iv) agroclimatic zone based SSNM approach using digital, GIS, bigdata, machine learning DSS, AI, etc.; (v) the state agriculture universities (SAUs) should include the new/innovative organic and inorganic fertilizers in their recommended package of practices; (vi) for green credits/carbon farming, MERVs need to developed taking into Indian farmer scenario and NDCs; (vii) public-partnership-producer partnership needed to bring innovations in research and policy framework of India; (viii) Centre of Excellence on Fertilizers (CoEF) is the 'way forward' for multi-disciplinary, multi-institutional and public-private partnership approach; (ix) pilot plants need to be developed with a Center of Excellence; and (x) repurpose fertilizer subsidy policy, which needs a separate brainstorming session.

Dr Upendra Singh in his special remarks, congratulated the organizers for this important Dialogue and highlighted on the need for a holistic approach to improving efficiency from fertilizer production to application in the second largest consumer country. He also emphasized on international collaboration for innovations in fertilizer products and application methods and echoed for popularizing the art and science of 4R nutrient stewardship to promote the best fertilizer management practices for maximizing efficient fertilizer use. He also shared IFDC experiences in site-specific nutrient management (SSNM) linked with decision support system (DSS) and advocated for wider dissemination in India context. He emphasized on the concentrated efforts to encourage alternative sources such as NPKs, SSP, TSP, compound and specialty fertilizers and promote crop-specific grades in place of generic grades. There is a need for tailor-made compounds from existing carriers by adopting wet or dry granulation process in a decentralized system. He reiterated to revisit deep placement of the fertilizer with mechanized planting and fertilization. He further highlighted that India has tremendous potential of nutrient and waste recycling and value-additions with organo-mineral fertilizers, which IFDC has championed in the past few years. For the industry, he echoed for revamping existing urea plants with cleaner fuels and more efficient processes and tapping the opportunities for green ammonia.

In his concluding remarks, **Dr RS Paroda** highlighted the country's great strides in foodgrain production, horticulture production and the white revolution.

He shared that the contribution of fertilizers to these achievements has been ignored in the past. The fertilizers contributed around 40 to 60 per cent in yield enhancement. The fertilizer use has increased by 426 times since independence. He also shared that the country has invested heavily for the development of the fertilizer industry. The significant increase in fertilizer use is one of the key sources of second-generation soil and environmental health problems including – declining fertilizer response ratio, imbalanced nutrient status of soils. Low nutrient use efficiency, deteriorating soil health, climate change with unpredictable weather patterns, high GHG emission from fertilizers and other environmental consequences due to improper utilization of fertilizers. He also highlighted that last year the country spent 2.25 lakh crore (0.7 per cent of GDP) on fertilizer subsidy with majority on N fertilizers i.e. 64 per cent urea, DAP 26 per cent and MOP 10 per cent. The NBS based subsidy is leading to imbalanced use of fertilizer which is causing agro-enviro-economic crisis in the country. He also highlighted that India is one of the largest importers of fertilizers, the global geo-political situations play a vital role on the fertilizer prices. The fertilizer sector faces multi-faceted challenges, including volatile fertilizer prices, soil health and environmental concerns, depleting nutrient use efficiency (NUE), imbalanced fertilizer uses due to subsidy and urea favoring policies, increasing fertilizer subsidy, import dependence, and supply-chain disruptions. To address these issues, he suggested to – transform fertilizer sector from subsidy to incentives system, allocating 5 per cent of subsidy amount on fertilizer innovations, enhance corporate social responsibility (CSR) funding to fertilizer research, use organic and inorganics judiciously, initiate new research through fertilizer innovation centre development in India, emphasize on circular economy by converting industry waste into plant nutrition products, and include cutting edge information and communications technology (ICT), drones and artificial intelligence (AI) in the fertilizer sector. He emphasized that the industries should innovate for being competitive in the global market and cater to the needs of fertilizers and contribute to 'One Health' starting from soil to environment to livestock and to human beings. He also advocated for eco-regional planning at the country level for fertilizer research and development of application technologies. He also echoed for a relook at the subsidy policy and transform it into an incentive-based system to promote production and utilization of efficient products and application technologies layered with other best practices. He also emphasized on use of disruptive technologies for new products and application methods but with rigorous scientific R&D based approval. He lauded the industry on their commitment for R&D in the fertilizer sector but emphasized that industry needs to innovate in their agribusiness model and be more competitive to global level because business as usual is not an ideal

way forward. He exhorted to develop a Center of Excellence on Fertilizers (CoEF) to cater to R&D demands and skill needs of the diversified stakeholders. He also emphasized on collaborations and learnings from the international organizations like IFDC for enhancing innovations. He concluded by thanking all the participants and organizers and shared that a policy brief on the way forward will be shared soon with stakeholders.

Dr Rajbir Singh expressed gratefulness and profuse thanks to Dr RS Paroda, Chairman, TAAS for his vision on this important stakeholders' dialogue. He also expressed his gratitude to DG ICAR, DDG (NRM) and Directors of ICAR institutes and Vice Chancellors of SAUs for their active participation and sponsoring concerned scientists from their respective organizations and making the program a success. He also expressed his appreciation for all the organizers for their collaboration in organizing the Dialogue. He also shared that various Government schemes and programs are proving effective towards improving soil health and nutrient use efficiency. He mentioned about the commitment of NRM Division, ICAR on innovations in the soil health and plant nutrient sources and technologies in India. Finally, he thanked all the distinguished guests, eminent experts, invitees, and participants for their kind presence and all those who helped in organizing the Stakeholders' Dialogue.

MAJOR RECOMMENDATIONS

The participants attending the Stakeholders' Dialogue expressed the need for urgent steps towards addressing the existing challenges and constraints and enhance the fertilizer/nutrient use efficiency by restoring and sustaining soil health. It was emphasized that the Indian fertilizer sector requires multipronged research, development and policy interventions of all stakeholders including ministries, R&D institutions, and the private sector such as industry. The major recommendations emerged from the Stakeholders Dialogue on policy, development and research are as follows:

I. Policy

1. The fertilizer/nutrient use efficiency needs to be doubled by 2030 in a mission mode in fertilizer technology, innovation, research, and extension through factory-to fork (F2F) approach by investing at least 1 per cent of existing subsidy amount (around US$ 250 m) in novel research and state-of-the-art infrastructure. This investment is necessary for developing efficient fertilizer products (organo-minerals, multi-nutrient granules, slow-release fertilizers, etc.) and technologies, which will curtail the subsidy budget by 50 per cent and

reduce carbon footprint by 30 per cent mediated via development of carbon farming/ green credit markets.

2. A Centre of Excellence on Fertilizers (CoEF) needs to be established in public-private-producer partnership (4Ps) along with a pilot plant with innovative laboratory facilities to promote innovations in fertilizer technologies including efficient production, and improved NUE efficiency with support of international organizations like IFDC which will cater skill and knowledge development needs of different stakeholders, especially the youth of India. The CoEF may be established through strategic involvement of the Ministry of Chemicals and Fertilizers (MoC&F) with technical backstopping of the Indian Council of Agricultural Research (ICAR), and the State Agricultural Universities (SAUs).
3. To inspire higher investment for research from the private sector, the GoI needs to consider incentivizing the companies for developing and scaling up new innovations (efficient products and INM solutions and technologies).
4. There is an urgent need to reorient the current fertilizer subsidy policy into incentive-oriented policy under the PM Program for Restoration, Awareness, Nourishment, and Amelioration of Mother Earth (PM-PRANAM) Scheme linked with soil health cards (SHCs) for balanced nutrient application. Also, there needs to be a provision of rewarding and incentivizing researchers, industry, and farmer producer organizations (FPOs) centering on development, promotion, and adoption of climate smart and scientifically proven fertilizer products with INM supported by direct benefit transfer (DBT).
5. There is a need to develop district wise soil health maps, every 5 years, under One Health initiative by establishing a soil conservation fund of ₹ 10, 000 crore to monitor and implement appropriate solutions including incentivizing the farmers adopting appropriate fertilizer inputs and maintaining the soil organic carbon (SOC) above 0.5 per cent.
6. The Fertilizer Control Order (FCO) needs to be revisited to expedite the registration process of new fertilizer carriers/molecules through scientific data backed system, while having compliance of norms to ensure quality and adequate quantity of product in the market to ensure easy availability, accessibility, and affordability.
7. In view of high dependence on import of P and K fertilizers, it would be desirable if Government decides to build contracts, and collaborations for setting-up joint ventures abroad and also create a sovereign fund of US$ five billion for sourcing raw materials or investment in foreign rock phosphate mines

by Indian fertilizer companies in resource rich countries, especially from Africa and Central Asia.

8. An enabling policy decision is needed to include glauconite-K mineral as part of minor/associated minerals. This will help in harnessing the potential of indigenously available K resources, as glauconite can complement potash imports equal to 1 mt annually, worth approximately US$ 590 m in foreign exchange and ₹ 1,518 million in fertilizer.
9. The use of organic fertilizers needs to be promoted through enabling policies along with proposed incentives of ₹ 1,500 per ton to manufacturers to produce quality organic manures using scientific methods of composting.
10. It will be desirable to incentivize nutrient recycling (organo-minerals) through industrial processing of wastes such as sewage sludge, poultry manure and distillery spent wash with a target for generation of 1.0 mt per year of recyclable nutrients through indigenous or industrial processing of wastes linked with enabling policy on INM targeting 75 per cent mineral and 25 per cent organic nutrients.
11. Since acid soils suffer more from sulphur (S), boron (B) and molybdenum (Mo) deficiencies, there is a need to strengthen strategy on integrated nutrient supply and management and enhance availability of custom-made fertilizers to assure balanced management of these nutrient deficiencies; use of glauconite-K mineral will reduce dose of lime and strengthen integrated nutrient supply and management. Application of lime to acid soils once in 3 years costs ₹ 4,800 per ha. Hence, there is a need to make provision of investment of ₹ 1,200 crore for ameliorating entire 25 m ha acid soils. Also, provision needs to be kept for cost of freight on sharing basis, 50 per cent each by the beneficiary farmer and the State Governments. SAUs and ICAR Institutes also need to disseminate technical advice on lime treatment.
12. Department of Fertilizers, MoC&F, GoI and the ICAR may consider bringing out a 'White Paper' on Fertilizers in India involving Think Tanks like the Trust for Advancement of Agricultural Sciences (TAAS), National Academy of Agricultural Sciences (NAAS) and other International Organizations.
13. There is need to convert: (a) fertilizer and other agricultural subsidies (Centre and State) – around ₹5 lakh crore (majority of which is on fertilizer), and (b) fertilizer use on soil test basis – up to ₹10,000 per ha to smallholder (80%) farmers, into incentives for adopting GAP using regenerative agriculture (RA) and conservation agriculture based sustainable intensification (CASI), which will make all the difference with direct benefit transfer (DBT) to farmers and not to industry, as at present.

II. Development

14. For promoting application of the best fertilizer management practices for maximizing efficient fertilizer use, a comprehensive awareness and educational program for extension/ field workers is needed. This would help popularizing art and science of 4Rs (right source, right rate, right time and right place) nutrient stewardship with a goal to promote site-specific nutrient management (SSNM) using available decision support system (DSS) and artificial intelligence (AI), etc.
15. Concerted efforts are needed to promote the use of alternative sources such as NPK, single super phosphate (SSP), triple super phosphate (TSP), nano-urea/DAP to bring down demand for imported fertilizers. To promote crop-specific grades in place of generic grades, there is a need for tailor- made compounds from existing carriers by adopting wet or dry granulation process in a decentralized system.
16. For science-driven efficient fertilizer management, *Krishi Vigyan Kendras* (KVKs) need to enhance knowledge sharing and promote resilient nutrient management practices and nutrient decision support systems (DSS) among communities, extension workers and farmers.
17. Tagging of nano-urea with fertilizer sale, as at present, is counterproductive. Hence, its purchase need not be made mandatory but left to farmers' choice. For such technologies, perfection for use of drones with sensor-based technology for precise foliar spray in N-deficient areas using artificial intelligence (AI) be given greater attention.
18. There is a need to promote the use of NP/NPK fertilizers with organic matter by making necessary changes in the Fertilizer Control Order (FCO). A minimum of 10 per cent use of biofertilizers be made mandatory in organo-mineral fertilizers.
19. There is an urgent need for new research to understand the impact of increased mineral fertilizers use on soil acidity in and align with their contemporary need for alternative fertilizer sources and application technology. There is a necessity to disseminate technical advice on lime treatment by SAUs and ICAR Institutes. This will help in sustaining acid soils and increase productivity by 0.5 t/ha in around 25 m ha, and an additional food production of 12.5 mt worth ₹2,500 crore.
20. For efficient soil testing facilities, creation of accredited private laboratories by well-trained young entrepreneurs under the Government Scheme of soil health cards (SHCs), is urgently required.

21. An urgent attention is needed to rationalize import duty structure of raw materials/ intermediates for 9 stepping up capacity utilization of phosphates and capping P_2O_5 at 10 mt per year with 50 per cent security through investments in mines and joint ventures.
22. There is a need to establish Neutral Fertilizer Platform- A Think Tank involving public-private sector and technical experts for better exchange of information and knowledge among stakeholders, and suggesting country's future needs and possible pathways including research, innovations, and policy advocacy, etc.

III. Research

23. Intensive research on agro-economic evaluation of specialty fertilizers must be taken-up by strengthening cooperation between public sector institutions and fertilizer industry to move forward the innovations from lab-to-land for commercialization.
24. There is need for updating and revising the package of practices recommended for use in the state and intensified efforts for their wider adoption by SAUs besides including climate smart fertilizers – specialty fertilizers (slow release, water soluble fertilizers, controlled release fertilizers, organics, etc.).
25. Understanding and documenting the translocation mechanism of nanoparticles relating to their effectivity and efficiency, are a must. Modus operandi of nanoparticles in soil plant (xylem and phloem) system is complex, hence in-depth research following a consortium approach at the national level by the ICAR-Indian Institute of Soil Science (IISS) be taken up on priority.
26. The existing mandate of the ICAR-AICRP on long-term fertilizers need to be revisited to align with contemporary needs and futuristic relevance to improved NUE. There is a need for focused research in the context of natural farming (NF), conservation agriculture (CA) and regenerative agriculture (RA) to make fertilizer research more holistic, and also ensuring economic and environmental sustainability.
27. Concerted efforts must be made for mechanization of fertilizer deep placement (FDP) by redesigning and innovating multi-crop, multiutility machinery for deep placement of fertilizers to reduce losses and carbon footprint with simultaneous improvement in FUE. Intensive research needs to be undertaken to promote one-time deep placement vis-a-vis repeated top dressings. The FDP has the potential to double the NUE (30 to 60%) which will save more than 10 mt of fertilizer, 10 hence, there is need to provide incentives on

fertilizer-cum-seed drill/planters, and promote the use of recommended 40 to 50 per cent N and 100 per cent P and K fertilizer as mechanized deep placement while seeding/planting and rest as foliar – split application using sensors, AI and DSS, etc.

28. The Ministry of Environment, Forest and Climate Change (MoEF&CC) in collaboration with the ICAR may consider developing protocols for the measurement, reporting and verification (MRVs) of carbon farming/green credit practices, including enhanced fertilizer use and efficient technologies for smallholder farmers.
29. Specific research is needed on inventing slow/controlled release Sulphur-coated urea variable dissolution rates i.e., 1DDR (1 Day Dissolution Rate) or 7 DDR. While such developments must pass the test of use efficiency, these also have to be economically favorable and ecologically benign.
30. A new agri-business model-oriented approach needs to be adopted to understand the fertilizer-based innovations from a business perspective with scalable adoption and markets. Also, to become self-sufficient in urea production, enhancing the recovery efficiency by upgrading the existing plants, is a must.

Annexure I

Technical Program

DAY 1: 28 SEPTEMBER, 2023

09:00 - 10:40	**Inaugural Session**	
09:00 - 09:30	**Registration**	
09:30 – 09:40	**Welcome and Setting the Context**	**VK Singh,** Director, ICAR-CRIDA
09:40 – 09:50	Special Remarks	**Harshdeep Singh,** Representing Chairman, FAI
09:50 – 10:00	Special Remarks	**Upendra Singh,** Vice President, IFDC
10:00 – 10:30	Address by Chief Guest	**RS Paroda,** Chairman, TAAS
10:30 – 10:35	Vote of Thanks	**Bhag Mal,** Secretary TAAS
10:35 - 11:10	***Group Photo and Tea/Coffee Break***	
11:10 - 13:00	**Technical Session I: Fertilizer Scenario- National and International Issues** ***Co-Chairs*** **: AK Singh,** Vice-President, NAAS **: Ramnendra Singh,** Advisor, Fertilizers ***Rapporteur*****: Alison Laing,** CIMMYT	
11:10 – 11:40	Fertilizer Use Efficiency for Sustainable Soil Health in Indian Context	**JC Katyal,** CCS HAU
11:40 – 12:00	Global Supply and Demand Scenario	**A Dobermann,** IFA
12:00 – 12:20	Indian Supply and Demand Scenario	**Kuldeep Sati,** FAI
12:20 – 12:50	Discussion	
12:50 – 13:00	Remarks by Co-Chairs	
13:00 - 14:00	***Lunch***	

14:00 – 15:40	**Technical Session II: Innovation in Fertilizers and its Scaling** ***Co-Chairs*** **: JC Katyal,** Former VC, CCS HAU **: ML Jat,** Global Director, ICRISAT ***Rapporteur*****: Padma Shanthi,** Grow Indigo	
14:00 – 14:15	Innovations in Fertilizer Research: Global Perspective	**Upendra Singh,** IFDC
14:15 – 14:30	Innovations in Fertilizers and Carbon Farming	**ML Jat,** ICRISAT
14:30 – 14:45	Climate Smart Agriculture: Role of Fertilizer Research in India	**VK Singh,** ICAR-CRIDA
14:45 – 15:00	Innovative Fertilizer Products in	**Vaishali Chopra,** Yara Fertilizers
15:00 – 15:30	Discussion	
15:30 – 15:45	Remarks by Co-Chairs	
15:45 – 16:10	***Tea/Coffee Break***	
16:10 – 17:40	**Technical Session III: Fertilizer Production and Energy Efficiency** ***Co-Chairs*** **: HS Gupta,** Former Director, ICAR-IARI **: V Geethalakshmi,** VC, TNAU ***Rapporteur*****: Shivalika Gupta,** IFDC	
16:10 – 16:25	Efficient Energy Options for Fertilizer Production in India	**S Nand,** FAI
16:25 – 16:40	Pilot Plant Research for Efficient Fertilizer Production	**Matt Miller,** IFDC
16:40 - 17:10	Discussion	
17:10 - 17:40	Remarks by Co-Chairs	
18:30 – 19:30	**Special Session: Evening Lecture** ***Co-Chairs*** **: RS Paroda,** Chairman, TAAS **: Himanshu Pathak,** Secretary, DARE & DG, ICAR	
	Soil Health and Fertilizer Use Efficiency	**Rattan Lal,** Ohio State University
19:30-21:00	***Dinner***	

DAY 2 : 29 SEPTEMBER, 2023

09:30 – 11:10	**Technical Session IV: New Avenues of Plant Nutrition and One Health** ***Co-Chairs*** **: BS Dwivedi,** Member, ASRB **: Rajbir Singh,** ADG, ICAR ***Rapporteur*****: CM Parihar,** ICAR-IARI	
09:30 – 09:45	Novel Fertilizers: Research Updates and Scaling Options	**SP Datta,** ICAR-IISS
09:45 – 10:00	Nano-fertilizer for Precision and Sustainable Agriculture	**Tarunendu Singh,** IFFCO
10:00 – 10:15	Specialty Fertilizers for Climate Smart Agriculture	**Shailendra P Singh,** ICL
10:15 – 10:45	Discussion	
10:45 – 11:00	Remarks by Co-Chairs	
11:00 – 11:30	***Tea/Coffee Break***	
11:30 – 13:00	**Technical Session V: Enabling Policies for Fertilizer Sector** ***Co-Chairs*** **: Ashok Gulati,** Chair Professor Ag., ICRIER **: PS Birthal,** Director, NIAP ***Rapporteur*****: Shankar Lal,** ICAR-IIMR	
11:30 – 11:45	Policy Interventions for Efficient Fertilizer Value Chains	**Amit Rastogi,** Coromandel
11:45 – 12:00	Transforming Indian Fertilizer Subsidy Programme to Meet the Future Challenges	**Praveen KV / Alka Singh,** ICAR-IARI
12:00 – 12:15	Enabling Policies for Sustainable Use of Fertilizers	**Prem Chand / Sant Kumar,** ICAR-NIAP
12:15 – 12:45	Discussion	
12:45 – 13:00	Remarks By Co-Chairs	
13:00 – 14:00	***Lunch***	

14:00 – 15:30	**Panel Discussion on Way Forward** ***Moderator* : RS Paroda,** Chairman, TAAS ***Rapporteur*: YS Saharawat,** IFDC	
	Panelists: **PK Singh,** Agri-Commissioner, GoI **BS Dwivedi,** Member, ASRB **Ramendra Singh,** Advisor, Fertilizers **KK Singh,** Group Head R&D, Zuari/PPL **Mahesh Gathala,** Senior Scientist, CIMMYT **Harbir Singh,** Rural Voice **Yash Saharawat,** IFDC	
15:30 – 16:00	***Tea/Coffee Break***	
15:30 – 16:00	**Plenary Session** ***Chair* : RS Paroda,** Chairman, TAAS	
16:00 – 16:20	Major Recommendations	**YS Saharawat,** IFDC
16:20 – 16:30	Remarks	**Upendra Singh,** IFDC
16:30 - 16:45	Concluding Remarks	**RS Paroda,** TAAS
16:45 – 16:50	Vote of Thanks	**Rajbir Singh,** ICAR

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