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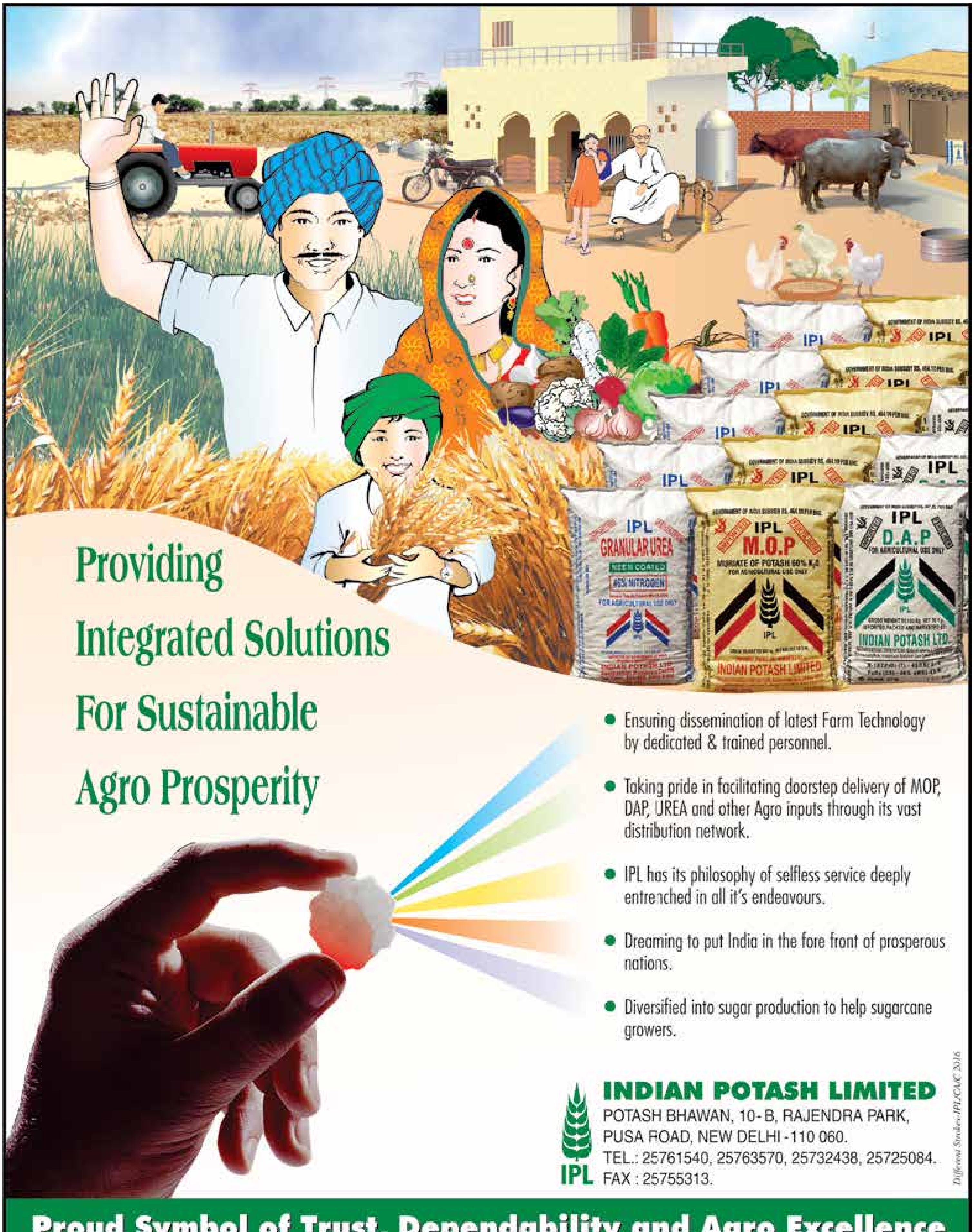
FAI ANNUAL SEMINAR 2021

December 1-3, 2021

Challenges in Fertilizer and Agriculture

PREPRINTS OF SEMINAR PAPERS

THE FERTILISER ASSOCIATION OF INDIA



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CHALLENGES IN FERTILIZER AND AGRICULTURE

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SESSION - I

CHALLENGES OF INDIAN FERTILIZER SECTOR

Chairman : **Mr. Rajesh Kumar Chaturvedi**
Secretary
Department of Fertilizers
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Challenges and Way Forward for Urea Industry

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The urea industry is part of an ecosystem with three major stakeholders *i.e.,* farmers, government and the industry. Immediate intervention is required to increase the fixed cost subsidy element for the industry. However, a long-term solution should address the needs of all three stakeholders. This requires a collaborative effort to improve (i) nutrient use efficiency (NUE), (ii) policy simplification, (iii) a gradual increase of farmgate price, (iv) liberalization and (v) reasonable returns for the industry. Improving NUE positively impacts all three stakeholders, and will also contribute to the country's sustainability goals.

Introduction

The critical role that agriculture plays in India is well documented-feeding a nation of 1.3 billion people, contributing circa 15% of GDP and providing employment to 40% population. As population grows and peaks in a few decades, the food requirement shall also grow; while cultivable acreages will likely remain at current levels. Add to this, growth in world population and changes in the Indian agriculture ecosystem which may lead to further growth in exports. Further, while the share of agriculture in GDP will continue to decline, as other sectors grow faster, at an absolute level the agriculture economy will increase.

Food security for India is to be seen from the context of availability to feed the large and growing population as well as balanced nutrition and affordability for a large proportion. Hence, containing food inflation will remain a key imperative over the coming decades. This, coupled with need to enhance farm income, inevitably leads to the challenge of improving the overall efficiency of farming *i.e.*, reduce input cost and increase output per unit of area.

India has three principal stakeholders for urea *i.e.* the farmer, the Government and the urea manufacturers. All three have their own challenges, *viz.* low farm incomes, poor return for manufacturers and subsidy for the government. Given the specific aspects mentioned above, and the overlap of the issues faced by the stakeholders, any sustainable solution for one will need to ensure that the others are not significantly impacted adversely.

Urea Industry Perspective

Over past five years, the urea industry has produced approximately 24 million tonnes every year while imports have ranged from 5.5 – 9.0 million tonnes. With new plants coming on stream, production is expected to cross 30 million tonnes, thus substantially reducing imports. While many aspects have been highlighted in the past also, the key points to be noted are:

Over the past 15 years, the average total cost of production of gas based urea units has been lower than import cost every year (**Figure 1**). This cumulatively translates to saving of subsidy of approximately Rs. 150,000 crore considering total production by these units. Thus, local manufacture, apart from ensuring availability has been significantly cost effective for the country and has reduced the financial burden of the Government and taxpayer.

- Of the total subsidy provided to farmers to keep urea price low, which is routed through the industry, 85-90% is essentially variable cost that simply passes through the industry to suppliers of gas, bags, rail & road transport. Hence, only 10-15% is actually attributable to the industry for its operating fixed costs and returns.
- While fixed cost of the industry has increased in line with general and wage inflation, subsidy to the industry corresponding to this has not been adjusted accordingly. Further, given the vintage of most plants, significant capital is increasingly required to refurbish/replace ageing equipment to keep the plants safe and efficient. As per data available for 25 urea units with FAI, 50% units are

Figure 1. Average Cost – Imported urea (Rs. /MT) and average cost – Indigenous urea (Rs./MT)

making losses from urea activity and others are also operating at wafer thin margins. Industry as a whole is having a negative return with profit after tax (PAT) as percentage of networth at (-)8.5% for 2019-20 and (-)5.2% for 2020-21 even after providing for nominal increase in fixed cost approved under Modified NPS-III. As costs increase every year, this will progressively become worse from an already very low return. The industry survives primarily through diversification of revenues.

- Urea policy has evolved over the years and though there has been some simplification, it still remains cumbersome and complex requiring substantial documentation, reporting and calculations.
- On a positive note, the unprecedented clearance of all outstanding subsidy by the Government of India in Financial year 2020-21 has been a significant step to reduce working capital and hence interest costs.

Urea Usage Challenges

Nitrogen Use Efficiency (NUE)

Figure 2 shows NUE for the world and for India. It is evident that there is a substantial gap between the global NUE and India's – while the global average touched a low of ~ 0.43 in 1988 and has since increased on 0.58, India's NUE continues to languish. This not only impacts farmer input cost but also the environment and the import requirement of urea, and hence adversely impacts the country as a whole. To highlight the importance of NUE – a 10% improvement in NUE will result in approximate reduction of more than 3 million tonnes of urea. This is equivalent to more than two new urea plants of 1.3 million tonnes per annum capacity *i.e.*, a capital investment of approximately Rs. 15,000 crore or an import bill reduction of approximately Rs. 7500 crore per annum (average cost of imported urea over

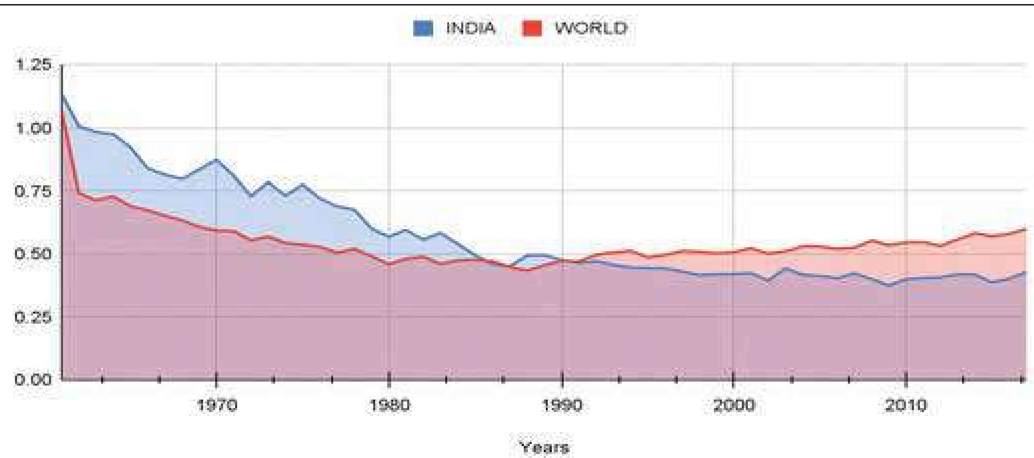
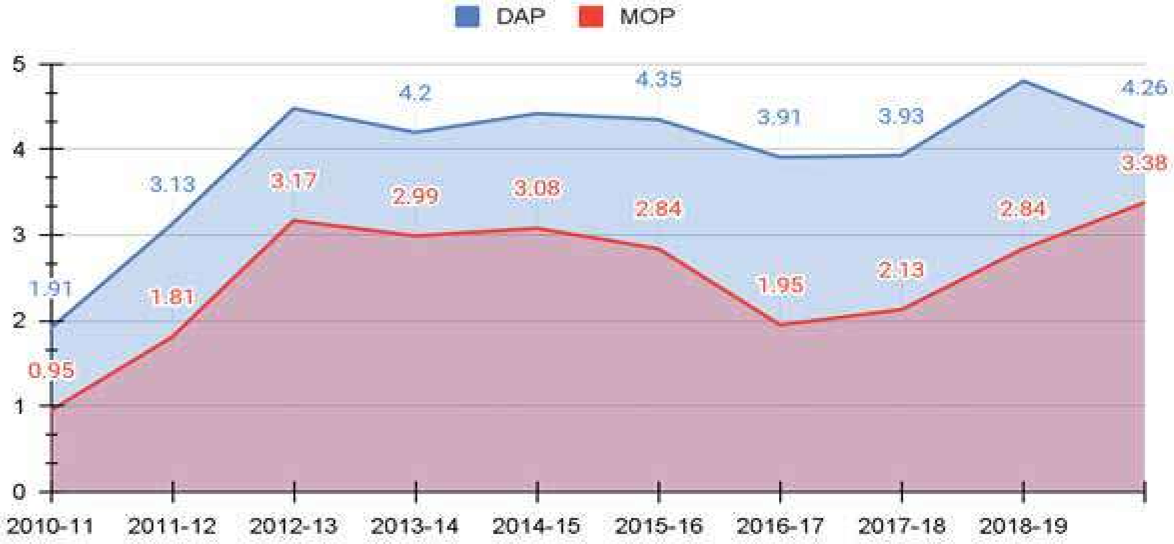


Figure 2. NUE: India vs World **Source: ifastat.org**



Urea Price = 1

Figure 3. Distortion in price ratio w.r.t. urea

last 10 years based on FAI data ~ Rs. 21991 / MT).

Urea Price

As **Figure 3** shows, over the past 10 years, with Nutrient Based Subsidy (NBS) for non-urea fertilizers the distortion between price of di-ammonium phosphate (DAP), the second highest used fertilizer, and urea has more than doubled. This has led to distortion in usage of urea, especially in the northern states, with extremely skewed NPK use ratios.

Way forward

While there are numerous actions required to be taken, a start has to be made towards liberalization of the urea industry. Following is suggested from an overall context, which addresses the needs of all three key stakeholders.

- In the short-term, action is needed to correct the fixed cost reimbursement to the industry. This should be one-off substantial adjustment to bring the fixed costs reimbursement at par with past inflation and thereafter it should be linked to an inflation index.
- Provide time bound fiscal incentive for low energy efficiency plants to improve and subsequently have a single energy norm.
- Simplify the urea policy, including above suggestions. In addition, elements such as freight, bags can be merged into one variable cost basis average cost for the industry. One of correction can be done considering the rise in input costs of these and thereafter index linkage similar to fixed cost. Automation of subsidy process should also be considered given advancement in digital technology.
- Enable the farmer to manage input cost escalation due to fertilizers through collaborative long-term programme between the central & state governments, agriculture institutes, the industry and farmers to drive improvement in NUE. This should include innovation to improve uptake & reduce losses, soil health analysis, and NPK use ratio. Efficiency improvement shall benefit all stakeholders and the country.
- Increase urea price gradually. which should help in curbing nutrient imbalance. Moreover, the freeing of retail prices would be possible after a certain price level is reached so that the industry can be transitioned to NBS similar to NPK fertilizers. It will also provide the Government with the much needed fiscal space.
- Implement direct benefit transfer (DBT). The complexity and challenge of an initiative of this magnitude is high. However, a start has to be made and refinement can be done over a period of time.

Conclusion

The Indian urea industry is one of the most efficient in the world and has been consistently providing urea at lower cost than imports. However, with the current trajectory, it will become increasingly unviable and hence urgent monetary and policy action is required. Simultaneously, it is imperative that usage efficiency is improved, which will benefit the country as well as, with addition of new capacity, make the country Atmanirbhar for urea. Sustained, collaborative efforts from government and industry is the need of the hour to achieve this. ■

Challenges and Remedies for P&K Fertilizer Industry

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The phosphatic and potassic (P&K) industry over the last decade has seen increased collaboration between Government and Industry with progressive reforms such as nutrient based subsidy (NBS) and direct benefit transfer (DBT) which have benefited all stakeholders. The sector has witnessed stable growth with a continuously rising demand for fertilizers. While these are positive developments, there are multiple areas such as balanced nutrition, self-sufficiency through Atma Nirbhar initiative, etc., where Industry and Government can work together to address these challenges. With the advancement of technology, there are multiple opportunities such as the adoption of data analytics, usage of drone technology, adoption of new technology products that have high potential if utilized in the right way. This paper seeks to lay out some of the key challenges in the P&K fertilizer industry with recommendations on some key initiatives that Industry and Government can work together on to bring about a positive change for all stakeholders.

Introduction

The agriculture sector has been quintessential in ensuring food security for the nation and generating livelihood opportunities for ~43% of the populace. Over the past five decades, Indian agriculture has tripled its food grain output and has become self-sufficient for its nutrient needs. Today, with the influx of technology and increased consumer consciousness, it stands at an inflection point to meet the twin objectives of food security and farm sustainability. Fertilizer, a key enabler for agriculture growth, stands to play a major role in shaping the Indian farms of the future and driving prosperity of the agriculture sector.

In the year gone by, the agriculture sector displayed strong resilience amidst the pandemic uncertainty, registering record food grain and horticulture output and emerged as a bright spot in the Indian economy (Agriculture GVA FY21: 3.6%). This reflects the indomitable grit and resilience of the Indian farmers ensuring food security for the nation under challenging circumstances.

The Government has also played a pivotal role in ensuring the continuance of farm operations through its various support packages, record procurement under MSP, MGNREGA expansion, credit disbursements, etc. Fertilizers and other agri-inputs were recognized as Essential services, which ensured continuous production and distribution of fertilizers. The disbursement of an additional Rs. 65,000 crore subsidy for the fertilizer industry in 2020-21 supported the working capital needs and has cleared the pending subsidy arrears for the industry. Data transparency enabled by the implementation of DBT 2.0 has also helped the industry players in making informed decisions.

While there have been many positive developments, the P&K fertilizer industry continues to face multiple challenges. The current year has been particularly tough with the spike in international prices of raw materials and finished products of phosphatic fertilizers due to competing demand from key fertilizer consuming markets and supply challenges from major sources. Though the Government has been taking proactive steps to ensure the availability of fertilizers through revising the NBS rates for 'P' nutrient and providing additional budgetary allocation, the industry has been impacted by the structural vulnerabilities in the value chain. This paper seeks to lay down some of the key challenges that are impacting the P&K fertilizer industry and provides recommendations to address the same through the Government's support and by leveraging certain opportunities in the agriculture space.

Table 1. All India consumption ratio: N & P_2O_5 in relation to K_2O

	N	P_2O_5	K_2O
FY10	4.3	2.0	1
FY12	6.7	3.1	1
FY14	8.0	2.7	1
FY16	7.2	2.9	1
FY18	6.1	2.5	1
FY20	7.1	2.8	1

Source: The Fertiliser Association of India, New Delhi

Key Challenges Faced by the P&K Industry

Balanced Nutrition

Over the years, Government policy and reforms viz. subsidy & farm gate prices, fertilizer movement, have played a significant role in influencing the consumption behaviour of agri-nutrients. Today, India ranks as the second-largest producer and consumer of agri-nutrients after China. Over the past three decades, India has doubled its fertilizer production (urea & phosphatic fertilizers) in ensuring its availability to the farming community.

With the introduction of NBS policy in 2010, India witnessed a major reform in phosphatic fertilizer. However, its partial implementation only for P&K fertilizers has impacted the nutrient application rates (ideal nutrient ratio N:P:K :: 4:2:1) and skewed consumption towards 'N' nutrient as shown in **Table 1**.

Even in the P&K sector, the nutrient ratio varies across the regions depending upon the choice of fertilizer consumed. It can be seen that markets with high NPK consumption share (South and East) have close to the ideal nutrient ratio of 4:2:1 of N, P_2O_5 and K_2O, while DAP dominant regions have experienced skewed nutrient balance as shown in **Tables 2** and **3**.

With around 24 NPK products covered under the Fertiliser Control Order (FCO), there is an opportunity for India to make a shift towards NPKs. Some of the NP grades like 14:28:0, 13:33:0:15S have similar nutrient ratio as DAP, while NPK products like 14:35:14, 12:32:16, 14:28:14 and 10:26:26 offer additional potash for 'K' deficient soils. The NPKs developed over a period of time can be customized as per crop and soil requirements and provide balanced fertilization to the soil. Further, fortification of NPKs with micro-nutrients like zinc, boron, manganese can facilitate yield improvement and reduce fertilizer application costs by delivering multiple nutrients through a single treatment.

India, with its diversified geographies, irrigation and cropping practices, can benefit through customization of NPKs suitable to specific soil and crop and which can not only improve the yield but also enhance the quality of produce thereby helping Indian farmers to compete in the export market. NPKs with fortified micronutrients can be a far superior substitute to the DAP fertilizer especially in the North and West markets and require concerted efforts on the part of industry to drive this change by collaborating with Government. This can not only bring balanced nutrition to the fore but can improve fertilizer availability through domestic source and industry sustainability.

India, with a domestic capacity to manufacture ~15.8 million tonnes of NPKs and ~12.3 million tonnes of SSP, can meet a large part of the phosphatic demand and substantially reduce dependence on DAP imports.

During the current year, the revision in the NBS rates for 'P' has helped in mitigating the impact of the sharp increase in raw material prices. However, it has created a price gap between DAP and NPK fertilizers which can impact the balanced nutrition aspect. The NBS policy, which has been there in existence for the last one decade has benefitted all the stakeholders – farmers, Government and the industry. The subsidy measures introduced during the year have improved the fertilizer availability; however, it has created price disparity between NPKs and DAP. This needs to be addressed by restoring the earlier status and ensuring NBS for all the grades.

Table 2. Regional consumption ratio: N & P_2O_5 in relation to K_2O (2019-20)

	N	P_2O_5	K_2O
East	4.2	1.7	1
North	18.2	5.5	1
South	4.4	2.0	1
West	7.5	3.4	1
Total	7.1	2.8	1

Source: The Fertiliser Association of India, New Delhi

Table 3. Regional consumption : DAP & NPK (2020-21 in million tonnes)

Region	DAP	NPK	Total	NPK share (%)
East	1.7	1.7	3.4	51
North	4.1	0.7	4.8	15
South	1.7	5.6	7.3	77
West	4.5	3.7	8.2	45
Total	**11.9**	**11.8**	**23.7**	**50**

Source: mfms

Due to the higher phosphoric acid requiement for DAP manufacturing (46% P_2O_5) and its limited availability globally, the domestic industry is constrained and its production has stagnated at 80-85% capacity utilization levels in last few years, as given in **Figure 1**.

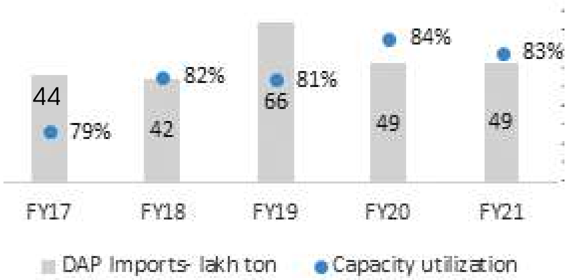

Figure 1. DAP import and capacity utilization

Source: The Fertiliser Association of India, New Delhi

Atma Nirbhar Bharat in Phosphatic Fertilizers

In the past five years, India's urea sector has witnessed considerable investment and is expected to create an additional 7 million tonnes capacity by 2025. While the urea industry has benefitted under the Atma Nirbhar Bharat initiative, the phosphatics sector is yet to attract fresh investments to achieve its self-sufficiency goals as shown in **Table 4**.

Table 4. India – Capacity utilization 2020-21

	Capacity	Production	Capacity utilization (%)
Urea	248	246	99
P&K	158	131	83
SSP	123	49	40

Source: The Fertiliser Association of India, New Delhi

Table 5. Customs duty on raw material & finished products

	Customs duty (%)
Raw material	
Phos acid – US	5.0 + 5.0
Phos acid – Morocco, Tunisia	4.0
Phos acid – Others	5.0
Rock phosphate	2.5
Ammonia	5.0
Sulphuric acid	5.0
Sulphur	2.5
Potash	5.0
Urea	5.0
Finished product	
DAP - Agri cess	5.0
NP/NPK	5.0

Source: The Fertiliser Association of India, New Delhi

With the revival of NPK consumption and growth of 3.6% CAGR in the last decade, India will need to create significant capacity in the P&K space as well to achieve self-sufficiency. Today, India imports more than 30% of its phosphatic demand, while the domestic capacity utilization remains at 80-85% levels.

Some of the factors impacting the competitiveness and investments in the P&K sector are as under:

High Customs duty on raw material: Presently, the raw materials and finished products for fertilizers attract similar customs duty as shown in **Table 5**, which is impacting the competitiveness of the domestic sector compared to imports.

The customs duty on imports for key raw materials like phosphoric acid, ammonia (customs duty: 5%) is equal to the agricultural cess on imported DAP (agricultural cess: 5%). This makes domestic manufacturing less competitive when compared with imports.

It is a long pending demand of the domestic industry for rationalizing the basic customs duty on raw materials from 5% to 0% to improve its competitiveness. The domestic fertilizer industry meets roughly two-thirds of the country's plant nutrient requirements, producing ~43 million tonnes of fertilizers annually and providing direct and indirect employment opportunities to a substantial workforce. Besides, it creates local value addition and unlike imports, produces throughout the year to ensure the adequacy of stocks well before the consumption period. It, therefore, needs a differential treatment to improve its competitiveness.

High capital expenditure projects with low to moderate returns – Need for stable subsidy policy environment: Today, one million tonnes integrated NPK fertilizer plant requires an estimated outlay of USD 450-500 million. With the low to moderate return profile of the sector, this has been a big entry barrier for attracting fresh investments. There is a need for ensuring reasonable returns for the sector that can help in attracting the investing community to look at the sector much more favourably. In addition, the Government can incentivize capacity additions in the sector. This can be in form of providing capital access at low cost, introducing production-linked incentives, fast-tracking/single window project clearances.

Supply security of mined raw materials: India imports the majority of its raw material requirements like rock phosphate and potash for manufacturing phosphatic fertilizers. While there are multiple sources of rock globally, these are relatively untapped and prone to geopolitical uncertainties. To de-risk the operations, the Government may offer support to the industry in developing overseas infrastructure and extend sovereign guarantees in resource-rich geographies for setting up joint ventures to ensure supply of stable mined resources of phosphate and potash to India.

Value addition through intermediate manufacturing (phosphoric acid, sulphuric acid): Presently, domestic industry meets 40-50% of its requirement of phosphoric acid and sulphuric acid, intermediates for manufacturing phosphatic fertilizers, through imports. Given the supply & pricing uncertainty around these raw materials, it is important to encourage the domestic industry to make further investments in intermediate capacities. Globally, with resource-rich nations' shift towards self-sufficiency (by converting intermediates to finished products), the availability of intermediates is expected to remain tight in the future. The Government and the industry need to partner together to chalk out a plan for reducing the supply side vulnerabilities.

One of the challenges relating to phosphoric acid investments is dealing with its by-product phosphogypsum. Apart from consumption by the cement industry, promoting its use in agriculture as a soil amendment for sodic soils, enabling logistics cost advantages for Indigenous gypsum and restricting gypsum imports can largely address the disposal challenges. Also, the promotion of alternative uses of phosphogypsum such as plasters through approvals from Government bodies such as BIS will enable market pull for plasters and encourage industry to invest in such opportunities.

Tapping domestic rock phosphates resources: With 45.8 million tonnes of phosphorite reserves available in Rajasthan and Madhya Pradesh, there is an opportunity to beneficiate low-grade rock and enable backward linkages to Indian manufacturers. This can augment SSP production in the country, which currently is dependent on imports for meeting its rock requirements.

Weak Positioning and Awareness on SSP - Promotion of SSP as a Viable Alternative to Imported P&K Fertilizers

Despite SSP being the cheapest source of phosphate providing multiple nutrients like sulphur and calcium, the industry has not realized its complete potential due to poor quality perception and raw material-related challenges. In the current scenario of DAP shortage, SSP can be a very good substitute especially for oilseeds and pulses and is suited for semi-arid & rainfed regions (60% Indian farmlands).

Further, the low-cost nutrient can cater to the needs of small & marginal farmers. Globally, SSP is a dominant fertilizer grade, with major agricultural countries like Brazil (24%), China (16%), Australia (18%), meeting a substantial share of its P_2O_5 requirement (India: 11%).

With ~5.0-7.0 million tonnes of DAP imported annually as given in **Figure 2**, there is high dependence on DAP imports. SSP can be a potential alternative to DAP, especially for small and marginal farmers providing 16% P_2O_5 and additional nutrients in form of sulphur and calcium.

With the SSP industry operating at 40% capacity, the unutilized capacity of SSP could potentially substitute part of annual DAP imports.

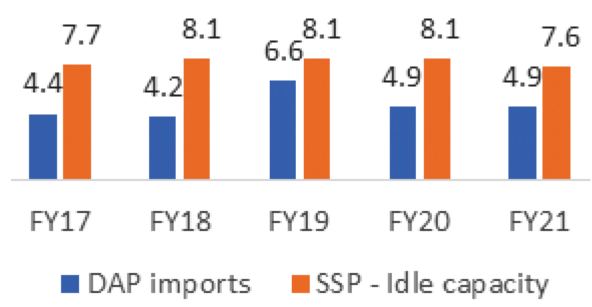

Figure 2. DAP imports *vs.* SSP idle capacity

Source: The Fertiliser Association of India, New Delhi

The Indian SSP industry has evolved over the years from using powdered SSP to the increased usage of granulated SSP. Value-added SSP with micronutrients such as zinc, boron has also gained traction. However, there is a need to improve the quality perception of the industry, which currently has not realized its full acceptability in the farms. While quality is paramount to promote SSP, the sampling process can be made more stringent at the marketplace rather than at the factory gate, which can inordinately lead to procedural delays. There is a need to strengthen quality assurance infrastructure in the country, and Government can support the setting up of NABL accredited labs for improved quality checks across the marketplace. Further, promotion of domestic rock sources, deregulating rock assessment procedure, simplification of the process for the introduction of new rocks and promoting the usage of SSP as a viable alternative to DAP can help reduce the import dependence for P&K Industry.

Policies Supporting Increased Organic Fertilizer Adoption

It is well recognized that Indian soils are deficient in organic carbon and this is leading to a poor response ratio of fertilizers viz. more and more fertilizers must be applied for achieving the same yield. The Government has been promoting the use of organic fertilizers to address the carbon deficiency in soils. The recent introduction of potash derived from molasses (PDM) is a welcome move towards addressing MOP shortage through organic fertilizers.

While these are positive developments in large scale adoption:

- The point of consumption is often far away from the point of generation leading to the substantial freight cost. Product freight subsidy is needed.
- Organic fertilizers are often promoted as suitable for only organic farming. There is a need to promote the use of organic fertilizers along with chemical fertilizers rather than for organic farming alone. This is well-aligned with the concept of integrated nutrient management (INM). To fully implement the INM concept, biofertilizers should also be promoted along with chemical and organic fertilizers.
- There are limited sources of organic fertilizers – city compost, pressmud compost, manure, etc. The limited number of sources also increases the transportation cost for these fertilizers. There is an urgent need to add other sources of organic fertilizers such as agri-residue, sewage, poultry manure, etc. This will increase the availability near the points of consumption and reduce the cost of these fertilizers.
- Globally, the concept of organo-mineral fertilizers has taken root. These are a combination of organic and chemical fertilizers. Government should permit the use of organo-mineral fertilizers as these also promote the concept of INM.

Maximizing Benefits to the Farmer through DBT

With the implementation of DBT in 2018, the fertilizer value chain has been connected digitally, bringing transparency and reducing supply-side volatility across the system. Presently, DBT claim generation and subsidy settlement process are fully stabilized. However, there are futher opportunities under DBT that can maximize the benefits for the farming community. With the high rural digital coverage and implementation of JAM (Jan Dhan, Aadhaar, Mobile) initiative, there is an opportunity for directly transferring subsidy to the intended beneficiaries in cognizance of the soil health information. This will help a farmer in making an informed purchase decision and can improve soil health and farm sustenance.

Leveraging New Opportunities

Technology and Data Analytics

Drone technologies for efficient dispensing of fertilizers: With the Ministry of Civil Aviation coming up with new Drone Rules in August 2021, drone usage for fertilizer application has been significantly liberalized. Drone-based fertilizer dispensing of liquid/ nano fertilizers can offer faster speed of operations, higher coverage, lower cost of application and inputs reduction. The industry can take a lead to leverage drone technologies for fertilizer application and crop diagnostics. Considering the higher capital costs of drones, custom hiring centres or subsidies under Agriculture Infrastructure Fund may be extended which can improve its adoption. The Farmer Producer Organization (FPO) ecosystem with over 10,000 FPOs in India could be leveraged to increase penetration of these technologies**.**

Data analytics: In order to facilitate accurate information gathering and decision-making with respect to the position of requirement/supply/ availability of fertilizers, the Department of Fertilizers has developed various dashboards. These reports are facilitating real-time monitoring of the availability and sale of fertilizers within each State. With the advancement in data analytics, available farmer data should be leveraged to provide actionable solutions to farmers.

The Government is creating an "Agristack" (a collection of technology-based interventions in agriculture) and is working with large technology firms and agritech startups to harness the farmer data available with the Government. Through this initiative, the Government is looking to set up a platform that will provide services for farmers across the value-chain. This can provide a conduit for agri-input players for extending targeted services to address farm-level challenges in the areas of customized product development, credit accessibility, mechanization and precision solutions.

If data on soil conditions and recommended nutrient dosage can be made available at a micro-level, the industry can perform analytics on the data and create customized nutrient recommendations and packages for specific region-crop combinations. Government support on promoting these customized recommendations will result in a win-win situation for all stakeholders as the farmer will get products with the right nutrients and industry will be able to provide differentiated products to the farmer. The use of blockchain technology to record the movement of fertilizer across the country will enable increased transparency in the recording of data which can help in faster disbursement of subsidy by minimizing the paperwork. This will also enable the industry to improve its supply planning and distribution capabilities

Increasing Adoption of New Technology Products

With the increased consumer consciousness, there has been a higher focus on sustainable farm practices. This is likely to improve the adoption of INM and bring a greater push towards efficient practices that can improve the use efficiency of resources as shown in **Table 6**. From a fertilizer perspective, this is leading to a shift towards technologically superior nutrient solutions (nano, liquid, coated), micro-irrigation,

Table 6. Nutrient use efficiency of different nutrients by application method

	Nutrient use efficiency (%)	
	Nutrient broadcasting	Drip + Fertigation
N	30-50	95
P	20	45
K	50	80

Source: Report by Department of Agriculture, Cooperation and Farmers Welfare, New Delhi

mechanization, etc. The recent launch of nano urea by IFFCO is a welcome development and it would be important for the industry to develop such products and promote the same to enable large scale adoption of such products.

Government support in the form of fast-tracking approvals for new technology products, promotional support in form of campaigns advocating benefits of products and associated dispensing mechanisms can enable large scale adoption of such products and technologies.

Conclusion

The Covid 19 induced uncertainties over the last two years have made the nations rethink their strategic priorities. For India, recognition of agriculture and fertilizer as essential sectors has further reinforced their importance in nation-building and achieving self-sufficiency targets. In the last few years, the Government and Industry partnership has strengthened significantly in driving Indian agriculture and going forward, the industry expects the reforms to further support sustainable farm practices. Though farm technology advancements are presently at a nascent stage, it is expected to bring significant change to the farming landscape. The fertilizer industry, with support from the Government, can play a decisive role in shaping the farming practices and driving farm prosperity.

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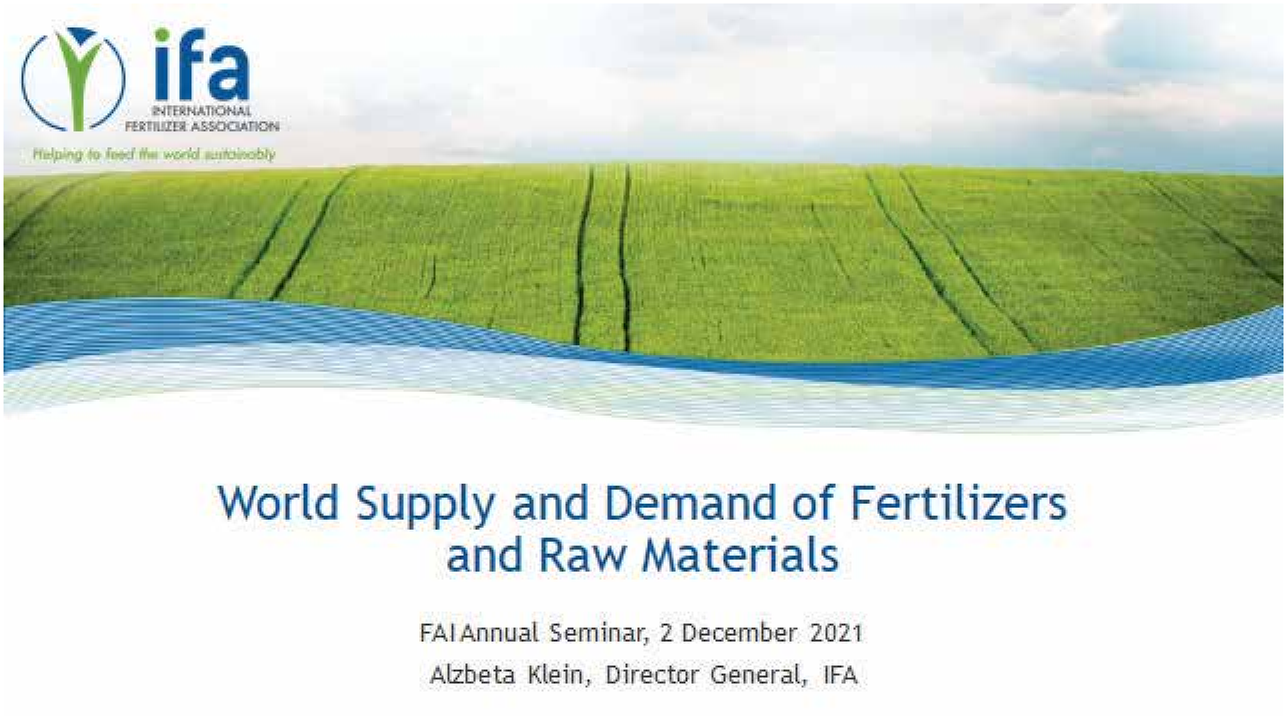
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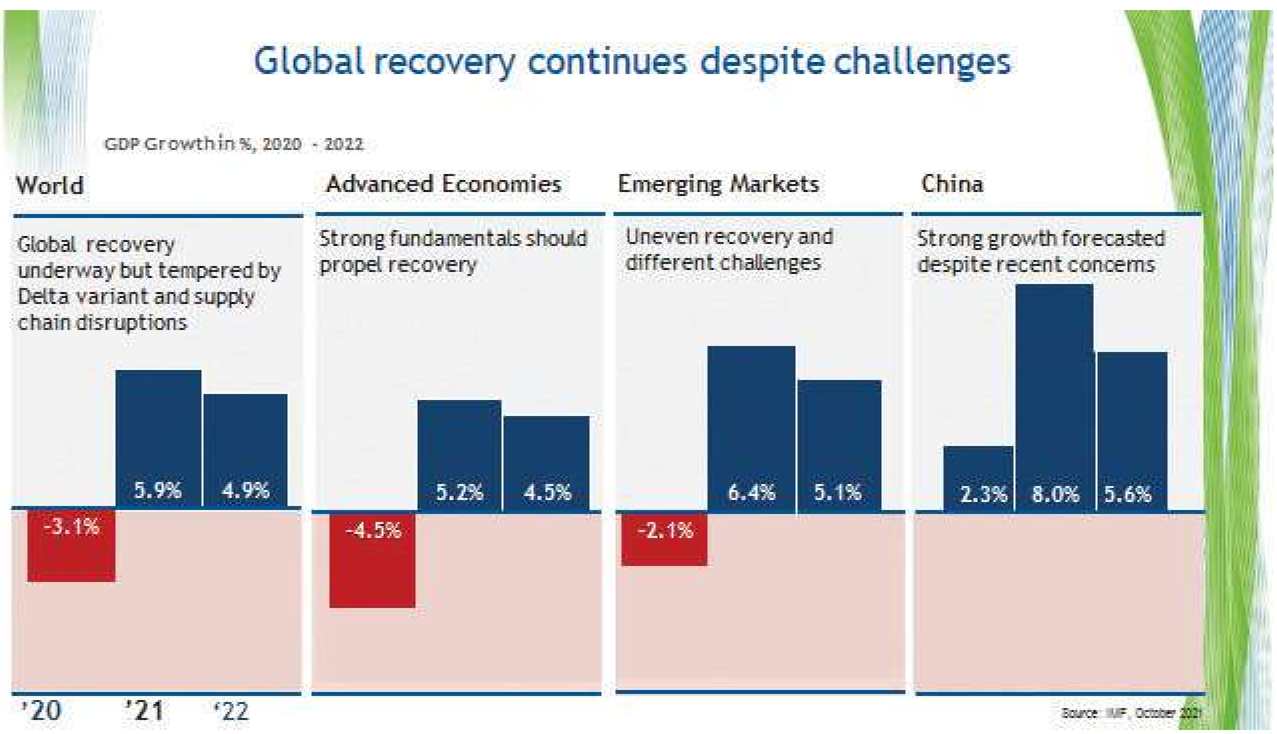
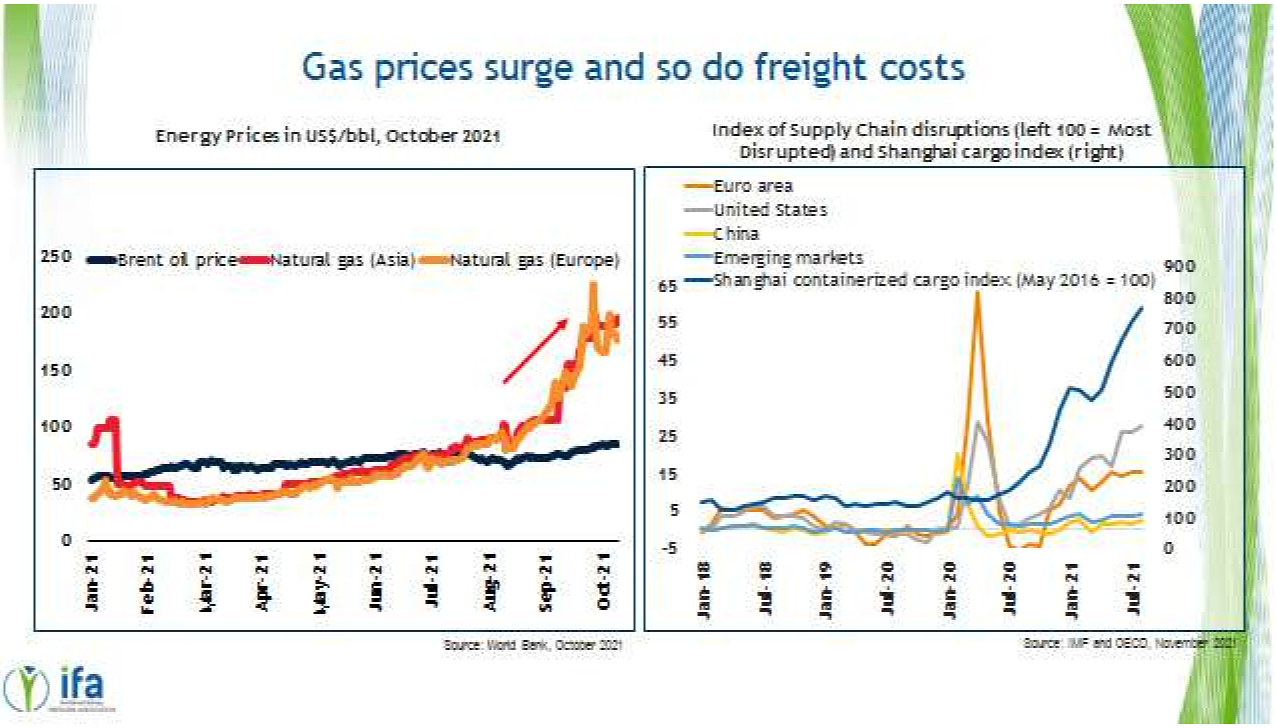
INTERNATIONAL FERTILIZER ASSOCIATION
Helping to feed the world sustainably
World Supply and Demand of Fertilizers and Raw Materials
FAI Annual Seminar, 2 December 2021
Alzbeta Klein, Director General, IFA


Global recovery continues despite challenges
GDP Growth in %, 2020 - 2022
World
Global recovery underway but tempered by Delta variant and supply chain disruptions
-3.1%
5.9%
4.9%
Advanced Economies
Strong fundamentals should propel recovery
-4.5%
5.2%
4.5%
Emerging Markets
Uneven recovery and different challenges
-2.1%
6.4%
5.1%
China
Strong growth forecasted despite recent concerns
2.3%
8.0%
5.6%
'20
'21
'22
Source: IMF, October 2021


Gas prices surge and so do freight costs
Energy Prices in US$/bbl, October 2021
Brent oil price
Natural gas (Asia)
Natural gas (Europe)
250
200
150
100
50
0
Jan-21
Feb-21
Mar-21
Apr-21
May-21
Jun-21
Jul-21
Aug-21
Sep-21
Oct-21
Source: World Bank, October 2021
Index of Supply Chain disruptions (left 100 = Most Disrupted) and Shanghai cargo index (right)
Euro area
United States
China
Emerging markets
Shanghai containerized cargo index (May 2016 = 100)
65
55
45
35
25
15
5
-5
900
800
700
600
500
400
300
200
100
0
Jan-18
Jul-18
Jan-19
Jul-20
Jan-20
Jul-20
Jan-21
Jul-21
Source: IMF and OECD, November 2021
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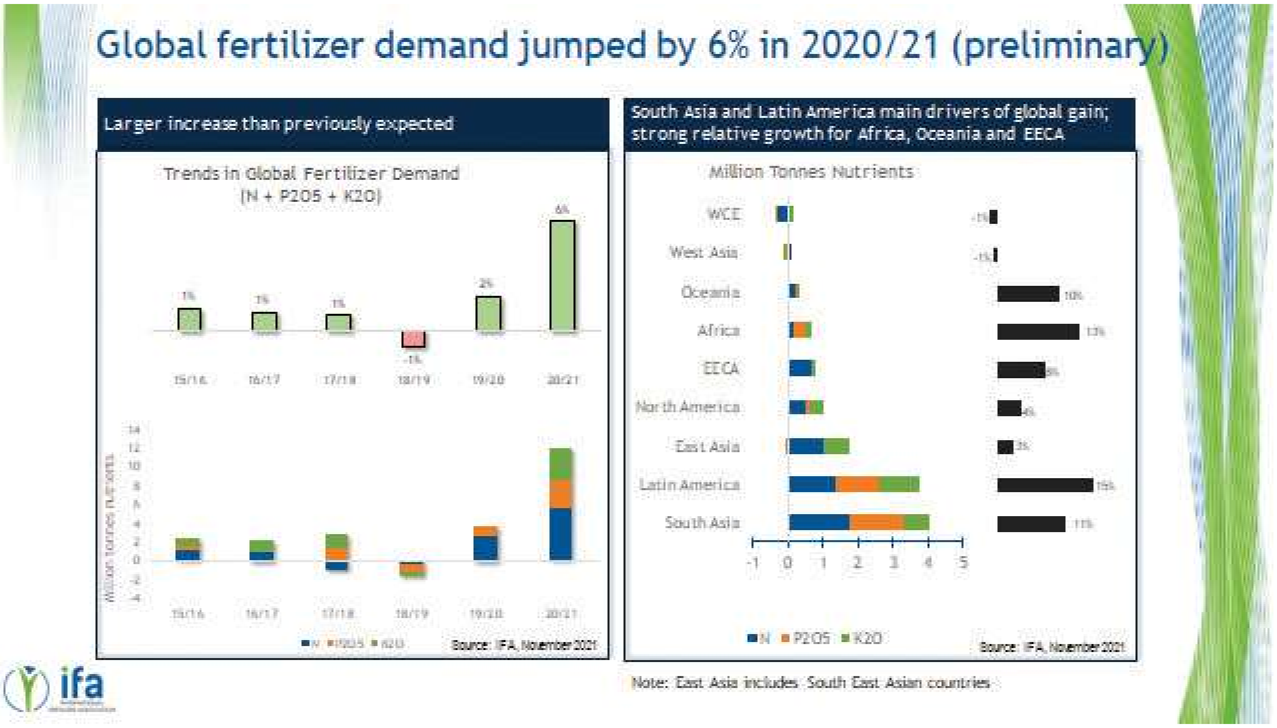
Rising trade restrictions and policies affecting fertilizers
Russia: 6 months export quota on N & P fertilizers (Nov)
Turkey: Export restrictions on N, P & K fertilizers (Oct)
USA: Establishment of a Task-Force to address short term supply chain challenges (Oct)
Egypt: Halted N exports unless cleared by MoA (Nov)
China: Export freeze on Fertilizers (Oct)
Vietnam: 6% import tax on DAP (Oct)
India: Increased fertilizer subsidies by 140% (May), and additional subsidies to help farmers cope with rising fertilizer prices
Sri Lanka: Reversed import ban on mineral fertilizers (Oct)
Source: IFA


Global fertilizer demand jumped by 6% in 2020/21 (preliminary)
Larger increase than previously expected
Trends in Global Fertilizer Demand
(N + P2O5 + K2O)
1%
1%
1%
-1%
2%
6%
15/16
16/17
17/18
18/19
19/20
20/21
Million tonnes nutrients
Source: IFA, November 2021
South Asia and Latin America main drivers of global gain; strong relative growth for Africa, Oceania and EECA
Million Tonnes Nutrients
WCE
West Asia
Oceania
Africa
EECA
North America
East Asia
Latin America
South Asia
-1
0
1
2
3
4
5
N
P2O5
K2O
Source: IFA, November 2021
Note: East Asia includes South East Asian countries
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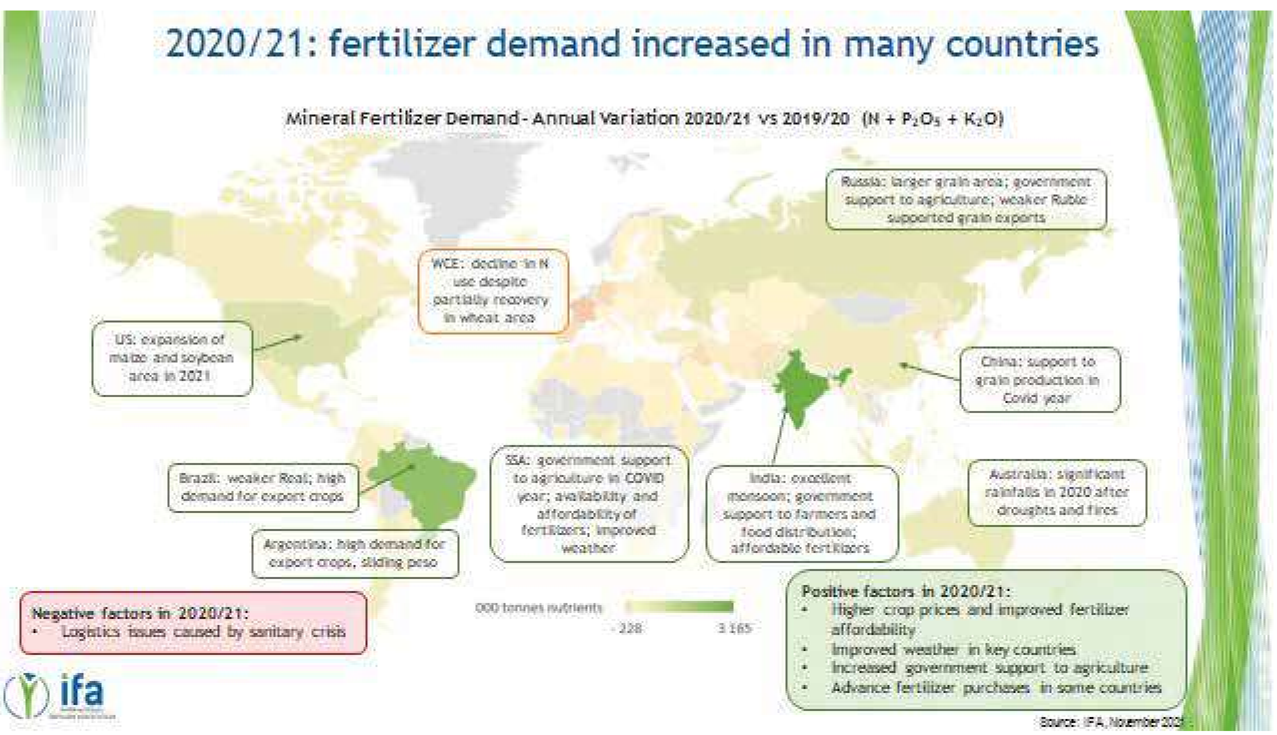
2020/21: fertilizer demand increased in many countries
Mineral Fertilizer Demand - Annual Variation 2020/21 vs 2019/20 (N + P₂O₅ + K₂O)
Russia: larger grain area; government support to agriculture; weaker Ruble supported grain exports
WCE: decline in N use despite partially recovery in wheat area
US: expansion of maize and soybean area in 2021
China: support to grain production in Covid year
Brazil: weaker Real; high demand for export crops
SSA: government support to agriculture in COVID year; availability and affordability of fertilizers; improved weather
India: excellent monsoon; government support to farmers and food distribution; affordable fertilizers
Australia: significant rainfalls in 2020 after droughts and fires
Argentina: high demand for export crops, sliding peso
Negative factors in 2020/21:
• Logistics issues caused by sanitary crisis
000 tonnes nutrients
-228
3 165
Positive factors in 2020/21:
• Higher crop prices and improved fertilizer affordability
• Improved weather in key countries
• Increased government support to agriculture
• Advance fertilizer purchases in some countries
Source: IFA, November 2021
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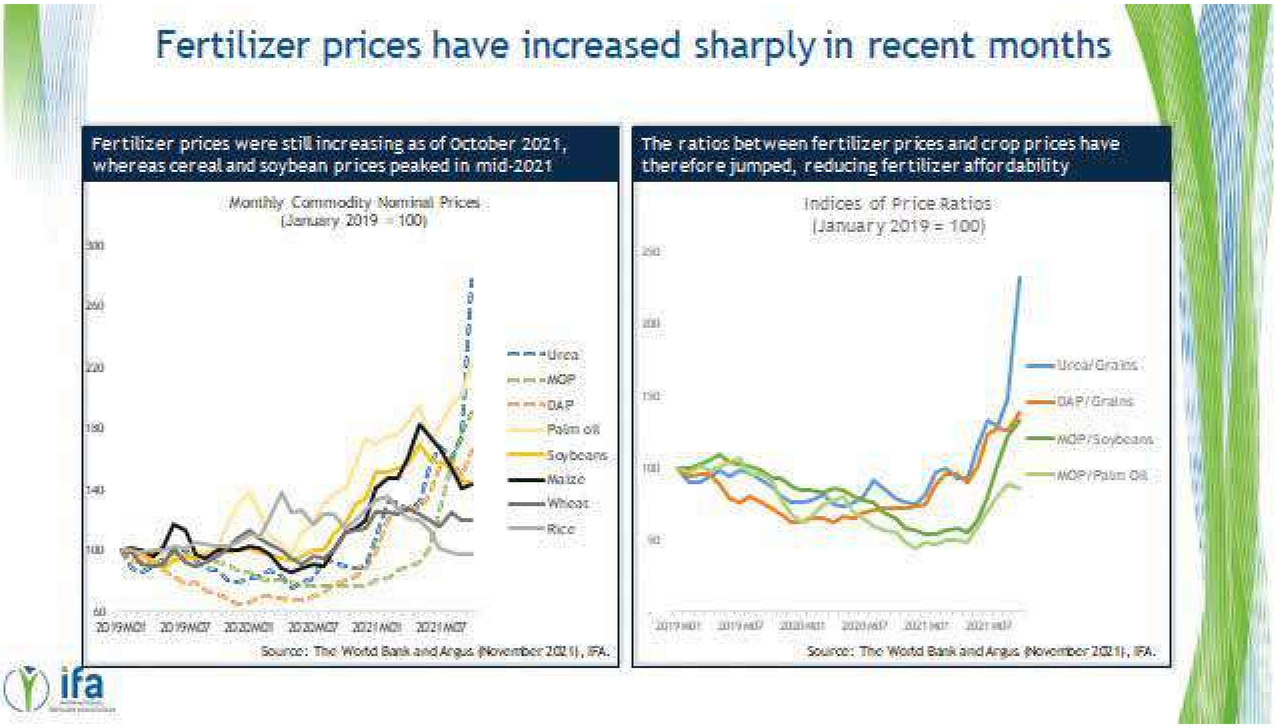
Fertilizer prices have increased sharply in recent months
Fertilizer prices were still increasing as of October 2021, whereas cereal and soybean prices peaked in mid-2021
Monthly Commodity Nominal Prices
(January 2019 = 100)
Urea
MOP
DAP
Palm oil
Soybeans
Maize
Wheat
Rice
Source: The World Bank and Argus (November 2021), IFA.
The ratios between fertilizer prices and crop prices have therefore jumped, reducing fertilizer affordability
Indices of Price Ratios
(January 2019 = 100)
Urea/Grains
DAP/Grains
MOP/Soybeans
MOP/Palm Oil
Source: The World Bank and Argus (November 2021), IFA.
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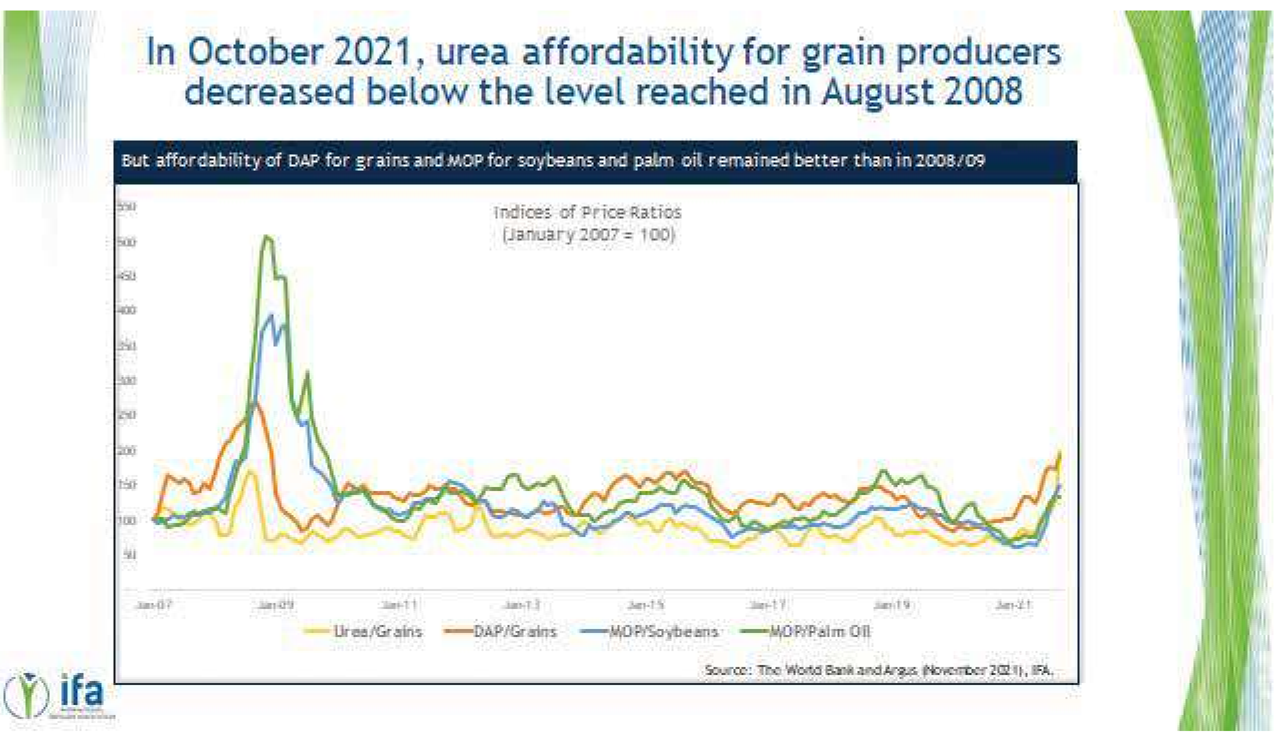
In October 2021, urea affordability for grain producers decreased below the level reached in August 2008
But affordability of DAP for grains and MOP for soybeans and palm oil remained better than in 2008/09
Indices of Price Ratios
(January 2007 = 100)
Urea/Grains
DAP/Grains
MOP/Soybeans
MOP/Palm Oil
Source: The World Bank and Argus (November 2021), IFA.
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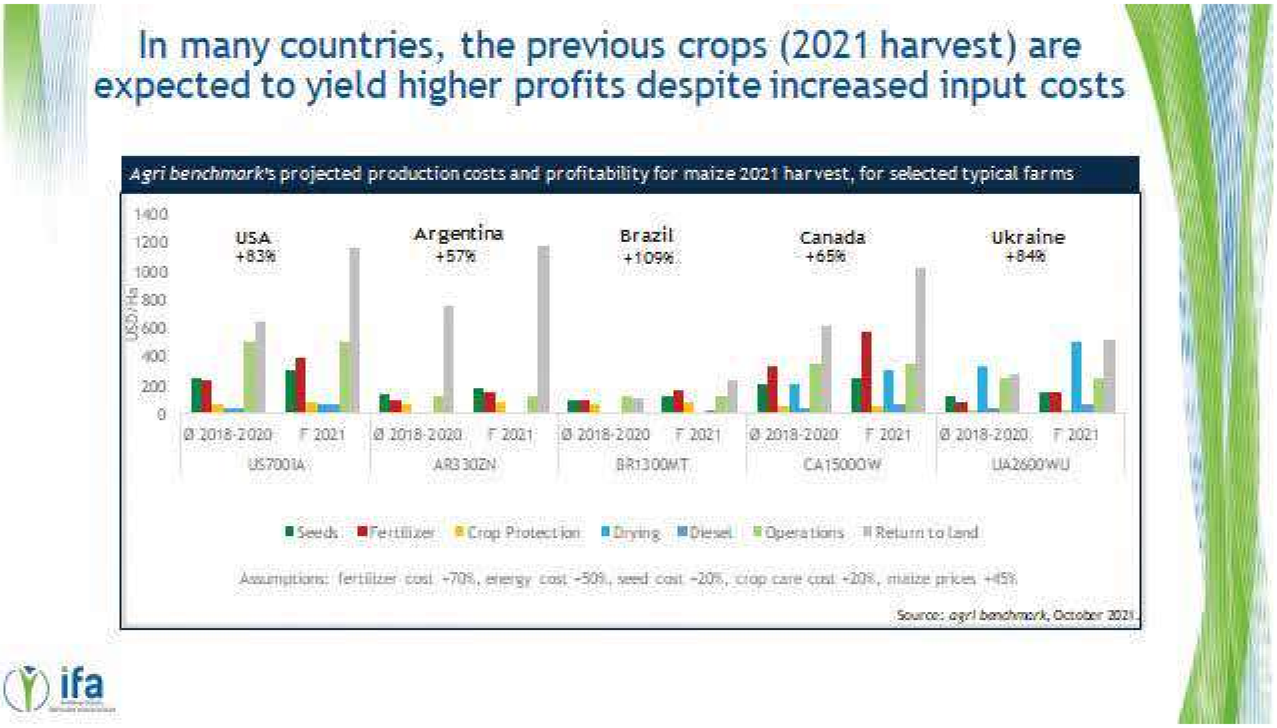
In many countries, the previous crops (2021 harvest) are expected to yield higher profits despite increased input costs
Agri benchmark's projected production costs and profitability for maize 2021 harvest, for selected typical farms
USA +83%
Argentina +57%
Brazil +109%
Canada +65%
Ukraine +84%
USD / ha
Ø 2018-2020
F 2021
US7001A
AR330ZN
BR1300MT
CA1500OW
UA2600WU
Seeds
Fertilizer
Crop Protection
Drying
Diesel
Operations
Return to land
Assumptions: fertilizer cost +70%, energy cost +50%, seed cost +20%, crop care cost +20%, maize prices +45%
Source: agri benchmark, October 2021
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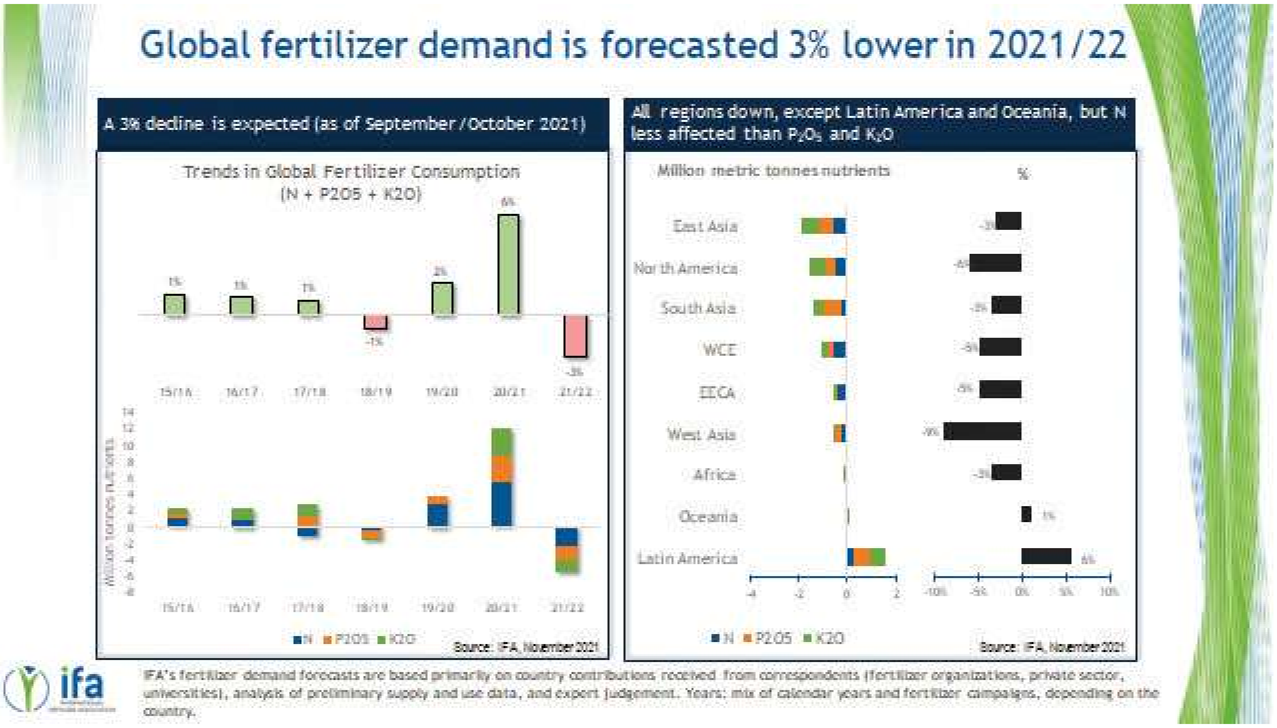
Global fertilizer demand is forecasted 3% lower in 2021/22
A 3% decline is expected (as of September/October 2021)
Trends in Global Fertilizer Consumption (N + P2O5 + K2O)
15/16
16/17
17/18
18/19
19/20
20/21
21/22
Million tonnes nutrients
N
P2O5
K2O
Source: IFA, November 2021
All regions down, except Latin America and Oceania, but N less affected than P₂O₅ and K₂O
Million metric tonnes nutrients
%
East Asia
North America
South Asia
WCE
EECA
West Asia
Africa
Oceania
Latin America
Source: IFA, November 2021
IFA's fertilizer demand forecasts are based primarily on country contributions received from correspondents (fertilizer organizations, private sector, universities), analysis of preliminary supply and use data, and expert judgement. Years: mix of calendar years and fertilizer campaigns, depending on the country.
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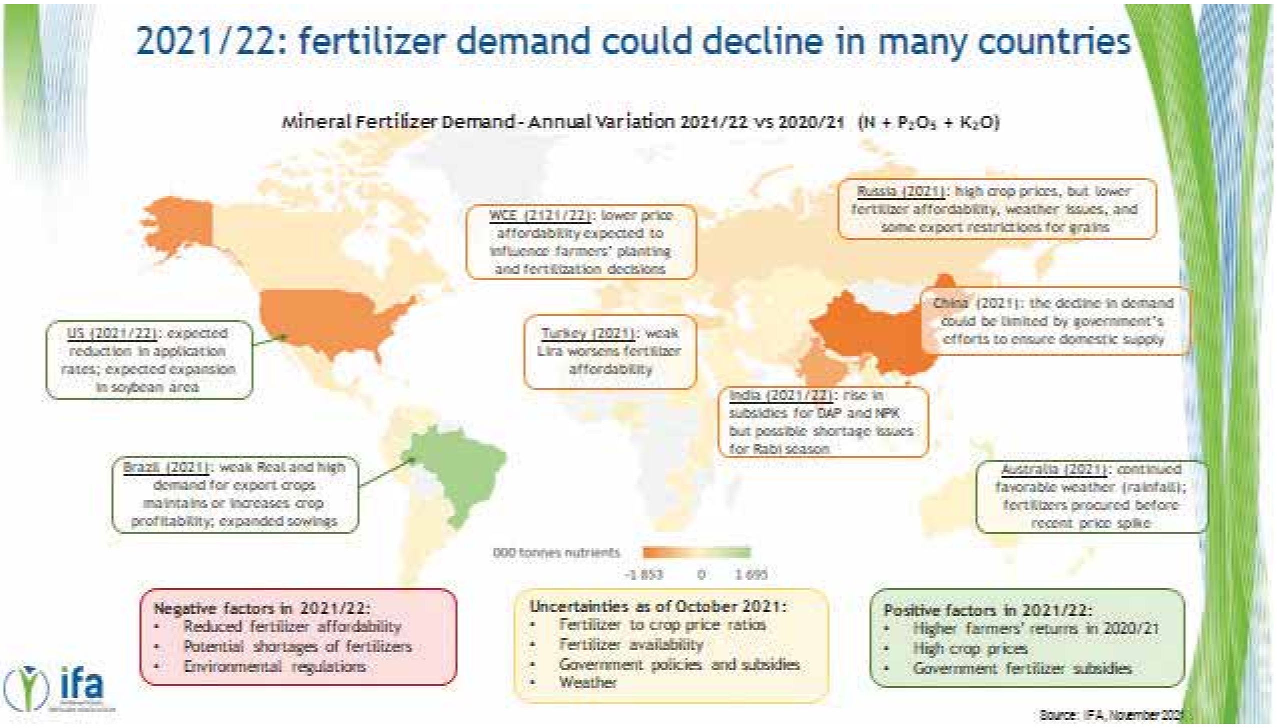
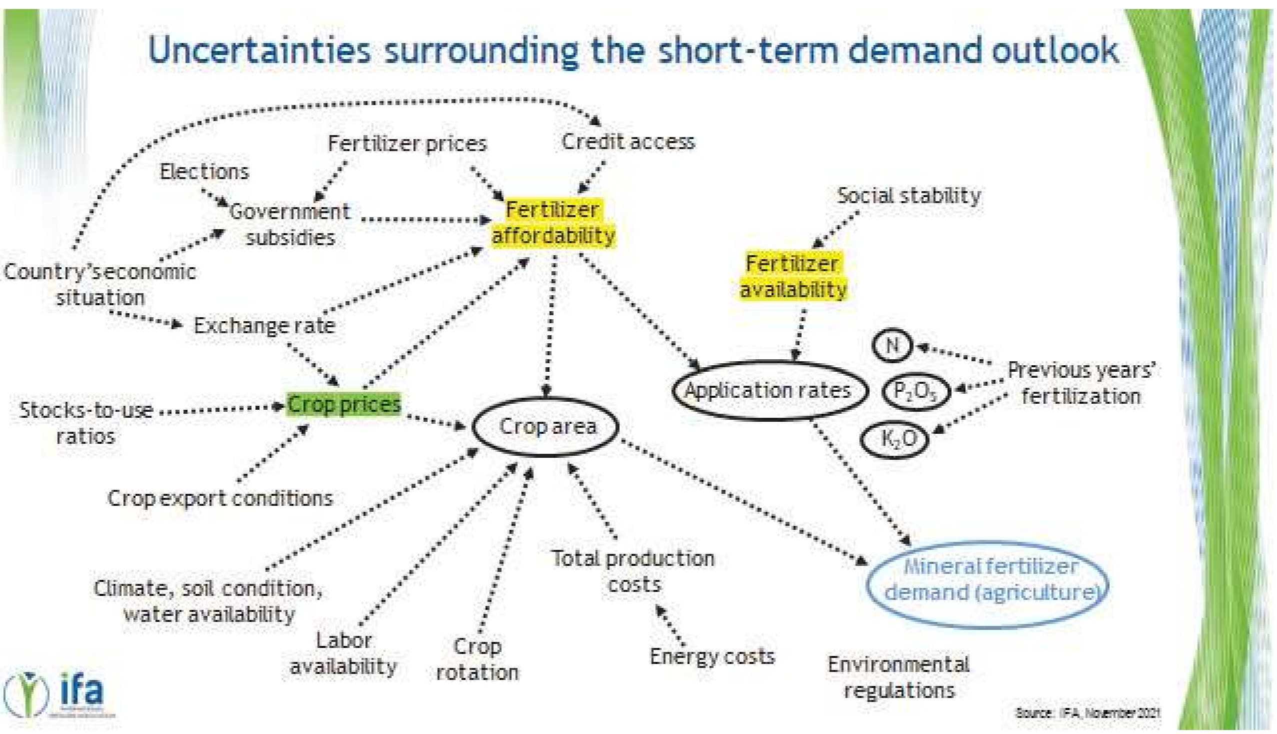

2021/22: fertilizer demand could decline in many countries
Mineral Fertilizer Demand - Annual Variation 2021/22 vs 2020/21 (N + P_2O_5 + K_2O)
WCE (2121/22): lower price affordability expected to influence farmers' planting and fertilization decisions
Russia (2021): high crop prices, but lower fertilizer affordability, weather issues, and some export restrictions for grains
US (2021/22): expected reduction in application rates; expected expansion in soybean area
Turkey (2021): weak Lira worsens fertilizer affordability
China (2021): the decline in demand could be limited by government's efforts to ensure domestic supply
India (2021/22): rise in subsidies for DAP and NPK but possible shortage issues for Rabi season
Brazil (2021): weak Real and high demand for export crops maintains or increases crop profitability; expanded sowings
Australia (2021): continued favorable weather (rainfall); fertilizers procured before recent price spike
000 tonnes nutrients
-1 853
0
1 695
Negative factors in 2021/22:
• Reduced fertilizer affordability
• Potential shortages of fertilizers
• Environmental regulations
Uncertainties as of October 2021:
• Fertilizer to crop price ratios
• Fertilizer availability
• Government policies and subsidies
• Weather
Positive factors in 2021/22:
• Higher farmers' returns in 2020/21
• High crop prices
• Government fertilizer subsidies
ifa
Source: IFA, November 2021


Uncertainties surrounding the short-term demand outlook
Fertilizer prices
Credit access
Elections
Government subsidies
Fertilizer affordability
Social stability
Fertilizer availability
Country's economic situation
Exchange rate
N
P_2O_5
K_2O
Previous years' fertilization
Application rates
Stocks-to-use ratios
Crop prices
Crop area
Crop export conditions
Climate, soil condition, water availability
Labor availability
Crop rotation
Total production costs
Energy costs
Mineral fertilizer demand (agriculture)
Environmental regulations
ifa
Source: IFA, November 2021


A quick recap on 2020 - an exceptional year
Ammonia production, Mt
Phosphoric acid production Mt
Potash production Mt
Urea trade, Mt
MAP+DAP trade, Mt
Potash trade, Mt
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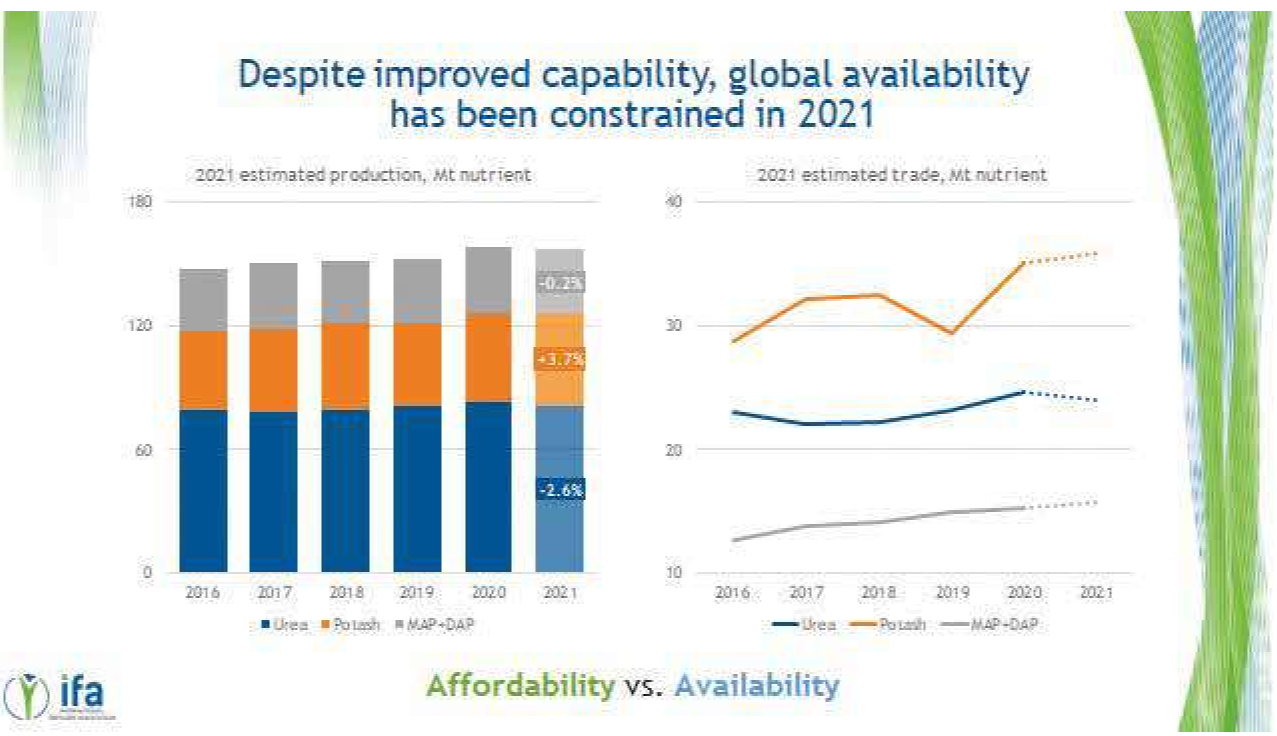
Despite improved capability, global availability has been constrained in 2021
2021 estimated production, Mt nutrient
-0.2%
+3.7%
-2.6%
Urea
Potash
MAP+DAP
2021 estimated trade, Mt nutrient
Urea
Potash
MAP+DAP
Affordability vs. Availability
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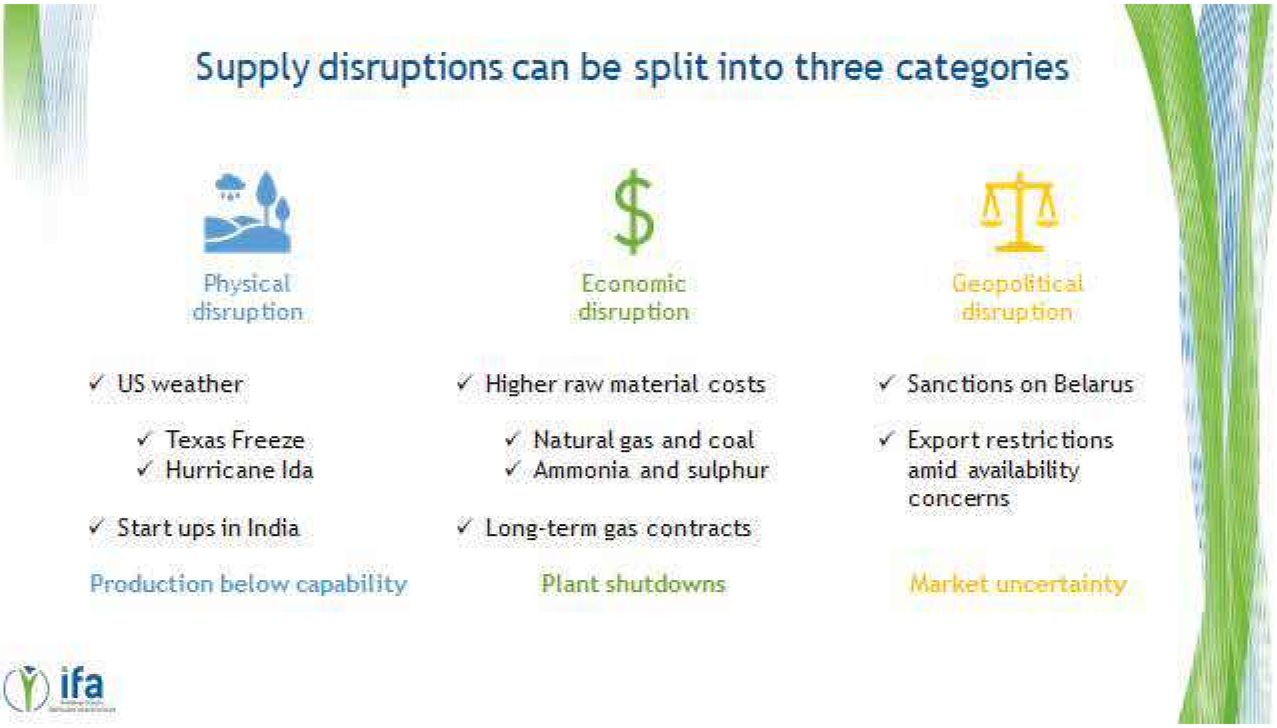
Supply disruptions can be split into three categories
Physical disruption
Economic disruption
Geopolitical disruption
✓ US weather
✓ Texas Freeze
✓ Hurricane Ida
✓ Start ups in India
Production below capability
✓ Higher raw material costs
✓ Natural gas and coal
✓ Ammonia and sulphur
✓ Long-term gas contracts
Plant shutdowns
✓ Sanctions on Belarus
✓ Export restrictions amid availability concerns
Market uncertainty
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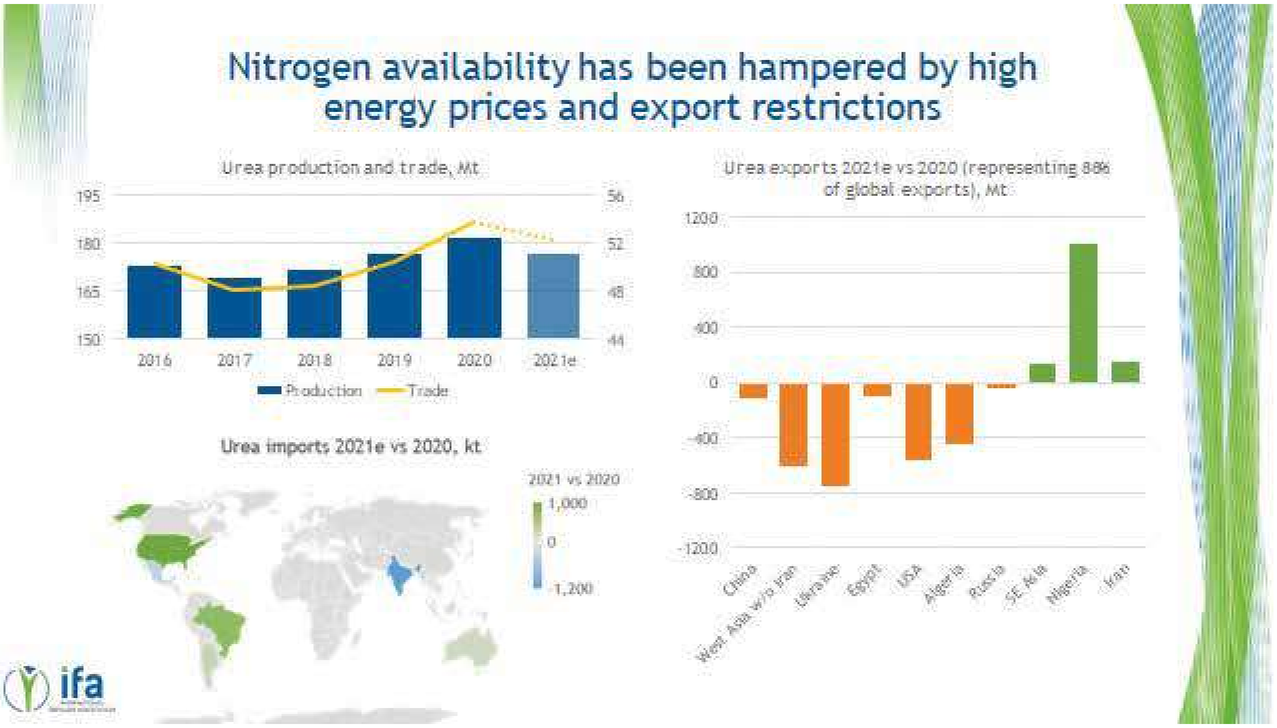
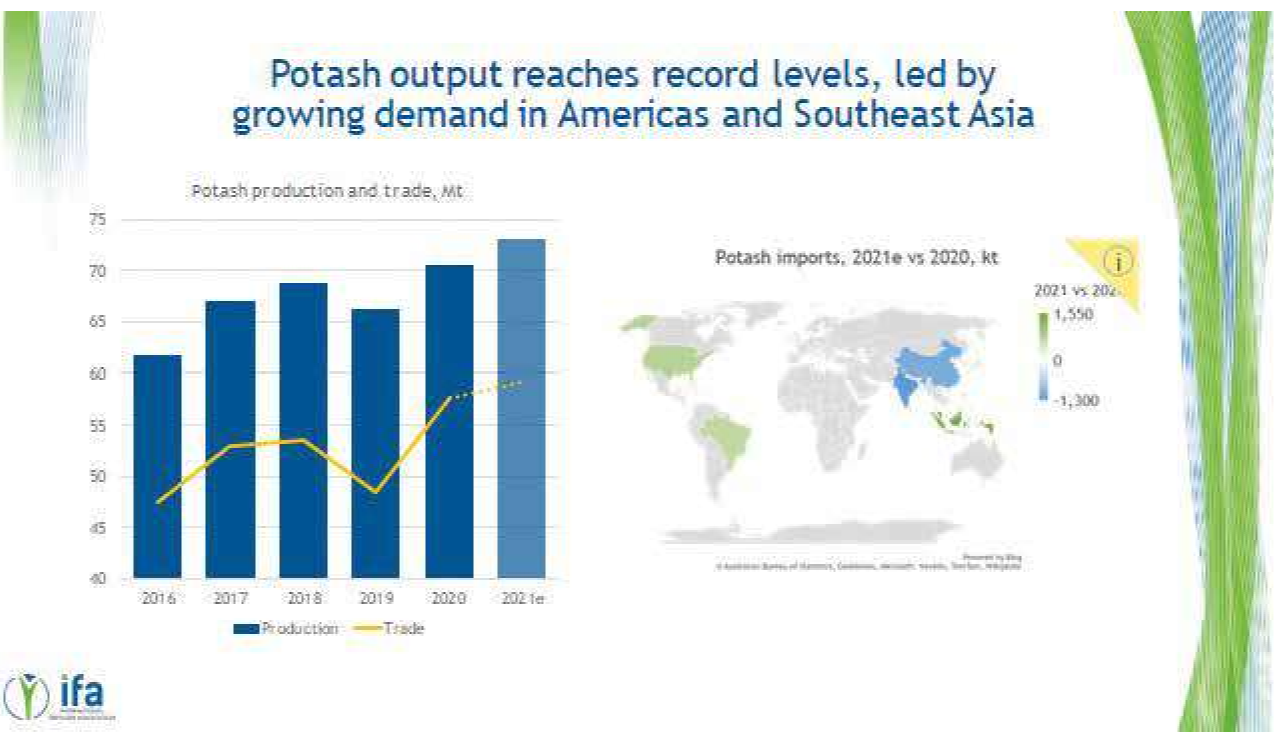
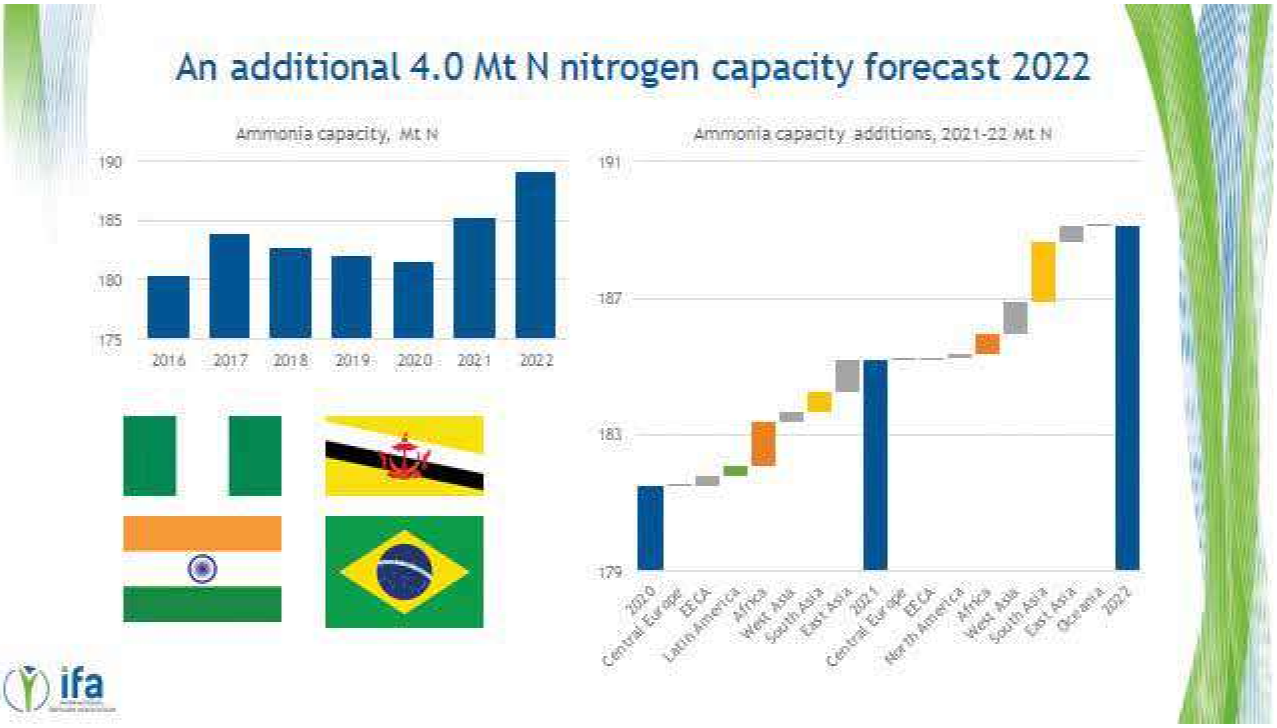
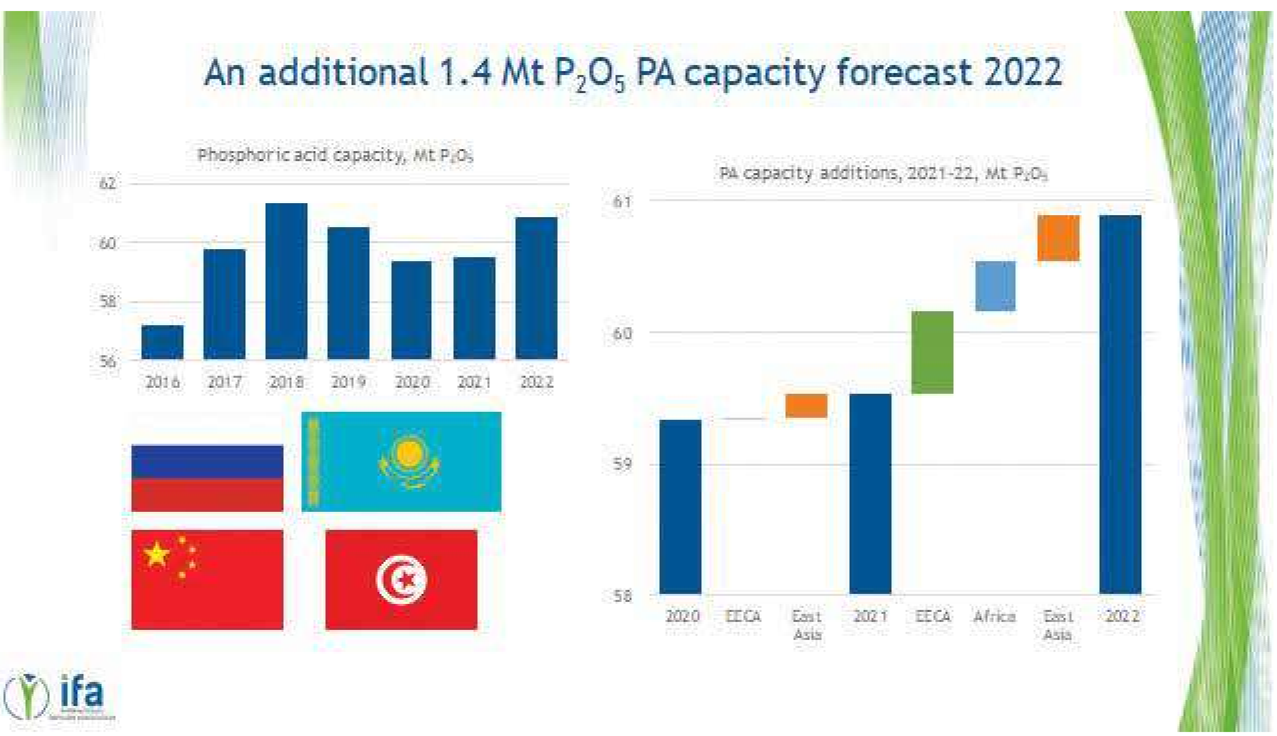

Nitrogen availability has been hampered by high energy prices and export restrictions
Urea production and trade, Mt
195
180
165
150
56
52
48
44
2016
2017
2018
2019
2020
2021e
Production
Trade
Urea imports 2021e vs 2020, kt
2021 vs 2020
1,000
0
-1,200
Urea exports 2021e vs 2020 (representing 88% of global exports), Mt
1200
800
400
0
-400
-800
-1200
China
West Asia w/o Iran
Ukraine
Egypt
USA
Algeria
Russia
SE Asia
Nigeria
Iran
ifa

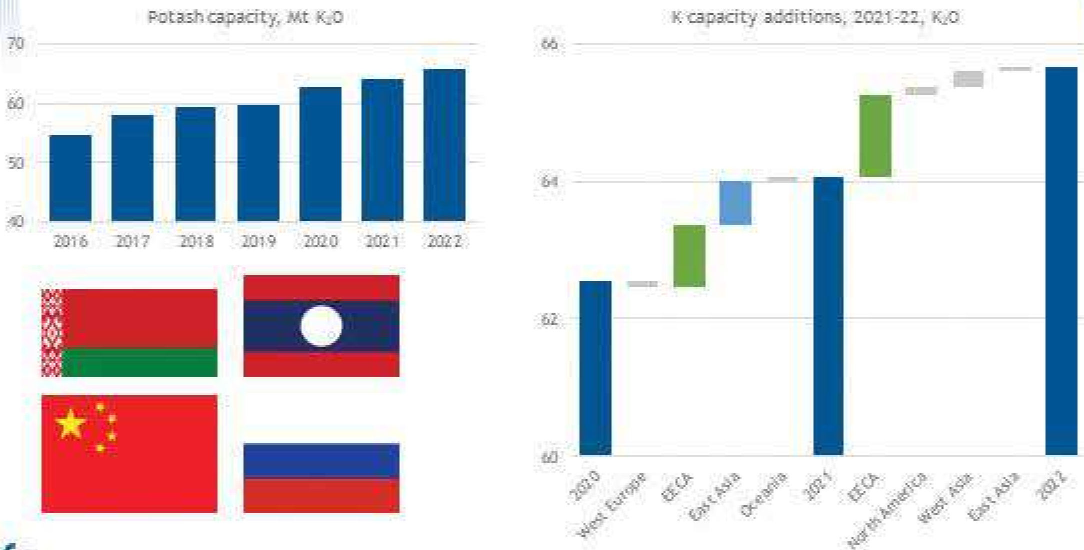

Processed phosphate trade driven by demand markets; China's role grows
DAP production and trade, Mt P2O5
17
16
15
14
8.5
8.0
7.5
7.0
2016
2017
2018
2019
2020
2021e
Production
Exports
MAP production and trade, Mt P2O5
10
7
4
1
DAP 2020
24%
DAP 2021
30%
MAP 2020
14%
MAP 2021
20%
China
Rest of World
ifa


Potash output reaches record levels, led by growing demand in Americas and Southeast Asia
Potash production and trade, Mt
75
70
65
60
55
50
45
40
2016
2017
2018
2019
2020
2021e
Production
Trade
Potash imports, 2021e vs 2020, kt
1,550
0
-1,300
ifa


An additional 4.0 Mt N nitrogen capacity forecast 2022
Ammonia capacity, Mt N
190
185
180
175
2016
2017
2018
2019
2020
2021
2022
Ammonia capacity additions, 2021-22 Mt N
191
187
183
179
2020
Central Europe
EECA
Latin America
Africa
West Asia
South Asia
East Asia
2021
Central Europe
EECA
North America
Africa
West Asia
South Asia
East Asia
Oceania
2022


An additional 1.4 Mt P_2O_5 PA capacity forecast 2022
Phosphoric acid capacity, Mt P_2O_5
62
60
58
56
2016
2017
2018
2019
2020
2021
2022
PA capacity additions, 2021-22, Mt P_2O_5
61
60
59
58
2020
EECA
East Asia
2021
EECA
Africa
East Asia
2022

An additional 1.6 Mt K_2O potash capacity forecast 2022



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Wrap up

- Survey feedback:
  - High energy prices
  - High crop prices
  - Carbon pressure
  - *"Uncertainty is the only certainty!"*
- Inflation and economic growth uncertainties
- 2022 will be dictated by affordability and availability

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International Price Trends of Fertilizers and Fertilizer Raw Materials

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Global fertilizer markets are facing perfect storm of external shocks, from Chinese export restrictions to high gas costs restricting urea production, resulting in substantial hikes in prices for most fertilizers and raw materials. This paper examines the reasons behind the price hikes and what we can expect in terms of price direction through to the first half of 2022. It concludes that prices look set to remain firm on tight supply and little relief in raw material costs. Particular attention is paid to the outlook for the Indian fertilizer market situation.

Nitrogen

The market outlook is firm for three fundamental reasons. Firstly, high gas prices will squeeze marginal nitrogen supply in Europe. This has led to an increased demand for African urea, prices for which have risen at the time of writing (early November) to $900/tonne FOB Egypt (**Figure 1**), on a par notionally with prices seen in the price boom of 2007-08 before the global financial crash. However, this comparison does not account for inflation.

Secondly, Indian domestic production has lagged 2020 levels throughout this year, despite the start-up of the Ramagundam plant which continues to run well below nameplate capacity. Overall Indian output has been hindered by maintenance issues but also the effects of Covid-19 related manpower issues and access to finance issues and is down nearly 4 per cent year on year (April to September) at 11.9 million tonnes. Imports are trailing 2020 for the same period by nearly 13 per cent at 3.97 million tonnes.

On paper, India still needs around 3.5 million tonne of urea in the fourth quarter of 2021, of which 740,000 tonnes was awarded under the RCF tender. As we go to press, RCF's 1 November tender has seen 465,000 tonne of offers accepted against total offered tonnage of just 510,000 tonne. With China effectively out of the running (see below), India will need to cover from the Middle East, Indonesia, FSU and North Africa.

In an attempt to ensure security of supply, RCF unusually specified west coast delivery only and just from producers thus avoiding trader speculation or lowballing. But some see this tactic as backfiring given the relatively low volume secured. Further, tenders are inevitable and indeed RCF issued a new tender closing 17 November for the supply of 1 million tonne of urea over 3-5 months beginning in 2022. This constant demand through the next three months will keep prices firm.

Figure 1. Egypt granular urea FOB prices 2007-2021 (source: Argus)

Trade balance						'000t
	Nov	Dec	Jan	1Q22	2Q22	3Q22
Export total	993	3,870	4,003	12,348	12,615	14,360
Import total	1,146	3,999	4,370	12,680	12,071	13,241
West of Suez balance	-39	-136	-558	-1,741	-297	-30
East of Suez balance	-114	7	191	1,409	841	1,149
Global balance	**-153**	**-129**	**-367**	**-332**	**544**	**1,119**

Thirdly, China has introduced restrictions on urea exports in a bid to ensure domestic supply, keep local prices stable and at a time when coal and natural gas supply is both tight and expensive. While there is no formal guidance from the Chinese government, mid-October saw at least four ports tell suppliers not to make new fertilizer shipments to them. Another port told shippers to report everything to the National Development and Reform Commission (NDRC) before loading.

The upshot has been a near paralysis of exports out of China since mid-October. At least three export cargoes, including two for India, have faced difficulties because of the new customs clearance regime.

Until recently the prevailing wisdom was that some demand destruction was inevitable for the simple reason that, unlike in 2007-08 when commodity prices kept pace with fertilizer prices, this time around the current urea bull run had left crop prices behind. However, corn prices have recently risen to around $590/tonne.

The gas supply shortage is not expected to ease in the near term as the northern hemisphere gas markets approach their peak winter consumption months. Unless Europe and China have mild winters, substantial gas demand remains which will test global gas supply infrastructures. However, EU gas prices have begun to retreat towards $20/million tonne Btu from $30/million tonne Btu. A cold winter could quickly see this price trend reverse however. Gas supply from Russia remains uncertain.

The outlook for prices over the rest of 2021 is firm into the first quarter'22 at which point Indian and Brazilian demand will fall away. Buyers also want to avoid high-priced inventory and will buy on an as-needed basis. Urea trend balance 2021-22 is given in **Table 1**.

Phosphates

DAP

As with urea, the outlook for the phosphates market is also firm basis export restrictions out of China. Some demand destruction in the European arena is expected as high prices render phosphates unaffordable. Some supply pressure will ease in the first quarter as Indian and Pakistan markets enter their lull seasons.

Full clarity on China's export policy has yet to emerge but we do know that exports are being restricted as producers have agreed with top economic planning agency NDRC. Some Chinese port authorities have halted fresh deliveries and as of 15 October, the General Administration of Customs started inspections of fertilizer export cargoes. The result is that Chinese suppliers have largely withdrawn from the market and it is likely export activity will be limited during the first half of next year, particularly in the first quarter due to the domestic spring application season and the lunar new year holiday. As we go to press, reports are emerging that small cargoes of DAP may be allowed for customs clearance. But clarity has yet to emerge and nothing has been cleared since the middle of October which has resulted in Australia turning to Morocco and Russia to augment import supply.

The Indian subcontinent will undoubtedly be hardest hit as a result of the Chinese export restrictions, as China and Saudi Arabia traditionally dominate the Indian DAP import market. Indian DAP prices had already been on a steep upwards curve since the beginning of 2021 (**Figure 2**) and have accelerated by around $100/tonne in a week at the end of October to reach $780/tonne CFR, the highest level since our weekly price assessment began. As we go to press, Jordanian DAP has been sold at $810/tonne CFR with the mid/high-$790s/tonne CFR also trading (**Figure 2**). The main concern for India is the level of DAP stocks, estimated at 1.5 million tonne, down from 5 million tonne at the end of September last year.

To ease the burden, India's top economic committee did sign off on cash injections for DAP fertilizer subsidies equating to $116/tonne covering the October to March 2022 period. It comes with government calls for importers to secure 1.3 million tonne of DAP for November arrival as well a call for domestic producers to lift production as supply rabi concerns persist. But CFR prices will remain firm, supply restrictions from China will persist and

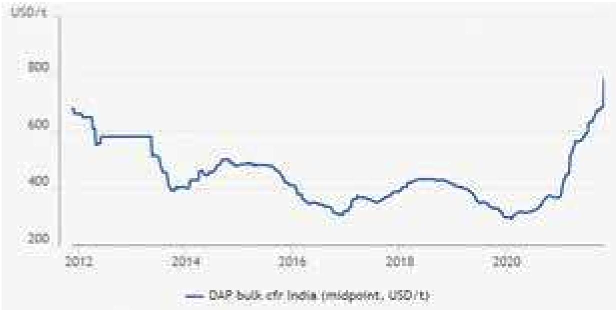

Figure 2. India DAP CFR midpoint 2011 2020 (source: Argus Direct)

October shipments are already being delayed into November. The subsidy boost is considered by many to be too little, too late. Moreover, as we go to press, OCP had just settled fourth-quarter phosphoric acid contracts with its joint-venture partners at $1,330/tonne P_2O_5 CFR, up by $170/tonne P_2O_5 on the third quarter.

Our medium term forecast estimates that India will consume 9.5 million tonnes in 2021, slightly below 2020 levels, mainly on account of potential fertilizer supply shortages limiting farmer access to DAP. Lower monsoon rainfall and high seaborne prices for ammonia, acid and DAP have cut availability.

Overall, according to our latest monthly phosphates outlook, the DAP market looks in significant deficit (**Figure 3**) through to year end which will keep prices firm. This is mainly on account of lower Chinese availability in the fourth quarter. 1Q 2022 will be relatively balanced as it is low season east of Suez and in Europe. We still expect some DAP import purchases on the Indian subcontinent to top up stocks as inventories are further eroded. Pakistan on paper has just about enough DAP to see it through Rabi but will most likely pick off cargoes. The second quarter should see a seasonal pick up in buying but

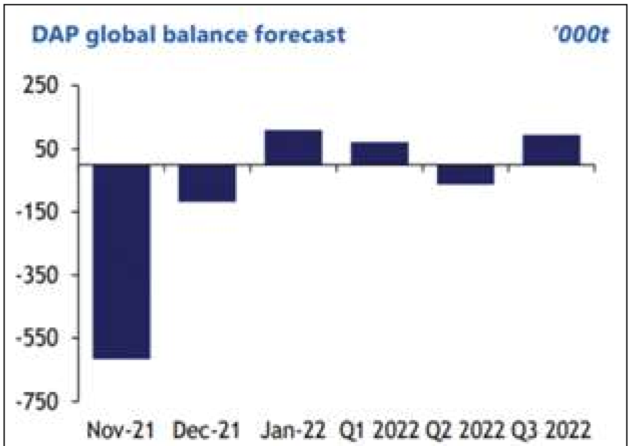

Figure 3. Global DAP balance (source: Argus Consulting)

may be quieter than normal as buyers wait for China to return to the supply side.

Potash

The overall outlook is flat to rising. This is because the global MOP market remains tight and will continue to be so, driving up prices for the rest of 2021. There are supply-side constraints as most producers have little inventory or the means to ramp extra production up quickly.

Prices look firmer east of Suez as new tenders are closed at higher prices, and crop prices in southeast Asia support the higher values. But generally there is discomfort over higher MOP prices, particularly in Europe as farmers choose essential nitrogen products over P and K. West of Suez, the main Brazilian season is coming to a close and the US is generally well stocked for the fourth quarter.

In the next 3-6 months, increased production in Canada may provide some supply side relief to a tight market, but possible disruption to Belaruskali supplies owing to US sanctions that are due to come into force on 8 December (and originally directed by the US Department of Treasury on 9 August).

The expected loss of Belarusian imports by year end has sustained a bullish US market despite estimates that buyers have secured most of their needs for quarter four. Increased supply from domestic potash producers could fill some of the potential supply gap from Belarus by the middle of next year, but the extent of potential export reductions is unclear, and will remain so until December. But a strong application season in the Corn Belt in the US could deplete stocks and boost demand for winter fill tonnage. BPC typically accounts for one-third of offshore US MOP imports each year.

The knock-on effect on global markets may be profound. On paper, the majority of BPC's potash exports (particularly MOP) are not affected by EU and UK sanctions on Belarus. And transit through the Lithuanian port of Klaipeda remains an option provided necessary financing can be secured. As EU officials have noted, the bloc's ban is relatively mild. However, Lithuania's transport and communications Minister Marius Skuodis haaid said in late August that US sanctions would lead to a cessation of Belarusian fertilizer exports through Lithuania — an EU member — from December. Although the US sanctions do not affect Lithuanian companies directly, the role of banks is essential in ensuring operations. Lithuanian banks have said they will cease operations with Belarusian companies subject to the US sanctions. Moreover, there is an "extraterritorial effect" of the US decision because of the importance of US financial institutions and the US dollar in the payment processes that underpin global trade.

The European Commission said it is "in principle" against the extraterritorial effect of the US sanctions. While sanctions against Belarus have been also coordinated with the US and the UK, EU firms are bound to comply with the EU's own sanctions. The commission is currently reviewing legislation — the EU's 1996 Blocking Statute — to make Europe "more resilient" to extraterritorial application of sanctions by third countries, notably US measures.

What is the effect on the Indian market? In one sense, the loss of the US market to BPC could see it turn its attention to the Indian market where supply is lagging. However, current contract prices have discouraged producers from selling typical volumes into the region. As a result, imports between April and September 2021 are down by 48 per cent year on year. BPC, ICL and APC are the only major suppliers actively shipping significant volumes under contract. Canadian producers, in particular, have withdrawn from the market. The problem for Indian importers has been the divergence between the yearly contract price and the spot price. In the latest buy tender in September, RCF received offers at $445/tonne CFR with 180 days' credit. This compares to the most recent Indian contract price of $280/tonne CFR agreed in April 2021. The upshot is that India will need to renegotiate a revised contract price for an unprecedented second time in the contractual year, most likely above $450/tonne CFR.

Ammonia

Gas prices will continue to determine the narrative in the west until consumer demand eases. But production losses in Europe and strong Moroccan and US demand means prices will remain firm. East of Suez, consumers are more comfortable and happy to await the arrival of Ma'aden tonnage now that the producer has increased availability and lowered phosphate production. Efforts by the producer are now centered on catching up on previous contract commitments to customers in India and east Asia and, therefore, spot demand from consumers in the region is thin and prices have been pressured.

Over the first quarter of 2022 our supply/demand balance shows a 70,000 tonne deficit as seasonal demand outweighs new capacity. New capacity coming on line sees the second quarter move into surplus of 378,000 tonne (**Figure 4**). Our expectations of second-quarter 2022 sees prices at $430-490/tonne FOB Pivdenny and $455-510/tonne FOB Middle East. The market moves again into deficit in the third quarter as demand ramps up and absorbs new capacity coming on line.

For the Indian market, October saw prices falling back on the back of improved supply optionality from Saudi Arabia and Qatar. However, as October ended prices are facing upwards pressure again as prices started to rise in surrounding FOB markets. Prices rose to $620-655/tonne CFR at the end of October. Most shipments into Indian ports are on a contract basis but any fresh spot inquiries are likely to be met at a significant premium to last done business, with Middle East ammonia trading at $715/tonne FOB this week.

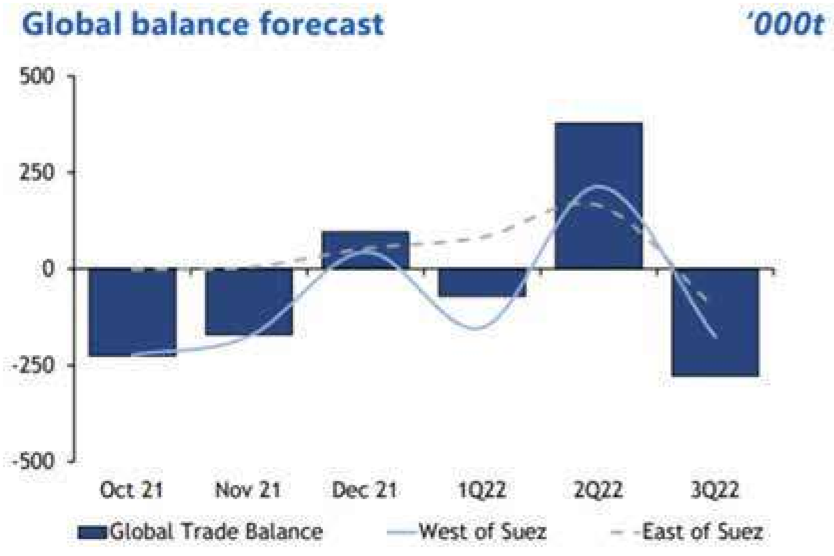

Figure 4. Global ammonia trade balance October 2021 to 3Q 2022 (source; Argus consulting)

Sulphur

Sulphur prices will remain firm going into the rest of the fourth quarter as the phosphates market continues its rally following China's introduction of restrictions on exports. Moreover, supply is tight despite plentiful supply as this is being absorbed by high demand. China's government has begun enforcing restrictions on energy consumption and intensity across several industries to help achieve Beijing's 2060 carbon neutrality targets. Restricted access to crude import quotas for refineries are preventing oil-based sulphur production from reaching expected levels. The Chinese fertilizer sector is also feeling the impact with restrictions placed on DAP and MAP exports as well as urea. This will push global prices for N and P up as supply tightens, underpinning the firm sulphur market.

This is particular evident in India, where sulphur prices are reaching record highs. Demand from phosphate producers remains strong as the country struggles with elevated DAP import prices. Demand is expected to grow as the government is encouraging replenishment of sulphur stocks to supply increased domestic fertilizer production in the wake of the Chinese clampdown on exports. Prices at the time of writing are in the mid/high-\$270s/tonne CFR. Delhi's decision to give the fertilizer subsidy a boost still implies domestic production is the most favourable DAP margins, which will continue to support sulphur demand.

On the supply side, state-owned refiners have increased refinery runs in October following an anticipated increase in fuel demand.

Middle East supply is tight due to stronger than usual demand and spot prices have risen with 4Q contracts settling at \$175-180/tonne FOB. Monthly contract prices from the Middle East were later announced in a \$226-230/tonne FOB range for November following further firming. Over the medium term (3-6 months) global prices will still remain relatively high but softening will eventually become evident as additional Middle East supply comes on stream. This includes Kuwait's new 615,000 b/d al-Zour refinery and the \$16bn Clean Fuels Project. ■

SESSION - II

MEETING CHALLENGES IN AGRICULTURE

Chairman : **Dr. S.K. Malhotra**
Agriculture Commissioner
Department of Agriculture,
Cooperation & Farmers Welfare
Ministry of Agriculture & Farmers
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Making Indian Agriculture Climate Smart

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Over the past few decades, the man-induced changes in the climate have intensified and the frequency of climatic extremes increased resulting in increased risks to agricultural production and food security. Agriculture sector causes climate change with emission of greenhouse gases (GHGs) and also suffers from the consequences. Indian agriculture is highly prone to the risks due to climate change because 2/3rd of the agricultural land in India is rainfed. Climate smart agriculture is a viable proposition for addressing the emerging challenges of climate change. Strategies such as cultivars tolerant to heat and moisture stresses, modifying crop management practices, improving water management, adopting new farm techniques (conservation agriculture, improving pest management), better weather forecasts and crop insurance can minimize the risks of climate change. Mitigation of GHG emission from agriculture can be achieved by changing land-use management and enhancing input-use efficiency. Concerted efforts are required for mitigation and adaptation to reduce the vulnerability of Indian agriculture to the adverse impacts of climate change, making it more climate-smart to ensure food, nutrition and livelihood security in the short- and long-term.

Introduction

The debate on whether the climate is changing or not, has been settled. It is changing and for real with substantial negative impacts. The Inter-Governmental Panel on Climate Change (IPCC) in its 6th Assessment Report released on August 9, 2021 observed that climate change is widespread, rapid and intensifying. The concerns currently getting raised are what the magnitude of such impacts could be, in which location and how to deal with them. The concerns are very pertinent as climate is the most important determinant of agricultural productivity globally and India, in particular. If climate goes wrong, Indian agriculture and in turn its economy cannot go right. About 50% of the total workforce is engaged in agricultural and allied activities accounting for 17% share in India's gross domestic product (GDP). Indian farming, though one of the oldest systems; is diverse, heterogeneous, unorganized and probably the riskiest with more than 50% area being rainfed and exposed to multiple biotic and abiotic stresses. Changing climate will make agriculture, which is already vulnerable, more risky and unsustainable.

Accomplishments and Challenges of Indian Agriculture

Indian agriculture with the net sown area of about 140 million ha (Mha) has made tremendous progress over the years. India was a food scarce country till 1950, transformed itself into a food shortage (1950-1970) to food sufficient (1970-2010) to a food surplus (2010 onwards) country. It has witnessed various agri-revolutions including Green (crop), White (milk), Blue (fish), Yellow (oil), Golden (honey & horticulture), Silver (egg), Brown (coffee) and Grey (wool) Revolutions. Food grain production in the current year (2020-21) has touched an all-time high of about 308 million tonnes (Mt). New records have been achieved in the production of all crops including rice, wheat, nutri/coarse cereals, maize and pulses. India also harvested the most outstanding production of horticultural crops, livestock, fisheries and aquaculture. Productions of various commodities in 2020-21 have increased by 6-50 times compared to those of 1950-51 whereas area under cultivation has increased only 1.3 times during the period. Indian agriculture not only made the country self-sufficient in food but also enabled it to export commodities worth Rs.1.30 lakh crores during 2018-19 (MoAFW, 2020). Moreover, production variability of Indian agriculture has reduced, though climatic variability increased over the years. In COVID-19 pandemic situation also, agriculture sector performed well, probably the best among all the sectors of the economy. There are also indications that the GHG emission intensity is reducing and fertilizer, particularly nitrogen use efficiency is no more decreasing, instead it has flattened and improving in recent years (Pathak et al., 2019; MOEFCC, 2021).

Along with these accomplishments, newer challenges have cropped up to the forefront in recent years. Population is expected to rise to more than 1.69 billion by 2050 before approaching stabilization, food demand is likely to rise to 400 Mt. Accordingly, an agricultural growth rate of 4% per annum is needed, not only to meet the increasing demand of food, feed, fibre and fodder but also to achieve 8-9% GDP growth to reduce poverty and boost the economic growth. Although agricultural production is increasing, yet the economic contribution of agriculture to India's GDP has been declining steadily from 57% in the 1950s to about 17% in 2018-19. In addition, despite the progress made by India towards achieving the various Sustainable Development Goals (SDGs), significant gaps remain to overcome poverty, hunger and malnutrition. The ever-growing population and income have raised the demand for food but the resource base (soil, water, air) responsible for increasing the production has been shrinking. Profitability has been adversely affected by increasing cost of cultivation. Agriculture, therefore, no longer remains an attractive choice. A recent study shows that more than 60% farmers are more than 50 years of age and about 40% of the farmers want to leave agriculture, provided an alternative occupation is available. Moreover, the productivity growth rate for many crops has become stagnant. Indian agriculture is unsustainable due to low and volatile wages, degraded natural resource base, rising labour and energy shortages, and the threats of climate change. Poor and small-holder farmers, constituting more than 85% of Indian farmers, are the most vulnerable to these changes. Indian agriculture, therefore, faces twin challenges of increasing productivity and profitability on one hand and making it climate-resilient on the other.

Vulnerability of Indian Agriculture to Climate Change

India is considered to be one of the most vulnerable regions to witness climatic changes at a large scale. Atmospheric temperature, which has already risen by about 1 °C, is rising consistently. Recent observations show that minimum temperature is rising more than maximum temperature; temperature rise is more in northern than in southern parts of the country and it is becoming more variable during *rabi* than *kharif* season. The amount, intensity, variability and extreme events of rainfall (unseasonal rain, drought and flood) are rising while the duration of rainfall is reducing (IPCC, 2019). Though the impacts of climate change will vary from place to place, it is projected that yield of major crops would decline by 3-18% by 2040 under representative concentration pathway (RCP) 4.5 scenario (Naresh Kumar et al., 2020). Area for suitability of growing rainfed rice to decline by 15-40%; coconut plantations to gain in western coast but lose in the eastern region; apple belt to shift to higher elevations (1250 to 2500 msl); Assam tea and Arabica coffee to lose yield; protein content in wheat to reduce by 1%, and Zn and Fe content to reduce in many food grains. Milk production from livestock may decline by 15 Mt in 2050 and quality of milk may also reduce. The cross breeds, however, will be affected more than the indigenous breeds. Poultry is to face heat stress, causing a reduction in meat and egg yield. There could be changes in sea surface temperature, precipitation, sea-water acidification, sea surface salinity, and oxygen deficiency affecting the growth of zoo- and phyto-plankton and fisheries production negatively. Altered abundance, distribution, breeding and migration of marine fish species are also projected.

In spite of all the adverse effects, there could be some positive impacts of climate change. Increased CO_2 level will have beneficial effects on the yield of crops. More rain, particularly in water-deficit areas and increased temperature in cool, temperate regions may have congenial temperature for crop growth and reduce cold injury. Increased breeding cycles and higher growth rates may also benefit freshwater fishes. The net impacts on climate change on Indian agriculture, however will be negative. With medium-term (2010-2039) climate change is predicted to reduce yields by 4.5 to 9.0%, depending on the magnitude and distribution of warming. Since agriculture accounts for approximately 16% of India's GDP, an adverse production effect of 4.5-9.9% means the cost of climate change is about 1.5% of GDP per year (Naresh Kumar et al., 2020; Aggarwal et al., 2021).

Climate Smart Agriculture

To address the emerging challenges and harness a few benefits of climate change, Indian agriculture needs to be climate smart. Climate smart agriculture (CSA) is defined as 'an integrated approach for developing technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change' (FAO, 2013). There are three pillars of CSA, namely, (i) sustainably increasing agricultural productivity and incomes, (ii) adapting and building resilience to climate change, and (iii) reducing and/or removing carbon emissions. The CSA aims to improve food security, help communities to adapt climate change, and contribute to climate change mitigation by adopting appropriate practices, developing policies and mobilizing needed finances (FAO, 2013). The key dimensions of CSA refer to the system, which is water smart, weather smart, nutrient smart, energy smart, carbon smart and also knowledge smart (Bhattacharya et al. 2020).

Technologies for Climate Smart Agriculture

Technologies and policy options for climate smart agriculture have been presented in **Table 1**. To address the emerging climatic risks on Indian agriculture several adaptation and mitigation technologies have been developed (**Table 2**). For field and horticultural crops, developing varieties tolerant to multiple abiotic and biotic stresses using stress-tolerant QTLs, genes and alleles in elite cultivars is efficient way of achieving climate resilience with easy access to farmers. Crop varieties such as CR Dhan 801 and CR Dhan 802 for rice, and HD 3068 and HD 3226 for wheat and several for other crops, which are tolerant to multiple stresses *i.e*., submergence, salinity, drought, heat and pest and diseases have been developed (Aggarwal et al., 2021). The strategy of inter-specific grafting of crops has been successful for flood-tolerance in tomato where grafting of tomato plants (cv. Arka Rakshak) were done onto brinjal rootstocks (Arka Neelkanth, Mattu Gulla and Arka Keshav). Grafted tomato plants exhibited better survival and improved fruit yield over the self-grafted and un-grafted plants under flooding (Anant et al., 2015). Crop diversification focusing on promoting climate-smart, hardy crops such as millets; and more remunerative fruit crops such as dragon fruit and pomegranate in drought prone areas could be another strategy for climate resilience. New crop such as dragon fruit has got high potential to increase farmers' income, particularly in climatic stressed areas (Nangare et al., 2020).

On the water-front, India has made significant progress in conserving, storing and enhancing water

Table 1. Technologies and policy options for climate smart agriculture

1. Weather ♦ Forecasting ♦ Agro-advisory ♦ Geo-ICT delivery ♦ Eco-regional crop planning	**5. Livestock** ♦ Stress tolerant breeds ♦ Feed and shelter management· ♦ Health care ♦ Small ruminants
2. Crop ♦ Multi-stress tolerant varieties ♦ Input-efficient varieties ♦ Diversification ♦ New crops	**6. Fisheries** ♦ Composite culture ♦ Diversification ♦ Cage culture ♦ Wastewater aquaculture
3. Water ♦ Micro-irrigation ♦ Direct-seeded rice ♦ Rainwater harvesting ♦ Drainage	**7. Energy** ♦ Solar-based machine ♦ Conservation agriculture ♦ Energy plantation ♦ Protected cultivation
4. Nutrient ♦ Site-specific nutrient management ♦ Integrated nutrient management ♦ Neem-coated urea ♦ Bio-fertilizer	**8. Policy** ♦ Leveraging Government schemes for incentives ♦ Contingency plan ♦ Seed bank, custom hiring center ♦ Insurance and credit

Table 2. Strategies and technological options with their potential benefits for climate smart Indian agriculture (Source: Agrawal et al., 2021)

Strategy	Technology	Adaptation benefit	Mitigation benefit	Productivity gain	Income gain	Ease of implementation	No regret character	Small farmer friendly	Average
1. Food and horticultural crops	Multiple stress tolerant varieties	5	1	4	4	5	4	5	4. 0
	Inter-specific grafting of vegetable crops	5	1	4	4	2	3	5	3. 4
	Diversification to stress-tolerant and new crops	5	2	4	4	2	2	2	3. 0
2. Livestock and poultry	Stress-tolerant breeds	4	1	4	4	3	3	2	3. 0
	Feed and housing management	4	4	4	3	3	4	2	3. 4
	Livestock health care for emerging diseases	3	1	4	3	3	4	3	3. 0
	Small ruminants in drought-prone areas	4	3	2	2	3	2	4	2. 9
3. Fisheries	Composite and drought-escaping fish culture	4	1	4	4	4	3	3	3. 3
	Diversification of fish species	4	1	4	4	3	2	3	3. 0
	Pen/cage culture of fish	5	1	5	4	2	2	1	2. 9
	Wastewater aquaculture	3	2	3	4	2	2	2	2. 6
4. Water management	Dry direct-seeded rice	4	4	3	4	3	2	4	3. 4
	Micro-irrigation (drip, sprinkler)	5	5	4	3	3	2	2	3. 4
	Rainwater harvesting and drainage	5	3	4	3	2	3	2	3. 1
5. Energy management	Solar energy-based machineries	2	5	2	4	3	3	2	3. 0
	Zero/minimum tillage	2	3	2	4	3	3	2	2. 7
	Energy plantation	2	4	2	3	2	2	2	2. 4
	Protected cultivation and vertical farming	5	1	5	5	2	2	1	3. 0
6. Nutrient management	Site-specific nutrient management	2	3	4	4	4	4	4	3. 6
	Microbial technologies and bio-fertilizer	2	4	3	4	3	4	4	3. 4
	Integrated nutrient management	3	3	3	4	4	4	4	3. 6
	Nitrification and urease inhibitors	2	4	4	4	3	4	4	3. 6
7. Management of soil carbon	Conservation agriculture	3	4	3	4	3	3	3	3. 3
	Agro-forestry	3	5	2	3	2	2	2	2. 7
	Residue management	2	3	2	3	2	3	3	2. 6
8. Weather forecasting and services	Weather forecasting and early warning	4	1	3	3	3	3	3	2. 9
	Contingency plan for	4	1	3	3	2	4	3	2. 9
	Insurance	5	1	4	5	3	4	3	3. 6
9. Institutional arrangement	Custom-hiring centres	3	1	3	4	2	3	5	3. 0
	Seed and fodder banks	4	1	3	3	2	3	5	3. 0
	Community nursery	4	2	4	4	3	3	5	3. 6

Note: The parameters have been evaluated using rapid expert judgement on a scale of 1-5, where the lowest gain is 1, and the highest 5. Suitable climate-smart technologies were short-listed from a list of reported technologies and prioritised using multi-criteria decision analysis.

use efficiency. Pressurized, low cost and demand-driven micro-irrigation methods are promoted with substantial success. Rice is the most water-demanding crop. Technologies such as alternate wetting and drying and dry direct-seeding can reduce water consumption in rice and mitigate methane emission (Pathak et al., 2015). Efficient management of nutrients can help in increasing resilience of the production system by limiting the adverse effects of the extreme weather events such as flood and drought. Nutrient efficient varieties, soil test-based fertilizer application, customized fertilizers, enhanced efficient N fertilizers, site-specific nutrient management, real time N application, integrated nutrient management, etc. are some examples of nutrient-smart practices. Use of *neem*-coated urea, soil health card and leaf colour chart for enhancing fertilizer use efficiency have been successfully utilized in India (Pathak et al., 2015). In the changing climate scenario, microbe-based technologies for nitrogen fixation, nutrient recycling, bio-residue management and alleviation of abiotic and biotic stress will be very useful (Bhattacharya et al. 2020). Another development is conservation agriculture to reduce the carbon foot-print of the production system, improve productivity and enhance adaptability by modulating soil mositure and temperature regimes (Somasundaram et al., 2020). Such practices are followed by farmers in large scale in western Indo-Gangetic Plain. However, refinemnent and promotion with incentives are required to entend the technology in climatic stressed, dryland areas. Mechanization in agriculture with renewable energy sources such as solar-powered machineries like water pumps, sprayers and weeders are better alternatives to diesel-powered machines in India. Such machines are economical, eco-friendly *i.e*., do not release GHGs and other polluting gases (Bhattacharya et al. 2020). Information and communication technologies (ICTs) for short-term weather forecast and advisories at block level; use of mobile agromet advisory system (mAAS), rural mobile phone based (Rnet) social networking, micro-blogs, awareness programmes through gosthi, chaupal *gapshap* (conversation); installation of rain gauge at village level and rainfall visualizer at local level could greatly help in addressing climatic extremes and develop contingency plans. Sustainable insurance system needs to be developed, while the rural poor should be informed about taking advantage of these opportunities.

To ensure climate resilient livestock production, stress tolerant breeds, heat stress resilient housing, providing enough good quality feed with supplements such as vitamin C for poultry (Khan et al., 2012), improving feeding strategy and extending financial and risk mitigation services will be of beneficial. For fisheries, composite and drought-escaping fish culture could be very useful. Amur carp (modified variety of common carp) is considered to have more growth and climate resistance compared to common carp (Medhi et al., 2018). In drought-escaping fish culture, fishes are grown in smaller ponds that retain water for 2-4 months and fish species such as *Pangasius* sp., *Puntius javanicus*, *Pygocentrus mattereri* and *Oreochromis niloticus* are cultured. Diversification of fish species *i.e*., culturing brackish water fish in freshwater and low salinity tolerant freshwater fish in brackishwater has been a reality (Trvidei et al., 2015). This will provide flexibility and resilience in fish culture. Several stress-tolerant species such as *Pangasianodon hypophthalmus*, *Anabas testidienus* and *Channa straiatus* have been identified for stress conditions (Kumar et al., 2018).

It has been assessed that with the currently available technologies, the projected yield loss can be compensated and with use some additional inputs and interventions, yield can be further improved (**Figure 1**). Besides, adopting the adaptation technologies, efforts should be made to harvest the positive aspects of climate change. For example, in several places, amount of rainfall may increase. Harvesting rainwater and its proper use will benefit the water-deficit areas. Increased CO_2 level in the atmosphere will have beneficial effects on yield. In many areas increased temperature will help reducing cold injury. Cooler, temperate regions may have more congenial temperature for crop growth and yield of several crops may increase.

India's Initiatives for Climate Smart Agriculture

The country has initiated timely action to address the problems of climate change. These efforts have provided valuable inputs in terms of the regional and national level impacts of climate variability and climate change on major food grains crops, horticulture and livestock production. It has launched the National Mission for Sustainable Agriculture (NMSA), which seeks to address issues regarding sustainable agriculture, and aims at devising appropriate adaptation strategies for ensuring food security, enhanced livelihood opportunities and economic stability. Ministry of Agriculture launched the National Initiative on Climate Resilient Agriculture (NICRA) which is a flagship programme of the Indian Council of Agricultural Research (ICAR) to undertake systematic long- term research on the impacts and adaptation of Indian agriculture to climate change covering not only agronomic crops but also

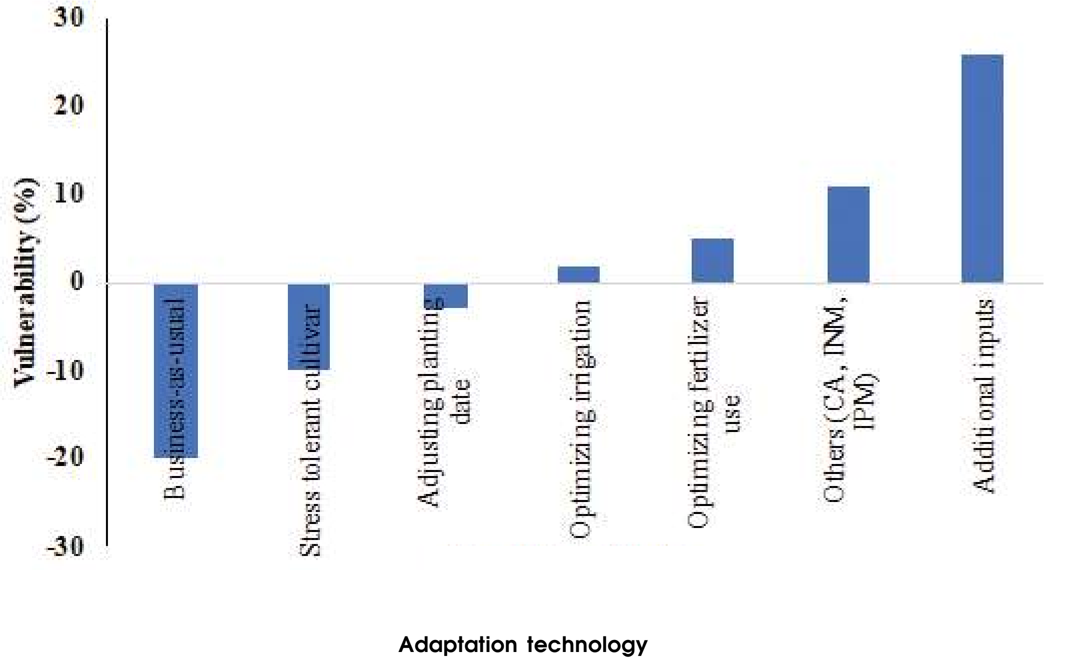

Figure 1. Benefits of adaptation technologies to compensate the vulnerability of climate change.

horticulture, natural resources, livestock and fisheries. The programme covering more than 21 central institutions and several state level agricultural universities is one of the largest projects in any developing country. It not only addresses strategic research but also demonstration of the best bet practices on farmers' fields to cope with current variability. In rainfed agriculture, several *in-situ* and *ex-situ* water conservation technologies which are being upscaled through the Integrated Watershed Management Programme (IWMP) and Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS). All major programmes such as National Food Security Mission (NFSM), Mission for Integrated Development of Horticulture (MIDH), National Mission on Sustainable Agriculture (NMSA), National Mission on Oilseed and Oil Palm (NMOOP), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Rashtriya Krishi Vikas Yojana (RKVY) and Paramparagat Krishi Vikas Yojana (PKVY) emphasize on implementation of climate-resilient technologies in farmers' fields. A dedicated component namely On-Farm Water Management (OFWM) under the NMSA is operational to promote water management in farmers' field focusing on enhancing on-farm water use efficiency. National Agroforestry Policy (NAP) has been formulated to encourage and expand tree plantation in complementarity and integrated manner with crops and livestock to improve productivity, employment, income and livelihoods of rural households, especially the small-holder farmers. National Livestock Mission (NLM) has been initiated for increasing livestock production while protecting the environment, preserving animal bio-diversity, ensuring bio-security and farmers' livelihood. A major initiative has also been taken in respect of fisheries with the launch of National Fisheries Development Board (NFDB) to achieve sustainable production system. In addition, the following schemes of Government of India have got considerable significance to climate change adaptation and mitigation.

i. Kisan Credit Card (KCC) Scheme
ii. Pashu Kisan Credit Card Scheme
iii. Pradhan Mantri Kisan Maandhan Yojana
iv. National Agriculture Market (e-NAM)
v. Livestock Insurance Scheme
vi. Soil Health Card Scheme
vii. Pradhan Mantri Annadata Aay Sanrakshan Yojana (PM-AASHA)
viii. Formation and Promotion of 10,000 Farmer Producer Organizations (FPOs)
ix. Agriculture Infrastructure Fund (AIF)
x. Rainfed Area Development and Climate Change
xi. National Project on Agro-Forestry

xii. National Mission on Horticulture

xiii. National Project on Organic Farming

xiv. Micro Irrigation Fund scheme

xv. Gramin Bhandaran Yojna

xvi. Pradhan Mantri Kisan Samman Nidhi (PM-KISAN)

xvii. Pradhan Mantri Urja Suraksha Evam Utthaan Mahabhiyaan (PM-KUSUM)

xviii. National Diary Development Plan

xix. Rashtriya Gokul Mission

xx. National Mission on Edible Oils-Oil Palm

Conclusion

Agriculture causes climate change and also suffers from the consequences. Adaptation and mitigation options are available to compensate the loss and get a stable production. Most of these are no-regret options and linked to achieving the SDGs. Moreover, productivity can be further increased as currently we are harvesting only 50-60% of the genetic potential of most crops. Institutions, however, need to be reshaped towards resource conservation and climate-resilience. Creating awareness among farmers, policy makers and extension personnel on the impacts of technologies for climate risk mitigation is equally important. Finally, to make Indian agriculture climate-smart, we need smart farmers. We need to start from the grass-root with a strong policy support for sustainable production, processing, pricing, procurement and promotion of climate-smart technologies.

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Innovations in Plant Nutrient Management: Conceptualizing a New Paradigm for Plant Nutrition

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Plant nutrient inputs play a critical role in nourishing the human family, supporting economic and social development, and safeguarding natural ecosystems for non-provisioning services critical for our existence. However, global disparity in nutrient use and crop productivity, ecological disruptions caused by nutrient losses at production and consumer levels, and poor nutritional outcome of food require a rethinking how we produce and use plant nutrients within food systems. The new paradigm of plant nutrition charts a path where all stakeholders, backed by sound science, policy and investment, contribute to a food system where plant nutrient use is people and planet safe.

Introduction

Plant nutrition reduced hunger and malnutrition for billions of people globally in the past century. Increased access to mineral fertilizers was one of the key drivers of rapid increase in crop yields that fed the world, anchored economic and social development (Haddad et al., 2016), and reduced expansion of agriculture into natural ecosystems (Stevenson et al., 2013). By 2008, inorganic N fertilizers fed up to 50% of the world's population (Maaz et al., 2021). Besides, improving food and nutritional security through production of adequate nutritious food, the adoption of improved fertilizer management practices enhanced soil health through soil fertility restoration and carbon sequestration (Moussadek et al., 2021). The unabated increase in global population, which more than quadrupled in the last 100 years, and the human prosperity, foresee a sharp increase in nutritious food requirement (Hatfield & Walthall, 2015). By 2050, food demand is expected to increase by 60% worldwide compared to 2005/2007, and by over 300% in Sub-Saharan Africa due to the fast growth of the human population (ten Berge et al., 2019). India must also increase the food grain production to around 320 Mt in 2025, and 405 Mt in 2050 to feed the projected population of about 1.7 billion (Patra et al. 2020).

While the access and use of fertilizers have immensely benefitted the human family, their use has imposed risks on public health, the economy, and the environment (Houlton et al., 2019). Public concerns on the impact of fertilizers in several areas including reduced biodiversity, accelerated climate change, eutrophication and hypoxic "dead zones" in the coastal oceans etc. are rising. While plant nutrition and fertilizers will remain crucial for future food and nutrition security of the human family (Vollset et al, 2020), the externalities caused by inappropriate use of fertilizers must now be addressed. Future plant nutrition solutions will have to address multiple global and regional challenges related to nutrients in the food system to transition to a more sustainable one where nutrients and their entire life cycle are managed in a more holistic manner.

Concerns

Recently, the EAT-Lancet Commission on Food, Planet, Health (Willett et al., 2019; https://eatforum.org/eat-lancet-commission/) presented an alarming scenario of human and planetary health and called for a transformational change in the food systems. The anthropogenic perturbation levels of global nitrogen (N) and phosphorus (P) flows may have already exceeded the limits that are deemed to be a safe operating space for humanity (Steffen et al., 2015). Climate variability accounts for almost 60 % of yield variability with a major negative impact on food production and farm income in recent times, causing food insecurity and climate shocks to 71% of households globally, and a US$ 5 billion per year economic losses in production of three major crops (wheat, maize, and barley) (Majumdar, 2020). While agricultural activities at the farm level account for 9% to 14% of greenhouse gas (GHG) emissions from all human activities, a full accounting for the global food system, including land use change and fertilizer production, raises the figure to 21% to 37% (Rosenzweig et al., 2020). Human-induced emissions of nitrous oxide (N_2O), which are dominated by fertilizer additions to croplands, have increased by 30% since the 1980s (SPRPN, 2020). N has the largest impact on energy use and GHG emissions for a wide range of crops, resulting from the large amount of energy required to produce N fertilizer and the large global warming potential associated with N_2O emissions (Camargo *et al.* 2013). With population pressure and increasing demand for animal-based protein, future demand for N is expected to grow substantially to ensure sufficient food for the expanding population (FAO, 2017).

Current food systems also favor the cultivation of staple crops at the expense of more micronutrient-rich food crops such as pulses. While more people now have access to adequate calories, around 155 million people were still facing hunger at a crisis level or worse Phase 3 or above in 2020 (FSIN and Global Network Against Food Crises, 2021), nearly 20 million higher than in 2019. The improved yields of crops achieved through better plant nutrition not necessarily translated into better quality of diets, rather it has actually deteriorated (Pinstrup-Andersen, 2013). This is evident in persistent hunger and malnutrition in Sub-Saharan Africa and other regions, including micronutrient-related deficiencies that particularly affect women and children (Pingali et al., 2017). The number of people who do not have access to nutritious and sufficient food has risen again and may continue to rise due to conflict, climate extremes, economic downturns, or outbreaks of diseases (FAO, IFAD, UNICEF, WFP and WHO, 2020). The wastage of food and poor distribution network aggravate this challenge as 1.3 billion tonnes (Bt) of edible food are wasted globally on an annual basis (FAO, 2020).

The rapid global loss and decline of biodiversity and ecosystem services is one of the most pressing challenges of our time (Brondizio et al., 2019). Considering the rates and extent of biodiversity loss globally, many authors suggest a sixth mass extinction could be underway (Caballos et al., 2015; Wake and Vrendenburg, 2008), and anthropogenic activities, particularly agriculture, are major contributors. Whilst the increases in food production have been profound, with food security increased for billions of people globally, there have also been considerable on-site and off-site biodiversity losses (de Graaff et al 2019; Waterhouse 2012) associated with fertilizer use in agriculture. Reducing the yield gaps — the difference between potential and realized crop yields, will require enhanced use of fertilizers (Pradhan et al., 2015) which could also have potentially negative biodiversity consequences (SPRPN, 2021)

Key Issues the New Paradigm Needs to Address

A new paradigm for plant nutrition needs to result in robust co-benefits by addressing the many challenges associated with plant nutrient use in agriculture. Recently, the Scientific Panel on Responsible Plant Nutrition (SPRPN) of the International Fertilizer Association (IFA), of which the author is a member, identified several issues that need to be addressed to achieve the seemingly conflicting goals of nutrient use in agricultural systems (SPRPN, 2020).

Decouple future crop production from growth in fertilizer consumption: For many decades, rising crop and livestock production was closely coupled with increasing input of nitrogen and other nutrients, as well as international trade of feed and food. This has led to a global divide, ranging from large nutrient input-output surpluses and environmental pollution in some regions to large nutrient deficits in others **(Figure 1**). This disparity is most pronounced in parts of Sub-Saharan Africa, where nitrogen is mined from diminishing soil pools to grow food (Houlton et al., 2019). On a global scale, the future growth in primary

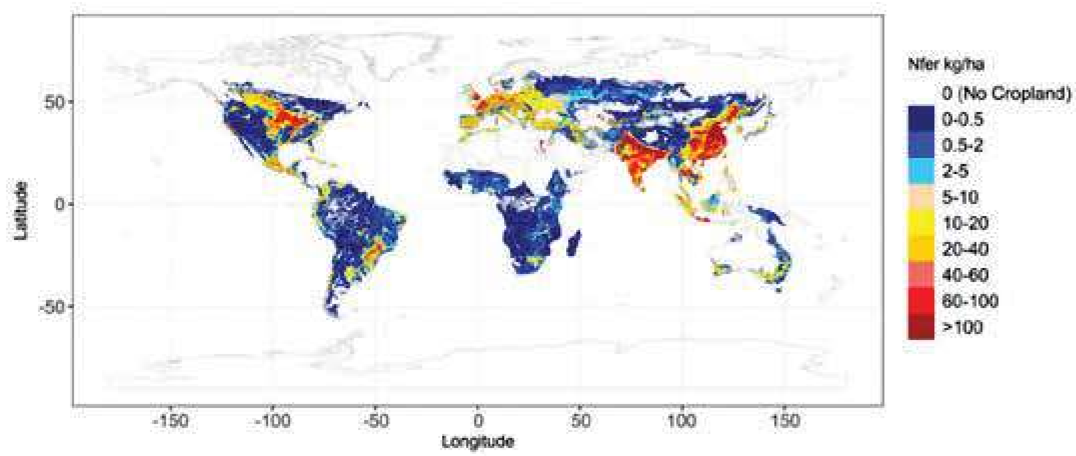

Figure 1. Synthetic nitrogen fertilizer rates (kg N ha^{-1}) in global croplands for year 2015 (Houlton et al., 2019)

crop production needs to decouple from growth in fertilizer consumption. Such decoupling must be regionally nuanced to capture the large disparity in fertilizer use and achieved crop yield and nutrient use efficiencies in different parts of the world.

Improve crop yields in Africa: Crop yield gaps in Africa are high (Bonilla-Cedrez et al., 2021). Africa has massive nutrient deficits that must be overcome to increase crop yields and achieve higher levels of food security within one generation (van Ittersum et al., 2016). Estimates of current nutrient use vary between studies but all are low, with most countries applying less than 10 kg of nutrients ha^{-1} – sum of nitrogen (N), phosphorus (P) and potassium (K) inputs - in organic and chemical fertilizers (Rurinda et al., 2013). Current fertilizer nutrient application rates in sub-Saharan Africa average only about 16 kg ha^{-1} yr^{-1}, compared with over 100 kg ha^{-1} in Europe and North America, and over 150 kg ha^{-1} in China in Asia (Rurinda et al., 2020). Lack of secondary and micronutrients application is also holding back crop yields in Africa (Kihara et al.,2017). Fertilizer alone will not be sufficient to lift crop yields, but it is a key ingredient to trigger an African Green Revolution (Vanlauwe and Dobermann, 2020), which must be based on good information, incentives for efficient use of nutrients, and specific measures to also tackle the still persistent forms of malnutrition.

Accelerate adoption of precise nutrient management by farmers: In many countries, farmers apply too much nutrients because they are relatively cheap or they do not want to risk loss of yield. In other situations, farmers may not apply sufficient nutrients or in the wrong formulations because of lack of affordability, access, knowledge or data. Either way, such application of nutrients in farm fields creates multiple on- and off-site externalities including economic losses to farmers. Precision nutrient management on the other hand is context-specific where nutrient applications are meant to address spatial and temporal variability between and within farm fields to synchronize nutrient application with crop requirement. Such precise application of nutrients enhances economic, social and environmental benefits, and are crucial for the new paradigm of plant nutrition. Many good examples exist worldwide (Sapkota et al., 2021) but adoption of precision nutrient management is slow, particularly in smallholder production systems.

Reduce nutrient loss and waste in agri-food chain: Significant losses of applied plant nutrients occur at the production and consumer ends of the agri-food chain (Alexander et al., 2017). Although accurate data are not available, estimates suggest that at global scale only around 20% of nitrogen compounds may reach useful products, with up to 80% lost to the environment in different forms (Sutton et al., 2012). At the production end such losses entail significant environmental and economic costs, while poor dietary intake and further adverse environmental outcomes are associated with the losses at the consumer end. There are huge variations in nutrient losses among countries and their food systems which must be addressed through various means, including greater recovery of nutrients from various waste streams in forms that allow safe recycling back to crop production.

Close leaky nutrient cycles in crop and livestock farming: Globally operating demand drivers and supply chains have caused a separation and concentration of crop and livestock farming, resulting in spatially disconnected, leaky nutrient cycles. The massive growth of the livestock sector has led to low nutrient use efficiency, increased waste and large greenhouse gas emissions. Global livestock supply chains account for one-third of all human-induced N emissions (Uwizeye et al., 2020). The transition of livestock production toward more efficient systems would significantly decrease livestock- induced GHG emissions, mainly by reduction in land use change (Havlík et al. 2014). Emission intensities were reduced by 20 to 63% for the main livestock products and by 25 to 62% for the main crop products by closing yield gaps through improved efficiency of resource use in mixed crop-livestock systems in Africa (Henderson et al 2016). Sustainable livestock production involves many steps, including more pasture-based systems and re-integration of crop and livestock farming to utilize animals for what they are good at: converting by-products from the food system and forage resources into valuable food and manure (van Zanten et al. 2019).

Improve soil health: Soils are the lifeblood for growing crops, but they also support other essential ecosystem services, such as water purification, carbon sequestration, nutrient cycling and the provision of habitats for biodiversity. Carbon and nutrient inputs are important triggers for improving soil health in crop production, which also increases the resilience of farming systems to extreme weather events. Sequestration of atmospheric CO_2 in soils can contribute to reducing global warming and improving soil health, but requires continuous organic matter inputs and nutrient inputs (particularly N and P) to form stable soil organic matter. Higher biological yield supported by mineral fertilizers also aids in greater below-ground carbon capture that improves soil organic matter content (Ladha et al., 2011; Geisseler and Scow, 2014). In Punjab, intensification of rice-wheat cropping system improved SOC by 38% over a 25-year period (Benbi and Brar, 2009). This enhanced C sequestration had resulted from increased productivity of rice and wheat. Hence, a holistic plant nutrition approach seeks to manage macro- and micro-nutrients for high crop productivity and nutrient use efficiency, but also utilizes biological N fixation (BNF), optimizes carbon storage and turnover, increases soil biodiversity, and avoids soil acidification or other forms of degradation.

Catalyze climate smart plant nutrition: Climate change is a multifactorial stress. Mineral nutrients in soils and crops have important and it is still difficult to predict their positive as well as negative interactions with global climate change. Rising atmospheric carbon dioxide (CO_2) and temperature may increase crop yields in certain regions of the world (Hijmans, 2007; Ivanov and Kiryushin, 2009) but may also cause decline in nutrient concentrations and nutrient use efficiency of food crops. Elevated (CO_2) was associated with significant decreases in the concentrations of zinc, iron and protein in C3 grasses and legumes (Myers et al., 2014). A recent report suggested that 175 and 122 million more people will be zinc and protein deficient respectively by 2050, because of elevated (CO_2), mostly in Asia and Africa (Steiner et al., 2020). Under elevated (CO_2), 18 countries may lose >5% of their dietary protein, including India (5.3%), and an additional 53 million people may become at risk (Medek et al., 2017). Changes in seasonality, precipitation and extreme weather events will affect the timing and efficiency of nutrient uptake, requiring integration of nutrient advisories with early warning and climate information systems. Balanced mineral nutrition has particular roles in adapting to environmental stresses in crops, such as drought, heat or high radiation, that are hallmark of climate change (Hasanuzzaman et al., 2018).

Reduce fertilizer related greenhouse gas emission: All pathways that limit global warming to 1.5 °C or well below 2 °C require land-based mitigation and land-use change (IPCC, 2021). Across the plant nutrition sector, low-emission "green" fertilizer production and transportation technologies, novel fertilizer formulations, inhibitors, genetic solutions to nitrification inhibition or fixing atmospheric N, as well as more precise nutrient application and agronomic field management offer numerous opportunities to reduce nutrient-related emissions of CO_2 and N_2O provided the surrounding policies and market conditions enable that. Through a combination of innovations in digital agriculture, crop and microbial genetics, and electrification, it is estimated that a 71% (1,744 kg CO_2e ha^{-1}) reduction in green- house gas emissions from row crop agriculture is possible within the next 15 years (Northrup et al., 2021). Importantly, emission reduction can lower the barrier to broad adoption by proceeding through multiple stages with meaningful improvements that gradually facilitate the transition to net negative practices.

Deliver more nutritious food through diversified cropping and crop management: More than 2 billion people in the world are affected by various forms of micronutrient malnutrition. Over 144 million children are affected by stunting globally while 47 million children are suffering from wasting (FSIN and Global Network Against Food Crises. 2021). Two-thirds of the Indian population are estimated to be micronutrient deficient (Rao et al., 2018). An estimated 61% of deaths in India were attributed to non-communicable diseases in 2017 (WHO, 2017), and the prevalence of stunting (short height for age) amongst children under 5 years old remains extremely high at almost 40% (UNICEF, 2017), indicative of the co-existence of overweight and obesity with under-nutrition (the "dual burden") (Alae-Carew et al., 2019). The world's major cropping systems are designed to provide calories, protein and a number of other nutrients or bioactive compounds. However, a handful of micronutrient-poor crops dominate the global food and feed chains and have often decreased the crop diversity or displaced traditional crops such as pulses. Besides dietary diversification and food interventions, biofortification of staple crops with micronutrients through breeding and/or fertilizers present clear opportunities to create more nutritious food (Welch et al., 2013). Where will this be most effective, and how can this be mainstreamed into agriculture if farmers do not get paid for such additional food quality value?

Improve stewardship across the entire plant nutrient supply and use chain: Digital technologies offer great potential for better monitoring, analysis, benchmarking, reporting and certification of sustainability efforts, including principles stated in the international Code of Conduct for the sustainable use and management of fertilizers. This is important for improving transparency, traceability, quality control, and sustainability assessment in the whole food sector, and it is critical for public sector engagement and evidence-based policy making. The International Code of Conduct for the Sustainable Use and Management of Fertilizers (FAO, 2019) or criteria for Environmental, Social, and Governance (ESG) provide guidelines that would be useful in this context.

Enabling Actions to Achieve Multiple Conflicting Goals

Human development, biological process requirements and mass balance principles make it clear that mineral nutrients, including fertilizers, will continue to be a key driver of future food systems. **It is now critical to develop integrated plant nutrition strategies and practices that minimize tradeoffs between productivity and the environment - and are viable in the farming and business systems of different regions, nations and localities.** Integration in this context has several dimensions, including a multi-nutrient food system approach, greater recycling and utilization of all available nutrient sources, alignment with other agronomic and stewardship practices, and compliance with high sustainability standards. In a nutshell, responsible plant nutrition will contribute to a more nature-positive approach of food production and consumption that adapts and integrates key agroecological principles (FAO, 2018) in a tailored manner. Implementing the new paradigm typically involves six interdependent actions:

Sustainability-driven nutrient policies, roadmaps, business models and investments that create added value for all actors and beneficiaries in the nutrient chain. Nutrient policies and roadmaps must be tailored to the specific food systems in every country, including ambitious goals for nutrient use, losses and efficiency. Specific targets and priorities for managing nutrients will vary, depending on each country's history and sustainable development priorities. Progressive science-based monitoring, stewardship (IPNI, 2016) and certification schemes will guide performance and reward farmers and businesses for innovation, reduction of nutrient losses, improvement of soil health, enhancement of biodiversity, and provision of other ecosystem services. Differentiated strategies will also lead to regional shifts in global fertilizer use, reducing nutrient surpluses and ensuring that more nutrients are moved to where they are most lacking and can produce the greatest benefit, particularly in many parts of Africa (Zhang, 2017).

Data-driven, more precise crop nutrition solutions. Knowledge-driven digital solutions and disruptive technologies will allow tailoring nutrient applications to local needs in an increasingly precise manner. Besides high-tech solutions for commercial farming, "low-tech" site-specific nutrient management approaches have shown consistent, large increases in crop yields and profits and nutrient use efficiency in many crops grown by smallholder farmers in Asia and Africa (Chivenge et al., 2021). On-farm use of digital tools supporting precise crop nutrition in India significantly improved the yield (Sapkota et al., 2021), nutrient use efficiency (Sharma et al., 2019), energy and water use efficiency (Parihar et al., 2017), and farm profitability and soil health (Parihar et al., 2020), while reducing the environmental footprint of fertilizer use (Sapkota et al., 2014, 2021). There is now a need for integrating such tools in digitally supported advisory systems and business solutions for upscaling the benefits to millions of farmers.

Circular economy solutions for greater nutrient recovery and recycling. Crop-livestock integration, less food waste, by-products use and increased nutrient recovery and recycling are key measures to optimize nutrient use efficiency across the full food chain. Political incentives, novel technologies, and shifts in behavior will drive greater nutrient recycling from multiple waste streams, as a key contribution to circular, bio-based economies. Such circular systems need to be safe and healthy for animals, humans and the environment, but they also allow the creation of novel business models, including side-streams within the agricultural sector for up-cycling of materials and the nutrients they contain. Improved full-chain nutrient flow monitoring, life-cycle analysis, benchmarking and certification will support the development of such solutions.

Nutrition-sensitive farming – producing food crops with higher nutritional value to address persisting as well as emerging mineral nutrient deficiencies. Besides dietary diversification and food interventions, plant nutrition solutions are part of strategies for addressing the triple burden of undernutrition, micronutrient malnutrition, overweight/obesity and other non-communicable diseases. Depending on the local context, nutrition-sensitive crop production may include more diverse crop rotations as well as biofortification of staple crops with micronutrients through breeding and/or fertilizers (Cakmak and Kurtman, 2018). The latter involves the targeted use of fertilizer products that deliver micronutrients of importance to crops, animals and humans. Besides essential plant nutrients such as iron or zinc, this may also include nutrients that are of particular importance to animals and humans, such as iodine (Fuge and Johnson, 2015) or selenium (Alfthan et al., 2015).

Energy efficient, low emission fertilizers. Fertilizers will increasingly be produced in an environmentally friendly manner and they will embody greater amounts of knowledge, to control the release of nutrients to synchronize with plant requirement. Significant reductions in pre-farm greenhouse gas emissions can be achieved by innovations in fertilizer production to make low-carbon emissions fertilizers. Various new technologies are already being explored to produce "green ammonia" from renewable, carbon-neutral energy sources, and also use it for energy storage and transport. A new "ammonia economy" could feed and power the world in a whole new, decentralized manner (Rouwenhorst et al., 2019). Innovation in fertilizer formulation will lead to new products that maximize nutrient capture by the crop and minimize environmental losses of nutrients (Chen et al., 2018).

Accelerated, more open innovation systems for faster translation of new ideas into practice. Future research and innovation systems need to foster co-creation and sharing of knowledge for rapid development and deployment of new know-how and technologies. This requires more openness and coordinated action of public and private sector players. A massive culture change is needed in science and science funding, towards a problem-focused and leaner science approach, transdisciplinary collaboration, entrepreneurship, and early engagement with farmers

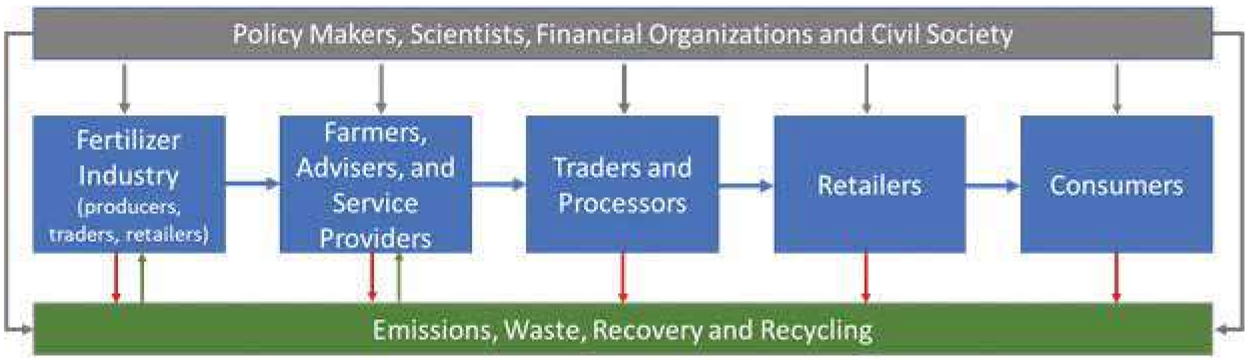

Figure 2. The agri-food chain from a nutrient management perspective. Blue boxes show groups of major actors who directly contribute to nutrient use and losses at different stages. Red arrows indicate greenhouse gas emissions, direct nutrient losses into the environment and waste that can happen in all parts of the chain. All opportunities to reduce emissions and losses must be exploited, while also increasing nutrient recovery and return to farming and industry (green arrows). The grey box shows actors who influence the major actors, drive innovation or set the societal framework for action (Source: SPRPN, 2020)

through farmer-led innovation processes.

Role of Different Stakeholders

Responsible plant nutrition is a complex and global challenge which can only be tackled through concrete action by those directly involved in the nutrient cycle, and those influencing it (**Figure 2**).

Policy makers at all levels need not only to create clear, science-based and harmonized regulatory frameworks for nutrients, but also evolve dynamic policies that incentivize innovation in technologies, practices and business models. They must set out a clear vision for national or regional roadmaps with sound targets for nutrients, nutrition and environmental indicators. They can drive changes in food consumption, as well as provide progressive incentives for the adoption of better practices by farmers. Policies need to properly balance food production and environmental goals. Technical assistance and extension services must be supported adequately to promote sustainable practices. Policy makers also need to ensure that farmers all over the world have affordable access to the internet and digital services.

The global fertilizer industry has recently recognized the need for a sustainability- and innovation-driven plant nutrition approach as its core business strategy (IFA, 2018). Fertilizer companies will have to increasingly become providers of integrated plant nutrition solutions that are based on new business models that do what is right for people and the planet. Sustainability and innovation, including transparent monitoring and reporting, will drive the transformation strategy for the entire industry, for every product and solution sold. Revenue growth primarily needs to be driven by growth in performance value offered to farmers and society, not volume of fertilizers sold.

Farmers, farm advisers and service providers carry the primary responsibility for improving nutrient use efficiency, reducing nutrient losses, recycling nutrients, and promoting soil health at the farm scale, which has huge implications at higher scales. They need to be able to fully adapt new knowledge, technology, and services, and they need to be rewarded for good practices. Many farmers are entrepreneurs and willing to change, and they are also aware of their role as stewards of land, water, climate and biodiversity. But doing things differently requires lowering risks and other adoption barriers.

Food traders, processors and retailers have enormous power to influence nutrient cycles, both through influencing what consumers eat or drink and how it is being produced. Vertically integrated, data-driven and more transparent supply chains that meet sustainable production standards and reduce production losses will become more widespread, including more direct sourcing from farmers. These developments offer numerous opportunities for implementing more holistic approaches to nutrient management. Monetizing such sustainable production practices is both a key challenge and an opportunity.

Consumers will drive significant changes in plant nutrition through changes towards healthier diets as well as an increasing emphasis on food that is produced in a more sustainable manner. Specific trends will differ among regions and income groups. On a global scale, changes in food behavior may be relatively slow and will also be partly compensated by growing food consumption due to rising populations and income growth in low- and middle-income countries. However, an immediate responsibility of consumers is to reduce excessive meat consumption, waste less food, and ensure recycling of waste that does occur.

Utility services providers and waste processors are an important and relatively new category of actors in the nutrient cycle, but their role will increase substantially in the coming years. Particularly in densely populated areas their needs and actions will increasingly co-define how farming and nutrient management will be done. This requires deepening the collaboration with other groups of actors and jointly developing a common understanding as well as common standards to meet.

Investors: Investment in plant nutrition research and innovation will need to increase massively to meet the complex plant nutrition challenges we face. Public, private and philanthropic investors should increasingly invest in technologies, businesses and organizations that support key elements of the new paradigm, including creating a growing ecosystem of startup companies and other enterprises. Use of blended public and private capital can de-risk and leverage more private investment.

Scientists: Science and engineering will underpin all efforts to achieve the multiple objectives of the new plant nutrition paradigm, but the entire science culture must change too, towards new ways of working that stimulate new discoveries and achieve faster translation into practice. Greater focus on explicit pathways to agronomic applications, reality checks and rigor in claims of utility are needed, as well as sharing of know-how and critical resources for more open innovation and entrepreneurship.

Civil society organizations play significant roles for the new paradigm through informing the public, grassroots mobilization, monitoring, alerting and influencing, and inclusive dissemination of new technologies and practices. This is a big responsibility, which should follow an evidence-based approach. Co-developing concrete solutions in partnership with government, industry, scientists and farmers should replace the often found emphasis on single issues or controversial debates.

Outcomes 2040 Envisioned by the New Paradigm of Plant Nutrition

Operationalization of the multi-stakeholder supported critical actions should be able to produce concrete outcomes by 2040 to transition the global food system to a more sustainable one:

- Widely accepted standards for quantifying and monitoring nutrients along the food supply chain inspire solutions for improving the overall nutrient use efficiency, increasing recycling and reducing nutrient waste across the whole agri-food system. Ambitious targets, policies and investments stimulate collective actions by governments, businesses, farmers and other stakeholders towards sustainable, integrated, and tailored plant nutrition solutions.
- On a global scale, crop yield growth meets food, feed and bio-industry demand and outpaces growth in mineral fertilizer consumption, while cropland expansion and deforestation have been halted. Crop nitrogen use efficiency – the nitrogen output in products harvested from cropland as a proportion of nitrogen input – has increased to 70%.
- Through responsible consumption, increased recycling, and better management practices, nutrient waste along the food system has been halved. Nitrogen and phosphorus surpluses in hotspots have been reduced to safe levels which minimize eutrophication and other environmental harm.
- Globally, soil nutrient depletion and carbon loss have been halted. Forward-looking policies and investments have triggered changes in farming systems and management practices that improve soil health, including soil organic matter. Regional soil nutrient deficits have been reduced substantially, particularly in Sub-Saharan Africa, where fertilizer use has tripled and crop yield has at least doubled, including improved nutritional outputs. Millions of hectares of degraded agricultural lands have been restored, including through the use of mineral and organic fertilizers and nutrient-containing waste or by-products.
- Extreme forms of chronic hunger and nutrient-related malnutrition have been eradicated through integrated strategies that include the targeted use of micronutrient-enriched fertilizers and nutrient biofortified crops. A new generation of more nutritious cereals and other staple crops is increasingly grown by farmers, driven by consumer and market demand. Policy and decision makers support mineral fertilization strategies for meeting specific human nutritional needs where markets don't provide the needed incentives.
- The fertilizer industry follows rigorous and transparent sustainability standards for the entire life cycle of its products and business operations. Greenhouse gas emissions from fertilizer production and use have been reduced by at least 30% through increased energy efficiency, carbon capture and storage and other novel technologies and products. At least 10% of the world's fertilizer-N is being produced from green ammonia with very low or zero carbon emission.
- R&D investments in plant nutrition research and innovation by public and private sector have tripled compared to present levels. Many companies spend 5% or more of their gross revenue

on research and innovation. Collaborative, open innovation approaches allow for scientific discoveries to become quickly translated into practical solutions and knowledge. Innovative, value-oriented business models drive growth throughout the industry. Customized crop nutrition products and solutions account for at least 25% of the global crop nutrition market value.

- Consumers appreciate the benefits of plant nutrients, including mineral fertilizers as a primary nutrient source. A nutrient footprint standard with high visual recognition informs consumer choices. Information on improvement of soil health and nutrient balances is widely available, and their linkage to the mitigation of air, water and climate issues will be broadly acknowledged.
- Farmers all over the world have access to affordable, diverse and appropriate plant nutrition solutions, and they are being rewarded for implementing better nutrient management and stewardship practices that increase their prosperity and enable them to exit poverty traps.

Conclusion

The next two decades will be most critical for transitioning the global food system to a new trajectory where all stakeholders look at food and nutrients in a holistic manner, including their hidden environmental, health and socio-economic costs. We have failed in the past to achieve that vision, despite many scientific and technical solutions that have existed for decades. Achieving it now, within one generation, will require a far more concerted effort by everyone involved, from the fertilizer industry to farmers and consumers of food and other agricultural commodities. Fast action is important, but it needs to be grounded in long-term sustainability thinking.

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Water Management: Issues and Strategies

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Scientific management of water is increasingly recognized as being vital to India's agricultural growth and ecosystem sustainability. Last few decades have seen dramatic rise in the demand for water in India due to a variety of reasons. This demand has been met both from surface water and groundwater resources. These resulted in over-exploitation of groundwater resources in many arid and semiarid regions, leading to falling groundwater table, deteriorating groundwater quality etc. Surface reservoirs are fast depleting due to siltation. Freshwater supplies are increasingly coming under threat of pollution from industrial effluents and municipal waste. Water scarcity is becoming a major constraint in producing food for growing population, ecosystem protection, and maintaining health and social security. There is also threat to our environment like water logging and salinity in many canal commands, seawater intrusion in the coastal areas, drying up of the wet-lands and low-flows in the streams etc. Climate change impact has taken its toll on water resources. The frequent occurrence of extreme events, such as droughts and floods, further-worsen the water scarcity situation and agricultural productivity. Spatial and temporal heterogeneity of flood and drought along with huge spatial disparity in expanding irrigated area are the challenges for a vast country like India. The irrigated agro ecosystem has got many challenges. Spatial disparity in expanding irrigated area in the country, poor irrigation efficiency mainly for the canal irrigation, regional disparity in groundwater development, and low use and filtration of wastewater for irrigation are the new challenges in our country. In rainfed agro-ecosystem, rainwater conservation in different land forms and its efficient utilization is one of the most appropriate strategy to create a favorable water regime for better crop growth and yields. Management of waterlogged areas and flood prone areas is the most challenging one. But there are several technologies available to address these challenges. In irrigated agro-ecosystem, performance improvement of canal irrigation system, introduction of pressurized irrigation system, drip fertigation for better water and nutrient use efficiency, use of sensors for precise application of water in the field are some of the options available to increase irrigation water use efficiency.

Introduction

Water is the most important natural resource for civilization to grow. Water is required for agriculture as irrigation, for drinking, and in sanitation for our rural and urban communities. Water is also necessary for most of the industrial production processes. Water also provides a wide range of ecosystem and environmental services (Das et al., 2021). It helps to dilute pollution caused by industrial effluents and domestic sewage. Pressure on freshwater resources is increasing across the globe.

As mentioned in the report of National Commission for Integrated Water Resources Development (NCIWRD), the percentage of water used for irrigation out of the total water use for the year 1997-98 was 83.30. Percentage of water for irrigation out of the total water use for the year 2025 under high demand scenario is estimated at 72.48 (PIB, 2020). From a macro perspective, the overall fresh water availability across the globe remains more or less constant. But, from a micro-perspective, the freshwater supplies in many regions and localities are dwindling due to alterations in hydrologic balances, and overexploitation and increasing pollution of freshwater reserves. Many third world countries are already facing serious water shortages. Increasing freshwater scarcity is becoming a major constraint in producing food for growing world population, ecosystem protection, and maintaining health, social and food security and peace among nations (Das et al., 2021).

India is not an exception to this impending crisis. Currently 1.38 billion population, preference for water intensive agriculture, and rapid urbanization and industrialization are putting enormous pressure on the fragile freshwater resources. Growing water scarcity problems pose serious threat to ecosystem management, social sustainability, and economic growth. Community managed and indigenous system of water management existed in India for many centuries; this met the irrigation, drinking and domestic water supply needs of the community (Pereira et al., 2009). The British built large barrages and canals, but the irrigation systems were governed rather than managed. Also, these were too large for the communities to play any significant role in their management (Chitale, 1991).

India had 20.85 Mha of net irrigated area during 1950-51. It increased to 67.4 Mha by 2020-21. During the same period the food grain production has increased from 50 Mt in 1951 to 305.4 Mt in 2020-21. These are the cumulative efforts to boost agriculture production and achieve self-sufficiency in food. Irrigation development was the major investment priority during the five-year plans (Bharadwaj, 1990). Several major, medium, and minor irrigation schemes were built. As a result, an annual growth of 2.42% in food production has been achieved. During 1964-65 to 1970-71 food-grain production grew at a record rate of 3.3%, mostly due to expansion in the irrigated area (Sarma and Roy, 1979).

Last few decades have seen a dramatic rise in the demand for water in India, triggered by the rise in population, especially in urban areas, causing increased demand for food production and domestic water supplies; industrial growth created increased demand for production purposes and triggered the water pollution. Water Supplies have also grown manifold to keep pace with demand through exploitation of surface and groundwater. As a result, groundwater resources were over-exploited in many arid and semiarid regions, leading to large drops in water levels, deterioration in groundwater quality, and sharp reduction in the availability of good quality groundwater. Freshwater supplies are increasingly coming under the threat of pollution from industrial effluents and municipal waste. Situation has developed steadily and dramatically.

At the time of independence, the per capita fresh water availability in the country was 6008 m^3 yr^{-1} (Engelman and Roy, 1993). In 1997, it stood at approximately 2200 m^3 yr^{-1}. The average annual per capita water availability in the years 2001 and 2011 was assessed as 1816 m^3 and 1545 m^3, respectively which may further reduce to 1486 m^3 and 1367 m^3 in the years 2021 and 2031, respectively (PIB, 2020). The situation is already critical in 6 out of the 20 major river basins, with the per capita freshwater availability going below 1000 m^3 yr^{-1} (Anand et al., 2018).

Water-related issues are becoming far more complex than ever before. Keeping these things in mind, attempt has been made to analyze the emerging water resources management issues and challenges in India.

Water Resources of India

Surface Water Resources

India accounts for about 2.45% of world's surface area, 4% of the world's water resources, and about 17% of the world's population. Country is subjected to uneven distribution of water, challenged by the negative impact of climate change. Thus, there is a need for proper water management and water conservation.

India receives an annual average rainfall of 1170 mm. Its uneven spatial and temporal distribution is a major concern for crop production. Out of the total 4,000 billion cubic meters (BCM) of total water resources, the utilizable water resources have been assessed as 1123 BCM (690 BCM surface water and 433 BCM groundwater sources). There are four major sources of surface water namely, rivers, lakes, ponds, and tanks. In the country, there are about 10,360 rivers and their tributaries longer than 1.6 km each. The mean annual flow in all the river basins in India is estimated to be 1,869 km^3. **Table 1** sums up the country's present water scenario. Major river basins of India are Indus, Ganga, Brahmaputra, Sabarmati, Mahi, Narmada, Tapi, Godavari, Krishna, Cauvery, -Barak, Subarnarekha, Brahmani-, Baitarani, and

Table 1. Present scenario of water resources in India

Average annual precipitation	4000 BCM
Average precipitation during Monsoon (June-September)	3000 BCM
Annual flow in river basins	1869 BCM
Total annual utilizable water resources	1123 BCM
Utilizable surface water resources	690 BCM
Utilizable groundwater resources	433 BCM

Mahanadi.

The projected water demand by 2050 will be 1447 BCM which is 324 BCM more than the present level of utilizable water resources. In addition to agriculture, the demand from other sectors such as industry, energy, municipal etc. are also increasing day by day. Thus, there is a need to identify and analyze the challenges in the agricultural water management sector and formulate strategies for (i) enhancing productivity of challenged agro-ecosystems, *i.e.* rainfed and waterlogged areas, (ii) producing more from less water by efficient utilization of surface and groundwater in irrigated areas, and (iii) safe use of a portion of grey water for agricultural production purpose in a sustainable manner.

Groundwater Resources

Groundwater plays an important part in India's economy. Unregulated groundwater extraction has led to overuse in many parts of the country, causing the groundwater table to plummet, progressively drying springs and aquifers. The annual replenishable groundwater resource is 433 BCM and the draft is 245 BCM, which accounts for about 62% of the net water available. Of this, 91% was used for irrigation. However, the effects on groundwater in different regions of the country have not been uniform. The situation is alarming in regions where groundwater exploitation exceeds replenishment. States like Haryana, Punjab and Rajasthan now draw more water than is annually replenished.

Regional comparison indicates that the groundwater recharge in Eastern India is highest, but the stage of development is among the lowest (40.7%) **(Figure 1)**. Therefore, there is a huge scope for using groundwater in Eastern India. The stage of groundwater development for the country as a whole is 63.3%. Recent estimate shows rapid depletion of utilizable groundwater storage in most parts of Northern and Eastern India during 2005-2013, losing 8.5 km^3 yr^{-1} and 5 km^3 yr^{-1} of total groundwater, respectively (CGWB, 2019). More than 85% of the groundwater usage in India is linked with irrigation abstraction practices during non-monsoonal months. In India 3% and 11%, blocks are under critical and semi-critical stage of development, respectively. Large-scale depletion could have unforeseen consequences in future food security. The summer groundwater droughts would intensify in future, to become severe to very severe by 2050, with the possibility of these spreading over all seasons.

Challenges in Water Management

Rainfed Agro-ecosystem Challenges

Rainfed agro ecosystem is a challenged ecosystem from water management perspective. It has both drought-prone areas as well as flood prone/ waterlogged areas which have unique characteristics of low agricultural productivity. Presently about 72 Mha area is under rainfed agriculture (net sown area under rainfed condition). It is noteworthy that about 33% of rainfed area

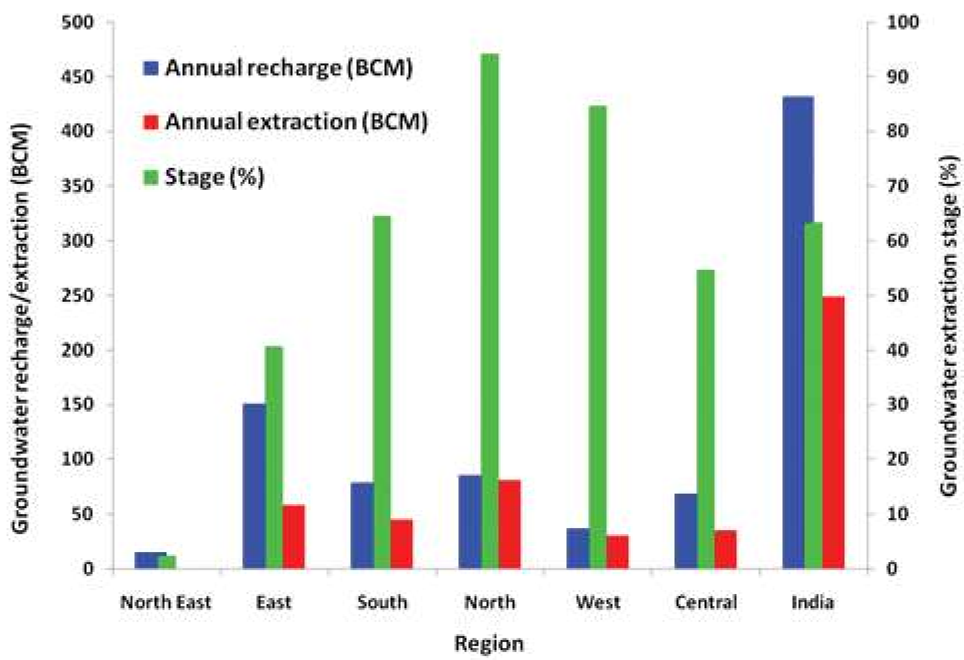

Figure 1. Region-wise comparison of groundwater recharge, extraction and stage of development

receives more than 1100 mm of rainfall and another 33% receives rainfall between 750-1100 mm.

Spatial and Temporal Heterogeneity of Flood and Drought

Floods and droughts accounted for 51% of all the natural hazards and 76% of the damages caused in India between 2000 and 2020 (EM-DAT, 2020). Floods and droughts are a recurrent phenomenon in India. The South-West Monsoon rains, between June and October, account for over 70% of annual precipitation in states located in many large river basins (GOI, 2019). The large river basins, such as the Indus, Ganges, and Brahmaputra, generate significant monsoon runoff leading to massive flooding in the plains. About 43% of the Indian population is prone to recurrent floods (Amarnath et al., 2017). The North-East Monsoon period (November to March) has mainly dry weather and a year with below-average monsoon causes droughts in many regions. Annually, droughts also expose a similar percentage of the population (Amarnath et al., 2017). Those hit hardest are the rural areas and with agriculture-dependent livelihoods, especially where rainfall is the only source of water supply for agricultural production. These areas include agriculture in rainfed, groundwater, and minor tank irrigated areas consisting of about two-thirds of the total cropped area (GOI, 2020).

Bihar and Assam in the Eastern Region (ER) have some of the highest exposure to floods. They also have some of the lowest levels of Gross State Domestic Product (GSDP) (**Figure 2**). States like Madhya Pradesh, Jharkhand and Uttar Pradesh have some of the lowest per capita GSDP but have relatively little exposure to floods. Gujarat and Rajasthan had the most extensive exposure to droughts in the early 2000s; more than 35% of the area and 45% of the GSDP in 2002 (Amarasinghe et al., 2020). However, the area exposed to droughts in these states decreased substantially to less than 5% of the total area in 2015. States of Madhya Pradesh and Jharkhand have also the reduced exposure to droughts.

High Spatial Variation of Crop Production and Productivity

Foodgrain production in India during 2016-17 was 275.1 Mt. Production of eastern region was 81.3 Mt, constituting about only 29.6% of the national production. This is in comparison to 28.5 Mt in the state of Punjab, 17.2 Mt in the state of Haryana, and 10.4 Mt in the state of Andhra Pradesh. The average national productivity was 1.9 t ha^{-1}. The average productivity of Punjab was 4.2 t ha^{-1}, 3.3 t ha^{-1}in Haryana and 2.7 t ha^{-1} in Andhra Pradesh. In eastern Indian states, the productivity was: 1.5 t ha^{-1} for Assam, 1.7 t ha^{-1} for Bihar, 1.0 t ha^{-1} in Chhattisgarh, 2.0 t ha^{-1} in Eastern Uttar Pradesh, 1.7 t ha^{-1} in Jharkhand, 1.3 t ha^{-1} in Odisha, and 2.4 t ha^{-1} in West Bengal (Directorate of Economics and Statistics, 2020). This wide gap of food grain production and productivity can be bridged to considerable extent by efficient irrigation water management.

Saline and Waterlogged Area

In the flat and low-lying areas canal irrigation without adequate drainage has resulted in a rise in water table, leading to waterlogging and secondary salinization. Subsurface waterlogging mainly resulted from deep percolation losses from excessively irrigated fields and/or seepage from irrigation networks coupled with lack of natural drainage. In this context, India has got about 11.6 Mha area as waterlogged. There are two types of waterlogged areas: one where the water table has risen due to over irrigation up to within root zone (approximately 2.16 Mha) and another where water stagnation occurs due to high rainfall coupled with land topography which hinders drainage. In addition to over-irrigation, run-off congestion, unscientific *in-situ* water

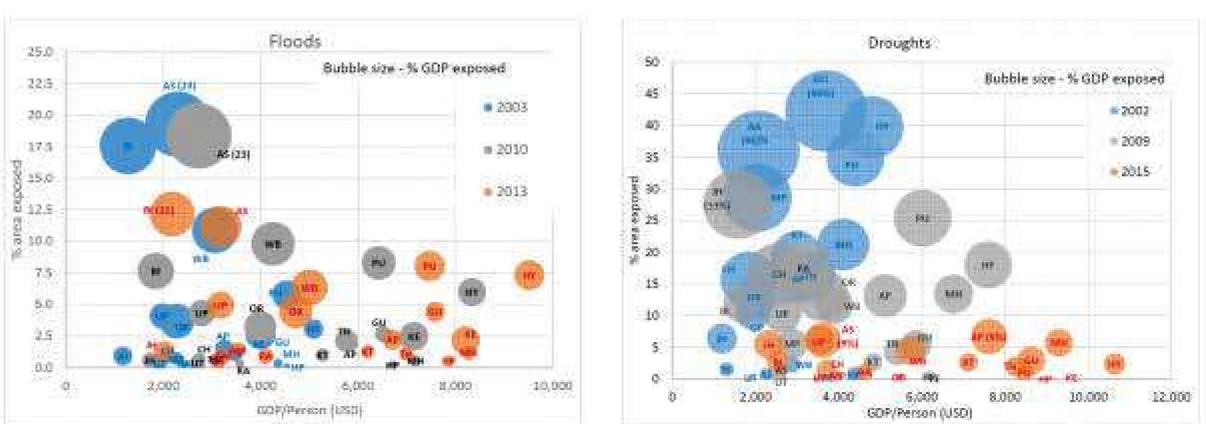

Figure 2. Spatial and temporal variation of flood and drought in India (Source: Amarasinghe et al., 2020).

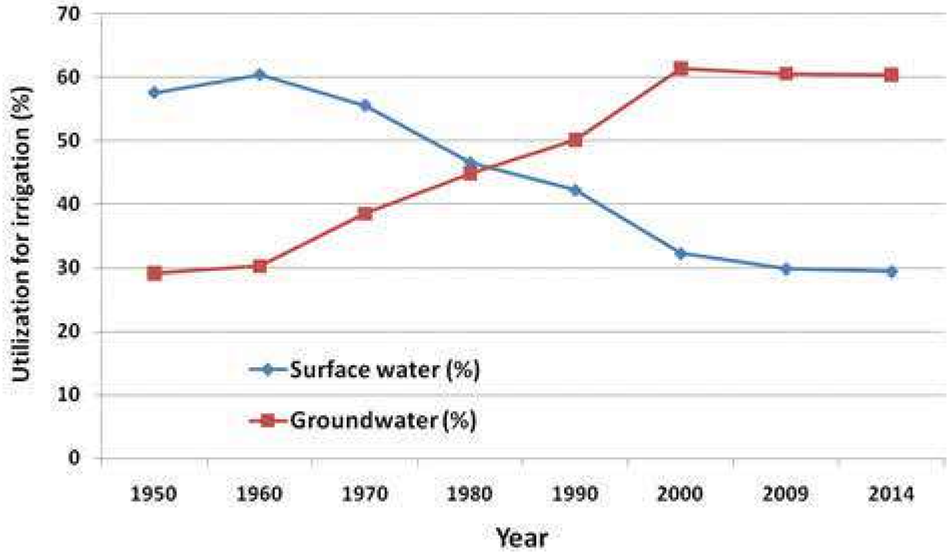

Figure 3. Temporal trend in utilization of surface and groundwater resources for irrigation in India (Source: Anonymous, 2014)

management, imbalance in inflow and outflow water in irrigated lands, and obstruction of natural drainage networks also play very important role in creating waterlogging. In arid and semi-arid region, it leads to build-up of soluble salts in the root zone causing twin problems of waterlogging and soil salinity simultaneously. In waterlogged saline soils, water table remains within 1.5-2.0 m from the soil surface and soils are saline with ECe more than 4 dS m^{-1}, pH less than 8.2 and ESP less than 15. Higher osmotic pressure in soil mass reduces the availability of water necessary for plant growth and plant suffers from water stress in spite of the saturated soil conditions in the root zone (Chaudhari et al., 2016). Among all the regions of India, Eastern India is having maximum waterlogged area. Because of high rainfall and saucer-shaped topography, this region has significant area under water stagnation of various depths. In the waterlogged area, the crop yield reduces drastically and at some cases total crop failure occurs. Therefore, suitable technological interventions need to be adopted to overcome this condition.

Irrigated Agro-ecosystem Challenges

Spatial Disparity in Expanding Irrigated Area

The percent of cultivated area under irrigation is 49.2% on national basis. It is as high as 98.6% in Punjab and 91.4% in Haryana. However, it is only 47.7% in Eastern India. Irrigation potential created and utilized with respect to ultimate irrigation potential is quite less in Eastern India in comparison to national average. Hence, there is a need for creation of more irrigation infrastructure in order to bring more area under irrigation in the eastern region.

Poor Irrigation Efficiency

India has low water use efficiency compared to the developed countries. The overall irrigation project efficiency in developed countries is 50% – 60% as compared to only 38% in India. Thus, more water per unit of production is being in India compared to similar crop grown in other countries. There are several technological options available to increase the overall project efficiency.

Regional Disparity in Groundwater Development

The average groundwater development in India is 63.3%. The stage of development in eastern and north-eastern regions are: 40.7% and 2.4%, respectively which are very low. It is only 11% in Assam, 46% in Bihar, 44% in Chhattisgarh, 28% in Jharkhand, 42% in Odisha, 45% in West Bengal, and 69% in Eastern UP. The average stage of development of southern, northern, and western regions of India is 64.6%, 94.3%, and 84.7%, respectively. Hence, this regional disparity needs to be minimized and water sufficient states ought to be encouraged to increase the groundwater development.

Declining of Groundwater Table

Utilization of groundwater for irrigation increased rapidly after independence and on the contrary the surface water utilization exhibited a decline (**Figure 3**). The groundwater level in India has declined by 61% between 2007 and 2017 and of the extracted water, 89% is used for irrigation, according to the census. As the groundwater level falls, farmers are left with two options – either to deepen their existing wells by buying powerful pumps or reducing the acreage they are irrigating. Deepening of wells means more investment, high maintenance costs, and increase of flat electricity tariff. North-western India has, perhaps, seen the most groundwater depletion in the world. Out of the total

6881 assessment units (Blocks/ Mandals/ Talukas/ Firkas) in the country, 1186 units (17%) have been categorized as 'Over-Exploited' and 313 units (5%) are 'Critical'. There are 972 semi-critical units (14%) and 4310 assessment units (63%) have been categorized as 'Safe'. Apart from this, there are 100 assessment units (1%), which have been categorized, as 'Saline' as major part of the ground water in phreatic aquifers is brackish or saline (CGWB, 2019).

Spatial Heterogeneity in Spreading Micro Irrigation

Micro irrigation in India is being popularized with a subsidy component, by both the central and state governments. As per the data provided by the Ministry of Agriculture and Farmers Welfare to the Lok Sabha, the agriculture land covered under micro-irrigation is 12.9 Mha in which drip irrigation is 6.11 Mha and sprinkler irrigation is 6.79 Mha. This means that out of total irrigated land in the country only 19% is under micro-irrigation. Maharashtra, Andhra Pradesh, Telangana, Karnataka and Gujarat together account for about 85% of total drip-irrigated area. In case of sprinkler system, Rajasthan and Haryana top the list. Madhya Pradesh, Punjab and Haryana lag far behind compared to their potential. However, groundwater development in these states is more than 100%. States of Eastern India are lagging far behind than the states of other regions (**Figure 4**). Eastern India covers only 1.82% and 10.39% of total drip and sprinkler irrigated area of the country, respectively. The southern region covers 47.86% of total drip irrigated area of the country and western region covers 44.63% of total sprinkler irrigated area of the country.

Poor Groundwater Quality

Poor groundwater quality is one of the causes of water scarcity in certain parts of India. In some areas, groundwater is not suitable for irrigation due to salinity and/or geogenic elements. For example, instances of high fluoride in 13 states; arsenic in West Bengal; and iron in the north-eastern states, Odisha, and other parts of the country have been reported. In West Bengal, arsenic toxicity has been observed as a result of over-draft, particularly, more withdrawal of groundwater during lean period for summer paddy irrigation. In Bengal delta basin, a geographic area of 17.3 Mha is affected due to arsenic contamination, exposing 36 million people to the risk. Beyond the Bengal delta basin, the widespread arsenic contamination in groundwater above the permissible limit (50 µg L^{-1}) has also been detected in several places. Excessive use of nitrogenous fertilizers has led to nitrate contamination in groundwater, particularly in light textured soils that has consequence on human/ animal health if used for drinking purpose.

Issues Related to Wastewater Management

High Microbial Load

Wastewaters are loaded with various types of microbes. It contains high concentrations of excreted pathogens such as viruses, bacteria, helminths eggs, and fecal coliforms. These excreted pathogens have the potential to cause disease if present in a human host in sufficient quantities. Intestinal nematodes pose the highest degree of risk of infection while bacteria pose a lower risk.

Rich Source of Organic and Chemical Pollutants

About 70% of the surface water resources and large proportions of groundwater reserves have been contaminated due to indiscriminate discharge of wastewater from the industry, agriculture, and household sectors which contain biological as well

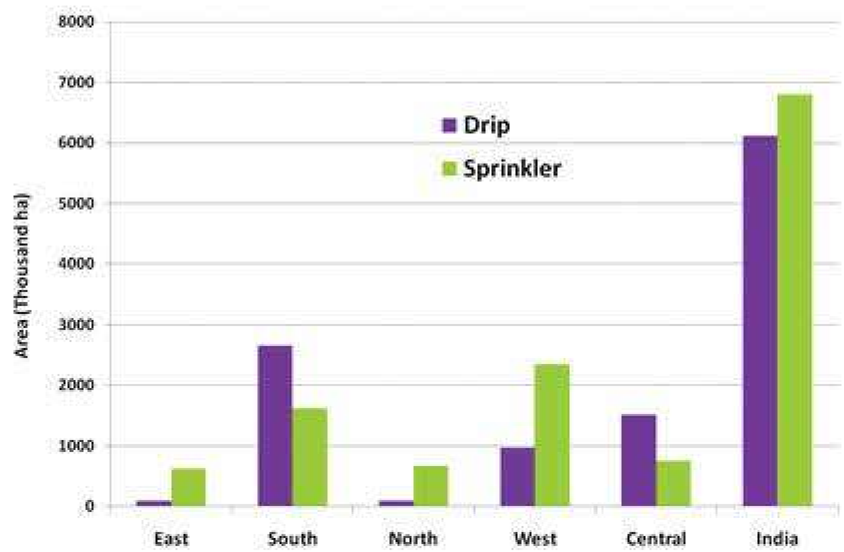

Figure 4. Spatial extent of drip and sprinkler irrigation in different regions of India (Source: GOI, 2020)

as toxic organic and inorganic pollutants. Municipal sewage and industrial pollution contribute about 75% and 25% of the point source pollution, respectively. Class-I and Class-II cities together generate an estimated 38,254 million litres per day (MLD) of sewage (CPCB, 2015) and it will increase by three-and-a-half times to 132,253 MLD by 2050. Both water quantity and nutrients contained in urban and peri-urban wastewaters make them attractive alternative water source for agriculture and aquaculture. Treated wastewater from off-site treatment plants can be reused for irrigation.

Strategies for Improved Water Management in Agriculture

Water Management Strategies in Rainfed Agro-ecosystems

Rainwater Conservation in Different Land Forms and its Efficient Utilization

Rainwater conservation/water harvesting using appropriate techniques at plausible sites and efficient utilization of harvested rainwater has been considered as the key water management strategy to improve the productivity of rain-fed agriculture. Some of the promising techniques are field bunding, contour bunding, farm pond, terraces, mulching, micro-catchment rainwater harvesting, tillage practices, check dam etc. The tank-cum-well system involves construction of tanks and wells in series along the drainage line in a watershed. The technology is recommended for plateau areas with slope of 2% to 5%. Contour bunding consists of constructing narrow based trapezoidal bunds on contour to impound runoff water behind them so that all the impounded water is absorbed gradually into the soil profile for crop use. Field bunding/contour bunding is adopted in flat to rolling lands (slopes less than 6%) to intercept the runoff flowing down the slope (Mishra et al., 1998). Dugout ponds are usually recommended in rainfed medium lands where water is not available for irrigation after monsoon prohibiting cultivation of *rabi* crop (Mishra et al., 2014). Rubber check dam is a flexible check dam, which is an inflatable structure built across a stream used for water conservation, flood control, and regulating flow of water in the stream.

Management of Waterlogged Areas

The development of irrigation projects in arid and semi-arid regions invariably led to the waterlogging and soil salinity problems in irrigation command areas. Hence, for optimal and sustainable use of irrigated agricultural lands, irrigation and drainage systems need to be designed, constructed and managed as an integral unit. Due to saucer-shaped topography and high monsoon rainfall, some parts of Eastern India remain waterlogged (> m surface water ponding). In these areas where the scope to dispose off the excess water is there, the excess water needs to be removed through surface or sub-surface drainage.

Surface drainage is the safe removal of excess water from the land surface through land shaping or construction of channels. Surface drainage in agricultural lands is needed to remove the excess rainfall as well as collection and disposal of excess surface irrigation water. Soils with low infiltration rates and heavy soils are susceptible to surface drainage problems. There are four types of drainage systems, mainly (1) random drain system, (2) parallel field drain system, (3) parallel open ditch system, and (4) bedding system.

Subsurface drainage refers to the removal of excess water present below the ground surface. It is required in agricultural land affected by high water table. While surface drainage removes the excess water before it enters the root zone, subsurface drainage lowers the water table and provides a better environment in the root zone. Tile drains including perforated pipes are a popular method of subsurface drainage.

Seasonal waterlogged areas constitute remarkable proportion of waterlogged area in Eastern India, where crop establishment has been a major problem. Such type of land ecosystem allows the cultivation of some aquatic crops like water chestnut which also facilitates fish integration and hence has a huge potential to generate additional net returns to the farmers. Land productivity of such lands can be enhanced tremendously by fitting a short duration *rabi* rice. The results of the on-farm study revealed that water chestnut fish integration resulted in enhancing the productivity of rice by 31.2%. Cultivation of Makhana with fish is another profitable option, which is more popular in waterlogged districts of Bihar.

Management of excess water in agricultural field is a major challenge globally as well as in India. Mitigation of problem of waterlogging through exploitation of transpiration potential of vegetation will not only provide an eco-friendly solution compatible to existing physical method but also the additional source of biomass in terms of timber, fuel wood, fodder etc. generating additional source of income. *Eucalyptus* and *Casuarina* can be used as potential bio-drainage plants.

Under submerged environment, waterlogging resistant varieties exhibit better adaptation and minimize yield loss. The farmers are recommended to grow rice varieties like CR 1009 and CR 1018 when water stagnation is up to 30 cm in the field. In case of submergence from 30 to 60 cm, rice varieties like Durga, Puja and Sarala can be grown for better resistance. However, when the field water level exceeds 60 cm, rice varieties like Varshadhan and

Hangseswari can be preferred. In case of flood-prone areas, farmers may cultivate flash flood tolerant varieties like SwarnaSub1 which can resist submergence of crop under flood water for about 10 days duration.

Management of Flood-prone Areas

The flood-prone areas are mainly found in the Eastern India where the lakes remain almost under-utilized but have the potential to yield 2.0 to 2.5 t ha^{-1} yr^{-1} of fish in semi-intensive culture system with suitable technological interventions. These lakes can be stocked with naturally collected or hatchery reared fingerlings of IMC (Indian Major Carps). The ox-bow lakes (defunct loops of rivers cut off from the main rivers) are also predominant in Bihar, West Bengal and Assam. Fish production in these lakes with cage and pen culture practices, and selective stocking of IMC can yield 1.5 t ha^{-1} yr^{-1} (Bhatt et al., 2012). To control flood hazard in low lying areas, where water recedes in about 4- to 6 months, there is a need to build check dams and ponds and to pump groundwater into the pond to ensure that level of water in low--lying areas does not decrease and full potential of fish yield can be harvested.

Strategies for Water Management in Irrigated Agro-Ecosystems

Groundwater Utilization and Management

After independence, the irrigated area has been increased many fold and the main contributor to this has been the tube wells. Between 2001-02 and 2014-15, net irrigation in India increased by 20%, with an alarming trend of massive groundwater extraction. While 41% of the net irrigated area in India got water from tube wells in 2001-02, tube well irrigation increased to 46% in 2014-15. Interestingly, during the same period, irrigation based on canal systems came down from 27% to 24% and well irrigation declined from 21% to 17% (**Figure 5**). Not surprisingly, area under groundwater schemes is increasing, but the irrigated area under surface water schemes is declining across India.

With this, the regional development has very high variation. Eastern region needs groundwater development and western region needs recharge. There is a need for enhanced government spending in the field of groundwater exploitation. A planned government intervention will also reduce the negative effects of groundwater exploitation such as excessive drawdown, land subsidence, and groundwater quality degradation. Groundwater withdrawal using open dug wells and tube wells should be designed in such a way that the total groundwater withdrawal should not exceed the groundwater recharge. Groundwater irrigation is more beneficial for irrigating low duty high value crops as it is costly because of energy required for pumping. Providing subsidy and encouragement to the farmers for opting to solar pumps can increase the groundwater use and bring down the area of fallow lands during *rabi* season.

During independence of our country the number of dug wells was seven hundred times more than the number of tube wells. Up to 1970, the growth of tube wells was minimal and between 1970 and 1988, the

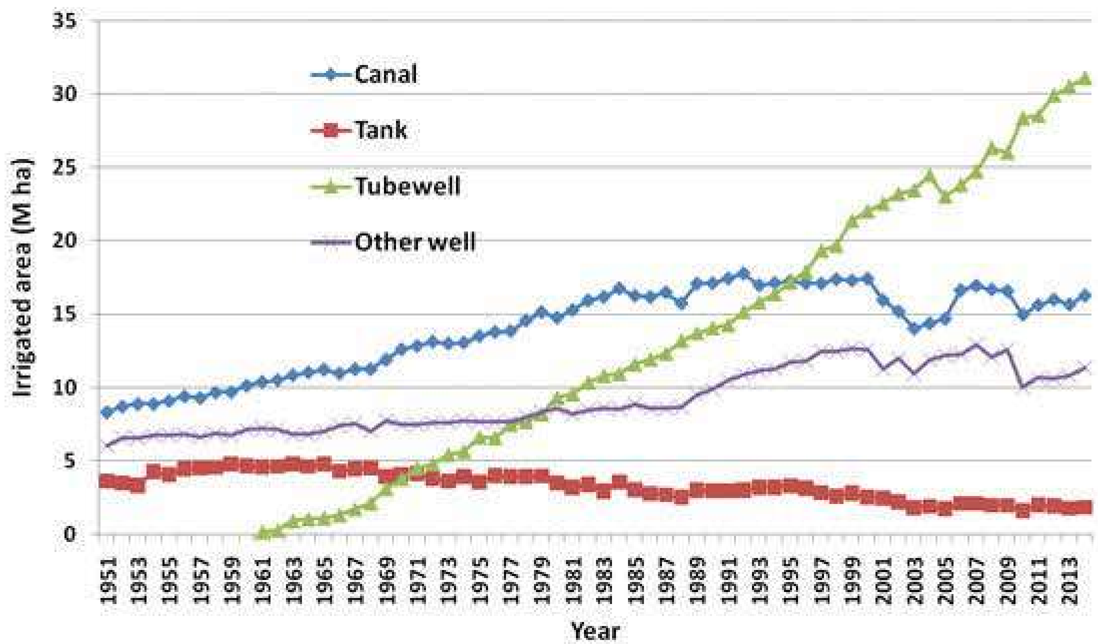

Figure 5. Temporal trend of irrigation in India

growth was linear and after 1990, the growth was exponential. Since 1960 the growth of dug wells was linear and reached its peak during 1994. After that the growth became negative. The number of tube wells overtook the number of dug wells during 2003 (**Figure 6**). Excess development of tube wells is causing harm to groundwater and creating secondary pollution. Recharge needs to be promoted and permission to dig tube well needs to be regulated.

Wells tapping the fractures in the hard rock aquifer are recommended for artificial groundwater recharge in such regions. Resistivity survey is recommended for identification of potential water bearing zones or fractures in the hard rock aquifer. Moreover, proper design of the filters should be ensured so that pollution of valuable groundwater resources is prevented. Also, in hard rock aquifers, implementation of watershed management structures like percolation tanks, check dams and field bunds may be recommended as suitable methods of groundwater recharge.

The geogenic contamination of groundwater with arsenic, fluoride and iron has caused havoc in India. For arsenic contamination one should avoid tapping groundwater from arsenic contaminated aquifer. Rainwater harvesting is essential. Conjunctive use of surface water and groundwater is a good option as it will dilute the effect of arsenic contamination. Treatment of groundwater for removal of arsenic using adsorption or precipitation and coagulation technique can be adopted. To combat fluoride contamination in groundwater and fluorosis mapping of contaminated area is needed. Some of the options available for removal of fluoride from drinking water are adsorption, ion exchange, Nalgonda technique, membrane technique, electro dialysis etc. To fight against iron contamination chemical oxidation, aeration and ion exchange method can be adopted.

Pressurized irrigation systems are more suitable in groundwater commands as there is less chance of clogging of the system. Initial cost of drip and sprinkler irrigation systems is relatively high. Hence, government has been providing subsidies for larger adoption of these pressurized irrigation systems in order to have better water use efficiency. Besides, there are other advantages like increased yield, saving in fertilizers, energy and labor. Thus, there should be concerted effort to bring more and more areas under pressurized irrigation system.

Efficient Utilization of Canal Water

Canal water management needs coordinated approach between individual, Pani Panchayat and State Government. Pani Panchayat or water users association (WUA) is a good initiative to manage the operation and maintenance of irrigation minors and sub-minors. However, they need to be strengthened substantially for enabling the members to get inputs at right time and right price. Further, WUAs may be involved in developing market infrastructure which is vital for crop diversification and value addition.

In order to have efficient utilization of water the canal delivery schedule should closely match with the crop water demand of the command. In this regard, based on the research result, an alternative canal delivery schedule was established for deltaic area irrigation system of Odisha through simulation model and a field experiment. Rotational schedule was found better than the prevailing continuous schedule. Efficient rotational delivery of canal water during *rabi* resulted in saving 10.3% water as compared to the continuous delivery system (Mishra et al., 2008).

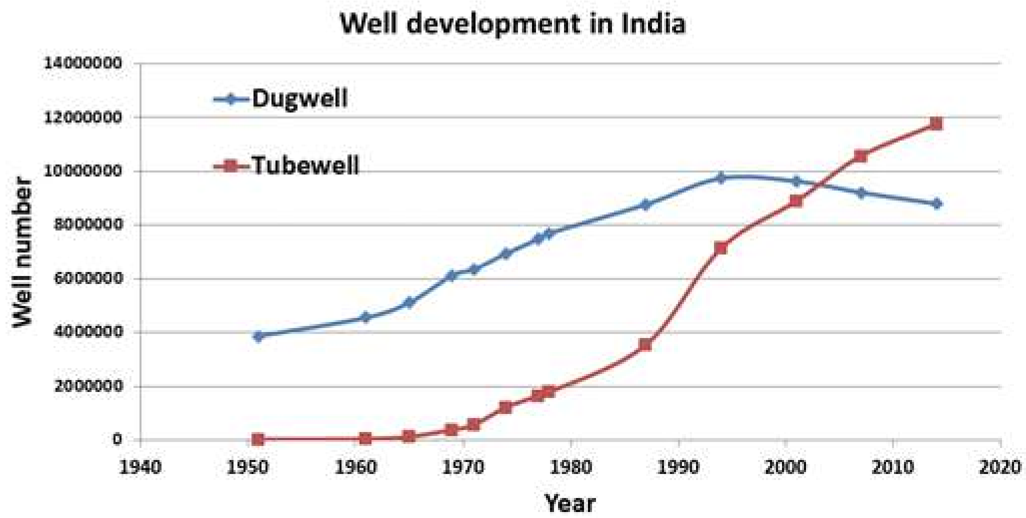

Figure 6. Chronology of development of wells in India

Secondary storage reservoirs in the command of the flow-based minor irrigation systems can be created to augment the water resource for irrigation during dry season. Secondary reservoir harvests rainwater during rainy season and excess irrigation water during each irrigation period. Optimal size of the secondary reservoir and optimal cropping pattern was computed through a multi-objective optimization routine for a minor irrigation system of Odisha (Mishra et al., 2009).

Warabandi is an organized way of water distribution to a large number of cultivators in the irrigation system. '*Warabandi*' means weekly rotation with each farmer getting water on a fixed day of the week. Each farmer gets an equal share of available water volume per unit area based on allocated time to his field. Raised and sunken bed system is a technology which can be used in waterlogging portions of canal commands. Here alternate raised and sunken beds are created by digging out soil from one strip of land and placing it on an adjacent strip. In the sunken bed, paddy can be cultivated and in the raised bed, vegetables can be cultivated.

There is a need to follow best water management practices in the outlet command to judiciously utilize the available irrigation water and improve the productivity. Use of field channel, pressurized irrigation methods, proper planting geometry, alternate wetting and drying in paddy crop, system of rice intensification, raised and sunken bed technology, land levelling etc. are some of the management practices which need to be followed appropriately.

Pressurized Irrigation System

In both canal and groundwater irrigated areas pressurized irrigation system will be helpful. Drip and sprinkler irrigation systems have become more popular pressurized irrigation systems in the country. They are more suitable in groundwater commands as there is less chance of clogging of the system. Application efficiency of drip irrigation system varies from 90-95%. The advantages of drip irrigation include about 50% saving in irrigation water, about 25% increase in crop yield due to frequent irrigation, improved fertilizer efficiency (saving of about 25% fertilizer), limited weed growth, less labor and energy requirement. Application efficiency of sprinkler irrigation system is about 75%.

Drip Fertigation for Better Water and Nutrient Use Efficiency

Fertigation is the application of fertilizer through irrigation water, preferably through drip. This allows fertilizer at a low rate to the vicinity of the root. It has been observed that in fertigation the nutrient absorption rate was 90% in comparison to granular application, where absorption rate was 40% (Pan et al., 2011). Drip fertigation is the most effective as it has high WUE with low loss of nutrient through runoff and leaching and minimize groundwater contamination. Urea is the most common and popular fertilizer used for drip fertigation. In the experiments under AICRP on IWM, it has been reported that drip fertigation can increase tomato yield by 71% over granular application of fertilizer (Nanda et al., 2021). For cotton, brinjal and chilli crops 25% NPK as basal and 75% NPK as drip fertigation is very remunerative.

Partial Root Zone Drying

The efficiency of drip can also be increased by partial root zone drying technique. Partial root zone drying (PRD) is an irrigation method in which water application is withheld from a part of the plant's root zone while the remaining part is irrigated. The irrigation is alternatively applied to each side of the root zone allowing the wet side to dry and dry side to wet. The PRD technique is suitable for horticultural crops including vegetables. It is more suitable for drip irrigation systems as alternating irrigation among two sides of the root zone is done more conveniently in the drip system. The partial root zone drying technology was evaluated for drip irrigated mango crop and highest water use efficiency was observed in 60% PRD treatment, which is 85% improvement over full irrigation treatment.

Sensor-based Irrigation

Automation in irrigation system would further save water and enhance yield over manual irrigation. The use of automated irrigation systems can provide water on a real-time basis at the root zone, based on the availability of soil water at the crop root zone, which also leads to saving of water (Ohja *et al*., 2015). Automated irrigation systems allow for high-frequency irrigation, thus maintaining the soil water potential relatively constant. Irrigation scheduling remains a reliable technique for applying the required amount of water at the appropriate time and automated irrigation systems based on crop water needs can maximize water use efficiency (Munoz et al., 2003). Ganjeer (2019) studied the use of automated irrigation over manual irrigation in wheat by use of humidity-controlled sensors and reported that maximum water use efficiency was obtained in sensor-based irrigation and there was 15.85% water saving through sensor-based irrigation. Panigrahi et al. (2021) studied automated drip irrigation and fertigation in banana crop based on soil moisture sensor and found that automated drip irrigation and fertigation system gave higher banana yield (70 t ha^{-1}) than manual drip irrigation system (60 t ha^{-1}) and surface irrigation system (44 t ha^{-1}). Sensor- based system also increased the water productivity of banana crop.

Strategy for Wastewater Management

Almost 80% of water supply flows back into the ecosystem as wastewater. This can be a critical environmental and health hazard if not treated properly but its proper management could help the water managers in meeting the water demand. Currently, India has the capacity to treat approximately 37% of its wastewater, or 22,963 million litres per day (MLD), against a daily sewage generation of approximately 61,754 MLD (CPCB, 2015). Wastewater is also generated from mining overburden sites. Judicious use of wastewater to grow crops will help solve water scarcity in the agriculture sector. To manage the harmful effect of wastewater one should go for restricted use of wastewater for irrigation. Restricted irrigation refers to the irrigation of crops not intended for direct human consumption, and thus covers the irrigation of industrial crops (*e.g.*, cotton, sisal, and sunflower); crops processed prior to consumption (*e.g*., wheat, barley, oats), and fruit trees, fodder crops and pastures. Filters can be used to reduce the harmful effect of wastewater. Bioremediation/phytoremediation of wastewater can be a good strategy for wastewater treatment.

Conclusions

In recent times India has made remarkable achievements in water sector, which is evident from the large growth in irrigated agriculture, increase in agricultural production, and advancements in drinking water supplies in rural and urban areas. In doing so, development of water resources has crossed the thresholds of physical sustainability in many areas, manifested by groundwater depletion, groundwater quality deterioration, dwindling supplies and increasing pollution of surface water. Recent advancements in water technology and water management in both the rainfed and irrigated ago ecosystems are capable enough to address and manage the challenges in water sector in India.

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Developments in Fertiliser (Control) Order

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Fertiliser (Control) Order 1985 has been the framework for regulating the supply and distribution of fertilizers in the country for more than 35 years. Since its introduction, FCO has been modified several times in response to the evolving requirements of the fertilizer sector. In continuation of the process of refinement and upgradation, which has been happening successfully over the years, FCO now needs to transform itself from a *regulating* to an *enabling* framework that will promote innovation in fertilizers to meet the challenges in agriculture. Several suggestions have been made by government committees and FAI members on the amendments that are required in FCO to facilitate the introduction of new and innovative fertilizers. In addition to easing the process of entry, it is also important to upgrade the quality management system to bring more transparency, speed, reliability, and moderation with respect to quality control and ultimately create a more enabling environment for innovative fertilizers.

Introduction

Fertilizer was included under the Essential Commodities Act in 1955 when indigenous production was limited; therefore, it was felt necessary to control production and distribution to avoid shortages. The rules currently in force for controlling the manufacture, import, quality, trade, sale, and price of fertilizers were introduced as Fertiliser (Control) Order in 1985. As fertilizer was viewed as scarce commodity, then the underlying theme of the order became that of regulation whereby it sough to define the boundaries within which the manufacturers, importers and distributors needed to operate.

Over the years, the FCO has been amended several times to incorporate new developments in fertilizer products, streamline enforcement mechanisms, and strengthen quality testing processes. Therefore, the boundaries defined by FCO are not rigid, rather these are flexible enough to incorporate feedback from various stakeholders – state departments of agriculture, agricultural research institutions, fertilizer industry, and central government departments dealing with fertilizers, food, and health.

This flexibility was clearly highlighted in the presentation by Dr. R.K. Tewatia, Director (Agricultural Sciences) of FAI during Webinar conducted by FAI on Recent Developments in FCO on 10 June 2021 (FAI, 2021). The presentation listed the amendments made to FCO in the last two years:

- A record number of products have been included in Schedule-1 of FCO in last 2 years.
- Two new Schedules namely Schedule-VI for Biostimulants and Schedule-VII for Nano fertilizers have been added in the FCO in February 2021.
- New category of liquid fertilizers with 8 new products has been introduced.
- The time limit has been reduced for dispatch of samples to 3 days, analysis of samples to 15 days, and reporting of results to 7 days.
- Provision of third analysis has been made.
- Reprocessing of fertilizer damaged during storage has been permitted.
- Tolerance limit for particle size has been relaxed.
- It has been made mandatory for every fertilizer testing lab to obtain NABL accreditation within a period of two years with effect from 28 September 2020.

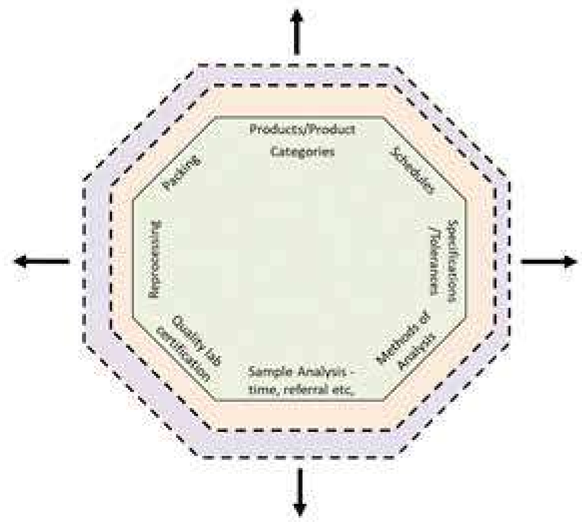

Figure 1. Gradual expansion of operating space defined by FCO

This clearly shows that the FCO is a dynamic and responsive framework rather than a static and rigid one. Therefore, the operating space defined by FCO has been expanding over time as depicted in **Figure 1**.

Recognizing this spirit of adaptiveness of FCO, this paper looks at ways in which FCO can become an enabling instrument for meeting the present challenges in agriculture as it governs the supply of one of the key inputs for agriculture.

Challenges in Agriculture and Fertilizer Productivity

It is established both globally as well as in India that fertilizers contribute to 50% of the agricultural output, which implies that if no fertilizers were applied, the yields would have dropped by half. Given that the agricultural production must increase to meet the food and nutritional requirements of growing population of the country, availability of highly efficient fertilizers will be essential for meeting the stiff production targets. The role of fertilizers in enhancing food production has become more challenging in the present scenario as the fertilizer application has to be both effective and sustainable to achieve high productivity with minimum adverse impact on environment and biodiversity.

Higher food production must now come from same or lesser area of land which means that productivity in terms of food production per hectare must increase. When this is coupled with the fact that environmental and resource constraints will tend to restrict the kg of nutrients applied per hectare, the agricultural productivity in terms of food production per kg of nutrients applied must increase even more dramatically to achieve higher food production per hectare. Stated differently, more food must be grown with the same or lesser quantity of nutrients. This is represented by the equation in **Figure 2**.

$$\textit{Productivity} = \frac{\textit{Production}}{\textit{Land}} = \frac{\textit{Production}}{\textit{Inputs}} \times \frac{\textit{Inputs}}{\textit{Land}}$$

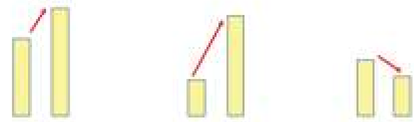

Figure 2. Increase in input productivity needed to achieve higher agricultural productivity

In this equation, inputs can refer to nutrients, though the same would also be true for other inputs such as water and agrochemicals. Therefore, higher agricultural productivity can only be achieved through higher partial factor productivity (PFP) of fertilizers which is expressed as food production per kg of nutrients applied. In this paper, PFP of fertilizers is referred in short as fertilizer productivity.

Increasing Fertilizer Productivity

Some of the challenges in raising the fertilizer productivity are enumerated below:

1. Declining soil health with respect to organic carbon content, moisture infiltration and water holding capacity, microbial population, acidity, alkalinity, etc.
2. Low nutrient efficiency of traditional fertilizers leading to nutrient losses to environment and therefore, lower uptake by crops.
3. Use of high analysis fertilizers with single or two nutrients and without secondary and micronutrients.
4. Impact of abiotic and biotic stresses.
5. Sub-optimal nutrient management with respect to rate of application, time of application, and placement of fertilizer at the right depth.

Impact of these limiting factors can be mitigated fully or partially using innovative fertilizers i) having higher nutrient use efficiency (NUE), ii) incorporating soil conditioners along with plant nutrients, iii) supplying secondary and micro-nutrients along with NPKs, iv) supplementing plant nutrients with ingredients which provide stress resistance, and v) possessing superior physical properties for precision application by machines.

The new types of fertilizers can combine many

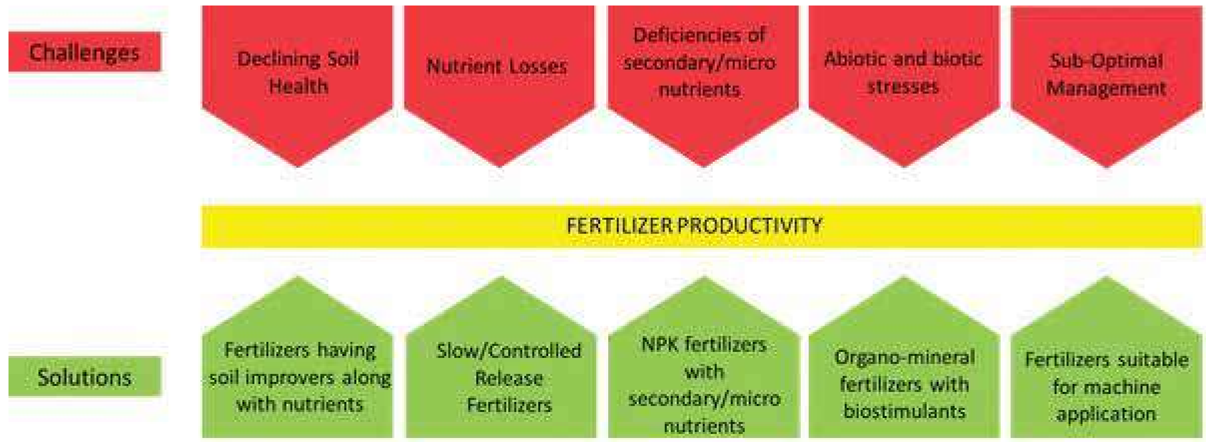

Figure 3. Attributes of new fertilizers for addressing challenges in agriculture affecting fertilizer productivity

features in one single product – high nutrient use efficiency, soil conditioning, balanced nutrition, stress resistance, and precision application. The physical forms of these fertilizers can be granules, powders, liquids, microgranules, suspensions, gels, etc. These should be suitable for application by machines such as drills, boom sprayers, drones, etc. which can be guided by digital models to deliver the precise dose at the right place and depth.

As depicted in **Figure 3**, fertilizer productivity can be enhanced using highly efficient innovative fertilizers which incorporate several features to overcome the current limiting factors. FCO, which governs the registration process for new fertilizers, can act as a catalyst for enhanced fertilizer productivity through creation of an enabling environment for introduction of novel fertilizers.

Introduction of Innovative Fertilizers

Recognizing the need for introduction of new fertilizers, a working group on Promotion of New/Alternative Fertilizers was set-up by government in April 2020. Very useful recommendations have emanated out of the deliberations in this working group (Anonymous, 2020). One of the recommendations of the sub-group on inorganic fertilizers of this working group is given below:

- *Innovative/alternate fertilizers, such as nano, slow/controlled release, coated, fortified, chelated, organo-mineral, liquid fertilizers, bio-stimulants, customized fertilizers, etc. should be promoted for use in combination with traditional fertilizers and manure/compost. Specifications of these products should appropriately be included in Fertilizer Control Order.*

The sub-group on organic fertilizers of the working group on Promotion of New/Alternative Fertilizers also made the following suggestion in its draft report:

- *Accord immediate approval of bio/mineral fortified organic fertilizers with known ingredients and dispense with the requirement of data generation. May be approved based on label claims.*

In the context of the recommendations given by the sub-groups of the Working Group, it is useful to study the current landscape of product categories in relation to FCO. This is presented in **Figure 4**.

The flexible approach of FCO towards inclusion of new product categories is demonstrated by **Figure 4** as FCO includes many different types of fertilizers. Some of the categories recommended by the working group such as nano fertilizers, biostimulants and liquid fertilizers have been recently included in FCO.

It is suggested that the following categories should also be considered for inclusion as these have been recommended by the two sub-groups of the working group on the Promotion of New/Alternative Fertilizers:

1. Slow/controlled release fertilizers
2. Organo-mineral fertilizers
3. Bio/mineral fortified organic fertilizers

Slow/controlled release fertilizers offer much higher NUE which in turn leads to lower nutrient dosages and consequently higher fertilizer productivity. Recognizing the importance of such fertilizers, Government has recently commissioned a Foresight Report through Technology Information, Forecasting and Assessment Council (TIFAC) of Department of Science & Technology in September 2020 on Future Prospect of Controlled Release Fertilizer in India (Macro & Micronutrients) (TIFAC, 2020). The report

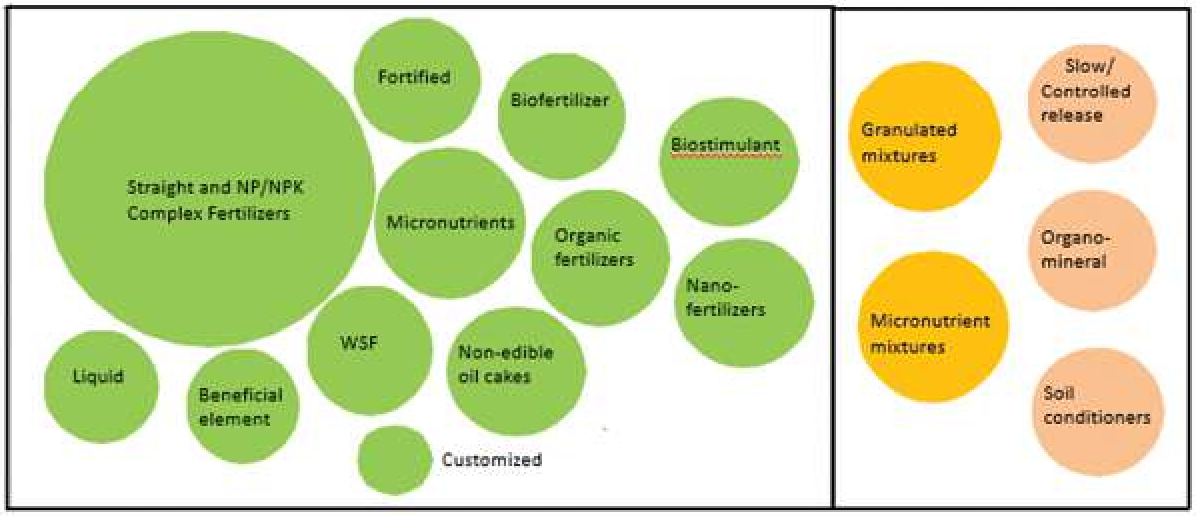

Figure 4. Landscape of product categories with relation to FCO

seeks to study different scenarios) for replacement of conventional fertilizers with controlled release fertilizers and recommend actions for large scale adoption of such fertilizers.

Organo-mineral fertilizers also supply biostimulants along with nutrients and therefore, help to combat, the stresses which can affect plant health and consequently nutrient uptake. Bio/mineral fortified organic fertilizers provide both mineral nutrients and organic matter to the soil and are beneficial, therefore, for crop productivity and soil health. The category of soil conditioners may also be considered for inclusion in FCO as this would ensure that quality products are used as soil amendments/ameliorants/ conditioners.

Granulated mixtures and micronutrient mixtures continue to be outside the purview of FCO as these are regulated by the States. It is recommended that these products be also brought under FCO to bring uniformity in the grades and quality standards across different States.

It is clear from the above discussion that FCO has demonstrated flexibility towards inclusion of new product categories though there are some which still need to be added to FCO to cover the entire landscape of fertilizer products. While many new categories have been included in FCO, the registration of new fertilizers under any particular category continues to be a time-consuming process which acts as a disincentive for the introduction of innovative fertilizers.

Registration Process for New Fertilizers

One of the stumbling blocks for introduction of new products in FCO is the unusually long registration process. Several suggestions for easing and simplifying the registration process were made by Mr. Sanjiv Kanwar of Yara in his presentation in the FAI Webinar on 10 June 2021. These recommendations are summarized below:

1. General specifications for macro, secondary and micronutrients
2. No efficacy trials for nutrients approved in the FCO
3. Time bound approval process
4. Permission to make label claims

These recommendations are based on a study of the regulations in Europe, USA, and Japan. The central idea governing these regulations is that the fertilizers should meet certain minimum nutrient values and if these are supplying known and approved nutrients, there is no need to seek approval for every combination of nutrients.

An important point highlighted by Mr. Sanjiv Kanwar regarding regulations in Europe is that in addition to nutrient values, they also regulate the levels of contaminants in fertilizers such as cadmium, lead, and arsenic which originate from the raw materials. This is also very important from the Indian perspective as India is a large importer of fertilizer raw materials from different sources in the world and it is important to ensure that only those raw materials are used which do not contribute to higher levels of heavy metal impurities in fertilizers as these may eventually will end up in the food chain. Therefore, the general specifications in FCO can also have maximum limits for these heavy metal impurities.

FCO has already implemented the principle of general

ELEMENTS	EXISTING	PROPOSED
Nutrient Values	Nutrient values of every product evaluated	General specification for nutrient values
Efficacy Trials	Efficacy data required to demonstrate nutrient effect	No efficacy data required for approved nutrients
Contaminants	No limit on contaminants	Max limit for contaminants
Label Claims	No label claim allowed	Label claim with supporting data
Time	No time limit for registration process	Time bound process for registration

Figure 5. Comparison of existing and proposed requirements for registration of new products

specifications for water soluble mixture of fertilizers. As this process is working successfully, the same can be extended to other categories of inorganic fertilizers.

Similarly label claims have been allowed for biostimulants in the recent notification in FCO. The label claim must be supported by data from agronomic trials to demonstrate the benefits relating to improvement in yield, quality, nutrient efficiency, and stress tolerance. The same idea of allowing label claims based on agronomic data can be extended to other categories of fertilizers.

The recommendations for general specifications and label claims have also been made by Dr. K.K. Singh of Adventz and Mr. V.S. Sirohi of KRIBHCO during the FAI Webinar on 10 June 2021.

Comparison of the existing and proposed requirements for registration of new fertilizers is shown in **Figure 5**. It is hoped that this proposed system will not only simplify the process of registration with respect to time involved but also expand the scope of registration to areas not covered in the existing system.

Quality of Fertilizers

Along with the introduction of new and innovative fertilizers into the country, it is also necessary to strengthen the quality management system under FCO as the current infrastructure is inadequate to meet the requirements of the new fertilizers. This has been highlighted in the draft by the inorganic sub-group of the Working Group on Promotion of New/Alternative Fertilizers reproduced below:

- *Present infrastructure for quality assessment of fertilizers is grossly inadequate. Fertilizer testing facilities need to be updated for effective quality control. Sophisticated fertilizer quality control laboratories with state-of-the art equipments and automated analytical techniques should be established with dedicated and trained manpower. Number of NABL-accredited labs need to be increased for ensuring countrywide better and uniform quality control.*

- *Testing methods of the products mentioned in FCO need to be updated and modernized for higher accuracy and also to save time. This is specially required for delivering quick results of the samples withdrawn from imported materials and subsequently informed to the importers. Current lead time is minimum 45-60 days. New testing method might reduce this lead time to 15 days.*

Detailed recommendations on the quality management system were made in the presentations by Dr. Amit Rastogi, Dr. K.K. Singh, and Mr. V.S. Sirohi during the FAI Webinar on Recent Developments in FCO on 10 June 2021. Some of the key recommendations are summarized below:

- Automation of analysis and establishment of sophisticated labs
- Web-based system for timely communication of reports of analysis
- Rationalization of tolerance limits
- Appropriate redressal mechanism with respect to cases involving quality
- Enforcement to differentiate between adulteration, laxity during manufacturing, and variation beyond control of producer, and
- Time bound process for quality inspection of import consignments.

It must be mentioned that Department of Agriculture, Cooperation and Farmers Welfare (DOAC&FW) of the MOA&FW, GOI has already effected changes in FCO to improve the quality management system. Notably, the notified fertilizer quality testing labs are now required to obtain NABL certification, time limits for analysis and reporting of results have been reduced, and provision of third analysis has been made. The other recommendations given during the FAI Webinar may also be considered by the DOAC&FW to bring

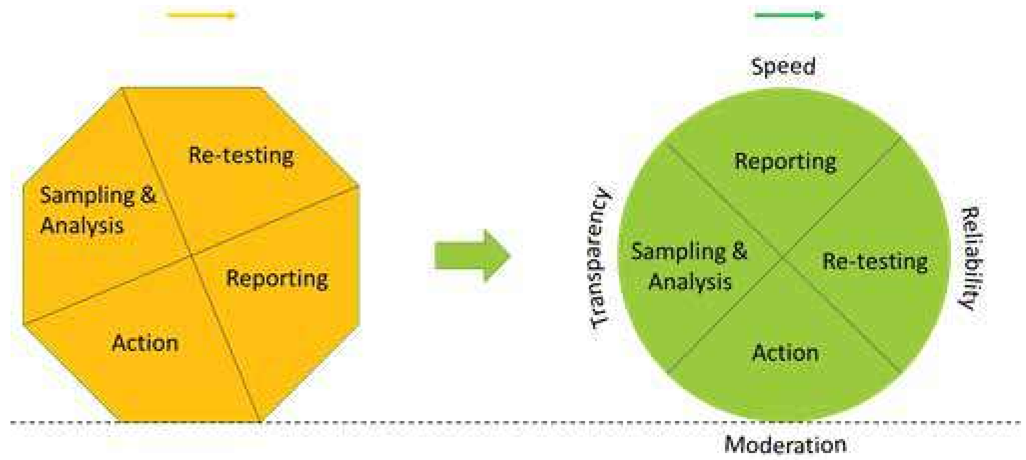

Figure 6. Improving the current quality management system for a smoother journey towards quality fertilizers

more transparency, speed, reliability, and moderation in the quality management system as this will make the journey towards supply of quality products smoother and easier to navigate. Schematic pathway is depicted in **Figure 6**.

Summary and Conclusions

Fertiliser (Control) Order 1985 has been continuously evolving over the years in response to the emerging requirements of the fertilizer sector. Now there is a need for its further upgradation to meet the challenges in agriculture through introduction of next generation fertilizers. Government has already instituted various committees to recommend steps for easing the process of introducing innovative fertilizers into the country. Fertiliser Association of India (FAI) has also played an active role in bringing various stakeholders together to propose changes to FCO which will transform it from a purely regulating framework to a more enabling one.

Major recommendations given by various government committees and FAI members to restructure the FCO have been highlighted in this paper. These recommendations will facilitate the introduction of innovative fertilizers which are required to achieve higher fertilizer productivity and consequently higher agricultural productivity. Proposed actions relate to both the registration process and the quality management system. These actions will create a more conducive environment for manufacture and supply of new fertilizers which will give farmers a wider set of options for improving yields and quality of produce, and sustaining soil health. The consumers will benefit from increased availability of safe, nutritious and better quality food.

Acknowledgements

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SESSION – III

SUSTAINABLE FERTILIZER PRODUCTION

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Integration is Key to Green Ammonia Viability

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KBR has developed the K-GreeN[SM] technology package, which consists of a fully integrated solution from the electrolysis of water to produce green hydrogen, separation of air to produce green nitrogen to the synthesis of green ammonia.

The KBR ammonia synthesis section is a proprietary design with proven unmatched reliability and lower energy consumption at lower capital cost (due to lower equipment count). We also offer the most efficient Nitrogen Generation Unit (ASU) and electrolyzers. KBR provides the licensed technology package with associated performance guarantees and delivery of critical equipment (including ammonia converters, loop waste heat boiler and unitized chiller). As part of critical equipment, KBR can also supply the electrolyzers and the Nitrogen Generation Unit (or ASU).

I. Introduction

KBR has developed the K-GreeN[SM] technology package, which consists of a fully integrated solution from the electrolysis of water to produce green hydrogen, separation of air to produce green nitrogen to the synthesis of green ammonia **(Figure 1)**. Integration of all steps is the key for consistent and reliable production of cost effective green ammonia. In developing its K-GreeN[SM] concept, KBR has leveraged on its past 75+ years of experience in designing ammonia plants, from very small capacity (~100 MTPD) to the largest single train capacity (6,000 MTPD).

The core of each ammonia plant is the synthesis loop ("Synloop"), where hydrogen (H_2) and nitrogen (N_2) are partially converted to ammonia (NH_3) according to the following exothermic reaction:

$$3H_2 + N_2 \leftrightarrow 2NH_3$$

Since the conversion is equilibrium-limited, the unconverted reactants are separated from the ammonia product and recycled back to the reactor after purging inert (such as argon), if any.

Feedstocks for the synthesis of green ammonia are:

- Hydrogen, generated from electrolysis of water by using renewable energy, such as solar or wind or hydro power
- Nitrogen, generated from separation of air, typically using a cryogenic system

Within a green ammonia complex the greater energy consumer is the electrolysis system that accounts for more than 90% of the overall power consumption.

If electrolyzers are driven by renewable power only, then storage of hydrogen is necessary to allow continuous operation of the synloop: unlike the electrolyzers that can operate on intermittent basis, synloop, as well as air separation unit ("ASU") must run continuously within an operating range, which is typically 60-100%. This range can be extended further and KBR has proven design to operate between 30% and 110%. Turndown lower than 30% is also possible and can be assessed on case-by-case basis.

By switching off the electrolyzers, when renewable power is not available, the power need of the complex is drastically reduced to less than 10%. Nevertheless, the complex needs to be connected to the grid to be able to maintain the synloop and ASU in operation constantly at its lowest turndown

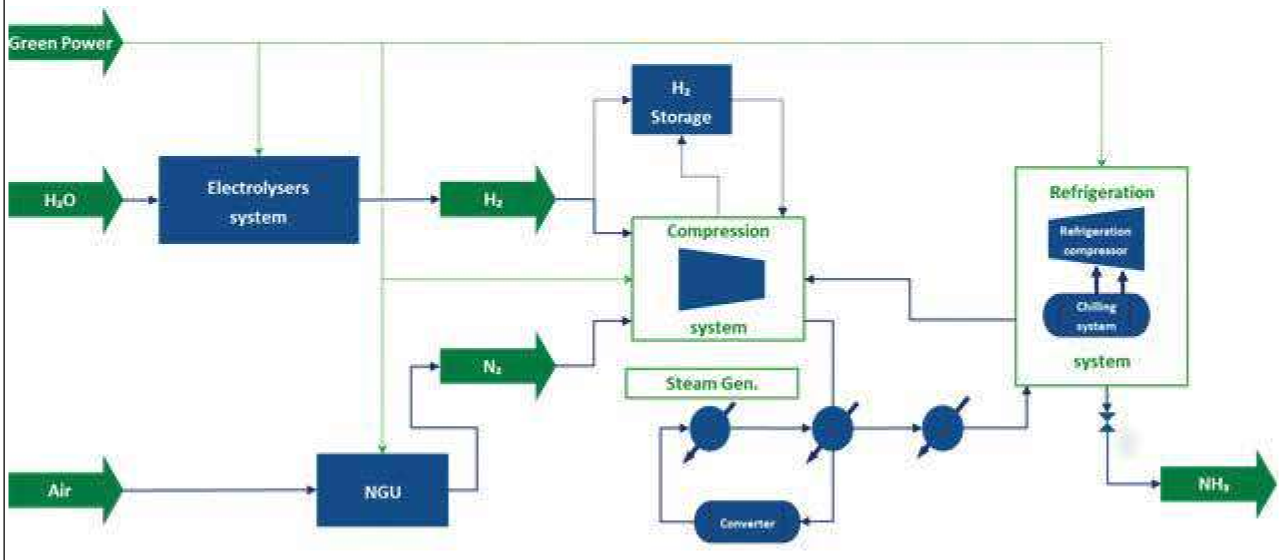

Figure 1. Block flow diagramme for K-GreeN® ammonia plant

ratio. Alternatively, renewable electric energy could be stored in batteries.

The electrolysis system is also the major component in the investment cost. Moreover, if they are operated only part-time, the investment cost is amortized on smaller quantity of product with a drastic increase in the levelized cost of production.

Electrolyzers could be operated using electric power from the grid when the renewable power is not available. In such a case the cost of the power from the grid will also play an important role in selecting the best configuration of the plant: if price rates of the power from the grid vary over 24 hours, then hydrogen storage should be designed to at least cover the peak hour price rates.

Electrolyzers operate at a pressure in a range between atmospheric to up to 40 bar. The air separation unit typically generates nitrogen at less than 10 bar. The synloop typically operate in the range 100-150 bar. Hydrogen storage can be at 30-80, 200, 300, 500 bar or more.

Designing an integrated compression system that takes into consideration the different pressure levels at which each unit operates, will play a key role in minimizing the investment cost and optimizing the energy consumption during the operation.

The conditions (pressure) and size of hydrogen storage is another key factor in assessing the economic viability of a project and need to be part of the overall feasibility study.

In coming paragraphs, we shall see more details of key sections of Green Ammonia process.

II. Electrolyzers

Hydrogen is produced from electrolysis of water. Electrolysis essentially means "breakdown (lysis) via electricity". Electrolysis uses direct electric current to drive a chemical reaction, in this case, HO is converted into hydrogen and oxygen. When the power used to drive the process utilizes renewable power source like sun or wind, this process produces zero-carbon hydrogen and oxygen. There are three main types of electrolyzers available:

i. Alkaline Based

- Uses a liquid electrolyte solution such as potassium hydroxide (KOH) or sodium hydroxide (NaOH), and water **(Figure 2)**.
- The hydrogen is produced in a "cell", which consists of an anode, cathode and membrane. These cells are typically arranged in series in a "cell stack" to generate more hydrogen and oxygen.
- When current is applied on a cell stack, the hydroxide ions move through electrolyte from the cathode to the anode of each cell, with hydrogen gas bubbles generated on cathode side of the electrolyzer and oxygen gas at the anode.

ii. Proton Exchange Membrane (PEM)

- PEM electrolyzers use a Proton Exchange Membrane, which uses a solid polymer electrolyte **(Figure 3).**

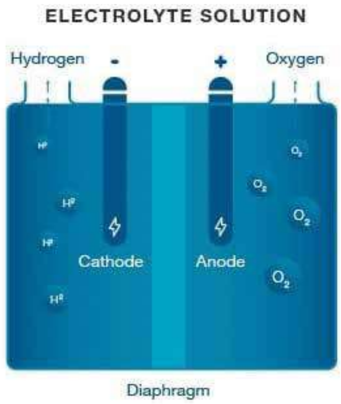

Figure 2. Alkaline based electrolysis

- When current is applied on a cell stack, the water splits into hydrogen and oxygen and hydrogen protons pass through the membrane to form H_2 gas on the cathode side.
- PEM provides high flexibility to meet the power fluctuations from renewable energy.

iii. Solid Oxide

- Solid oxide electrolyzer uses solid ceramic material as the electrolyte **(Figure 4).**
- Electrons from the external circuit combine with water as the cathode to form hydrogen gas and negatively charged ions. Oxygen then passes through the solid ceramic membrane and reacts at anode to form oxygen gas and generates electrons for the external circuit.

iv. Others

There are other technologies of water electrolysis (e.g. AEM or Anion Exchange Membrane) in development with different scales of TRL (Technology Readiness)

Table 1 summarizes some key performance indicators of four electrolyser technology today and in 2050.

III. Synthesis Loop

i. Overview

The makeup gas for green ammonia plants consists of hydrogen generated from electrolyzers and nitrogen generated from air separation unit. Since, that make up gas contains no carbon oxides and water, which are poisons to the synthesis catalyst (removal of oxygenated compounds in the hydrogen from electrolyzers might be required depending on electrolysis technology), it can be directly fed to the converter, joining with the recycle gas. Also, the make up syngas has little inert, which provides a low inert synthesis loop with high partial pressure of reactants H and N. This process scheme has two advantages.

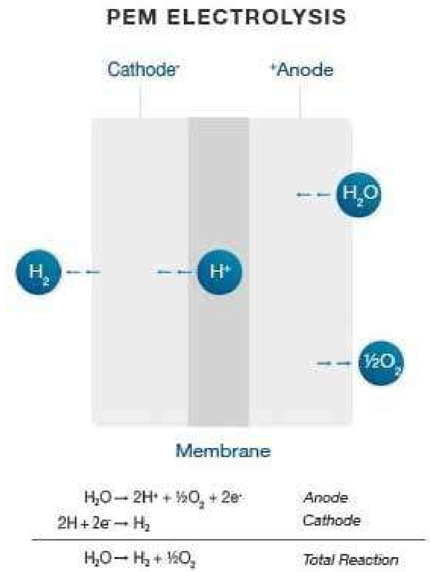

Figure 3. PEM electrolysis

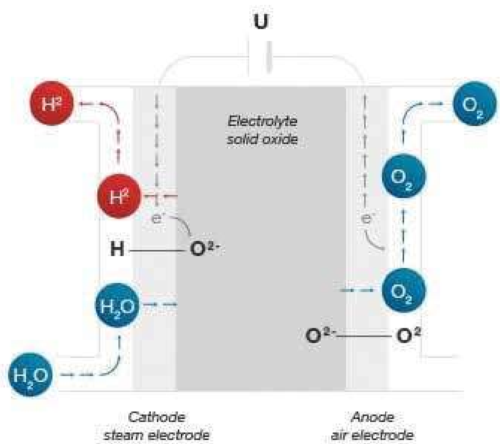

Figure 4. Solid oxide electrolysis

- First, refrigeration requirements will be lower than other schemes, in which the moisture containing make up gas is mixed with converter effluent to first pass through the chilling train before going back to the converter.
- Second, the ammonia converter capacity is increased because of lower ammonia content in the feed as a result of mixing the ammonia free make up gas with the recycle gas. The low inert level in the make up gas also permits operation of the synthesis loop at lower pressures for a given level of refrigeration, saving syngas compressor power.

Due to very low inert contents in a synloop, loop pressure can be significantly lower and lesser catalyst

Table 1. Courtesy of IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5pC Climate Goal,

	2020				2050			
	Alkaline	PEM	AEM	SOEC	Alkaline	PEM	AEM	SOEC
Cell pressure [bara]	< 30	< 70	< 35	< 10	> 70	> 70	> 70	> 20
Efficiency (system) [kWh/KgH_2]	50-78	50-83	57-69	45-55	< 45	< 45	< 45	< 40
Lifetime [thousand hours]	60	50-80	> 5	< 20	100	100-120	100	80
Capital costs estimate for large stacks (stack-only, > 1 MW) [USD/kW_{el}]	270	400	-	> 2 000	< 100	< 100	< 100	< 200
Capital cost range estimate for the entire system, >10 MW [USD/kW_{el}]	500-1000	700-1400	-	-	< 200	< 200	< 200	< 300

Note: PEM = Polymer Electrolyte Membrane (commercial technology); AEM = Anion Exchange Membrane (lab-scale today); SOEC = Solid Oxide Electrolysers (lab-scale today).

is needed. Thus, efficient ammonia plant with lesser compression power is achieved with significantly less CAPEX given in **Photo 1** of KBR systhesis ammonia loop.

In the KBR synthesis scheme for medium-large scale, ammonia synthesis is carried out in a single proprietary designed horizontal, three-bed converter.

Refrigeration in the synloop uses KBR proprietary designed unitized chiller. This exchanger takes the place of several refrigeration chillers and a recycle exchanger, thereby eliminating expensive high-pressure piping and fittings and significantly reducing the pressure drop compared to the sum of individual chiller pressure drops. The basic concept of this unit is the use of concentric tubes and a compartmentalized shell to replace several equipment items with one.

Due to the highly pure synthesis loop make up gas, the life of the ammonia synthesis catalyst is estimated more than 15 years.

The synloop design for medium-large capacity also incorporates high-pressure steam generation, which improves overall heat integration and improves energy efficiency. The steam generation can be at different pressure and temperature levels. KBR's technology has capability to generate superheated steam for use in steam turbine. This is important, when Green Ammonia plant is standalone and there is no requirement of steam in OSBL. The steam can be utilized for operating turbogenerator and produces electricity.

All the compressors are driven by motor drives provided with variable frequency drive (VFD). By doing so, start-up steam requirement is avoided and no OSBL boiler is required. This also helps in improving the response time of compressors against any capacity changes. Also, start-up is faster as there is no requirement of initial heating as is case with steam turbine.

The typical fired heater for start-up that is usually part of a conventional ammonia plant is replaced with electric start-up heater. Electric heaters are easy to start with minimum operator interventions. These can be started without any hold time/start-up time and thus, are faster in response than fired heaters. The electric heater also plays a key role when change in operating capacity of the synloop is required to cope with fluctuating renewable energy.

KBR's superior process design is complemented with a number of outstanding mechanical design features.

Advantages of process scheme:

- Well-proven design.
- Reduced number and optimised design of the high-pressure equipment, which is the most expensive part of the plant, and particularly the converter system and the chilling system.
- KBR's horizontal converter – design well-proven, having been used in more than 20 KBR ammonia plants since 1983.
- Unitized chiller – This equipment combines the feed/effluent exchanger, several chillers, and the compressor knock-out drums into one equipment item.
- Steam generation – Superheated steam generation making loop energy efficient.
- No start-up boiler required.

ii. Summary

- Reduced capital cost (CAPEX) due to fewer pieces of equipment
- Reduced bulk equipment costs ➔ lower CAPEX
- Reduced construction cost ➔ lower CAPEX
- Reduced operating cost (OPEX) due to lower loop pressure drop
- Reduced maintenance cost associated with fewer pieces of equipment
- Robust and reliable steam generation and superheating with process gas

IV. Turndown Capability

Turndown operation of ammonia synthesis loop is important when the renewable energy is not always available. To minimize the requirement of hydrogen storage, it is required to turndown the operation of ammonia plant. Synloop has been designed to be able to operate with a minimum turndown ratio in order to cope with the variable availability of hydrogen generated. Some key features of that design are:

- KBR proven design for operation range from 30% to 100%. Lower turndown is in principle possible.
- Electric heater with fast operation employed to prevent loss of reaction in ammonia converter during ramp-up / ramp-down.
- As long as the design conditions of material are not exceeded, minimal impact on plant integrity is expected. Compressors might require more frequent maintenance.
- It is possible to operate the Ammonia plant within an operating range of 30 to 110%. However, not all pieces of equipment can be turn-downed to 30%. In particular, most of rotary equipment operate at a minimum turn-down of 70-80% hence power consumption cannot be reduced proportionally to the capacity, unless redundant pieces of equipment are installed, e.g. two parallel compressors, each for half capacity, instead of a single full capacity item.
- In addition, for capacities below 60-70%, start-up heater shall be started to provide adequate heat to sustain reaction in the ammonia converter. Therefore, when capacity of ammonia plant reduces below 60-70%, the specific power consumption of Ammonia plant starts increasing to account for power consumption of start-up heater.
- Similarly, power consumption in Air Separation Unit (ASU) and utilities are not reduced in proportion to ammonia plant capacity.
- On the other hand, electrolyzer tends to operate more efficiently as capacity reduces. From 100% to 20% capacity, the energy consumption reduces. Taking into consideration that the large majority of the overall power consumed in a green ammonia plant is due to the electrolyser, the increase of electrolyser efficiency at lower capacity can partially or entirely offset the reduced efficiency of the ASU and ammonia synthesis at reduced capacity.

V. Dynamic Simulation for Optimization

KBR can perform dynamic simulation of the green ammonia plant to analyze various configurations of the complex with the aim of:

- Studying the impact of intermittency of green hydrogen flow to the ammonia synthesis and providing solution to minimize the impact of such disturbance to the process.
- Identifying acceptable range of hydrogen flow variability within one-minute time once flow is established.
- Assessing requirements in operation and control schemes for smooth operation of the plant at various conditions.
- Defining the optimum pressure in hydrogen storage and recommended inventory amount.

VI. Green Ammonia Economics

The project economics vary from region to region with factors like the profile of renewable energy

Photo 1. KBR Ammonia Synthesis Loop

source (solar, wind, hydro or hybrid), the cost of renewable energy and the capacity playing the most important role.

i. Feedstock, fuel and electricity cost comparison to produce green vs. grey ammonia

Regions like India, where the cost of natural gas is high due to imported gas, the production of green ammonia could be cost-competitive.

Figure 5 shows a comparison of variable direct cost for feedstock, fuel and electric power (F&F+EP) to produce one ton of grey ammonia (assuming natural gas price at $10/MMBTU) and one ton of green ammonia at various cost of electric power.

With a cost of electricity lower than $25/MWh, the variable direct cost (F&F+EP) to produce green ammonia is lower than to produce grey ammonia with NG at $10/MMBTU. Levelized cost of energy (LCOE) as low as $13.2/MWh has been recently recorded for solar photovoltaic (PV) power[1].

[1]August 2020 - Spanish company Enerland bid a new record low price of 11.1 euros/MWh ($13.2/MWh) in Portugal's latest solar auction, for a 10 MW project, according to media reports.

Enerland's bid pips the record $13.5/MWh tariff set by the giant 2 GW Al Dhafra project in Abu Dhabi in April 2020 and was 24% lower than the lowest price recorded in Portugal's previous auction in June 2019.
https://www.reutersevents.com/renewables/solar/portugal-sets-record-low-global-solar-price-california-probes-power-mix-after-heatwave-woes

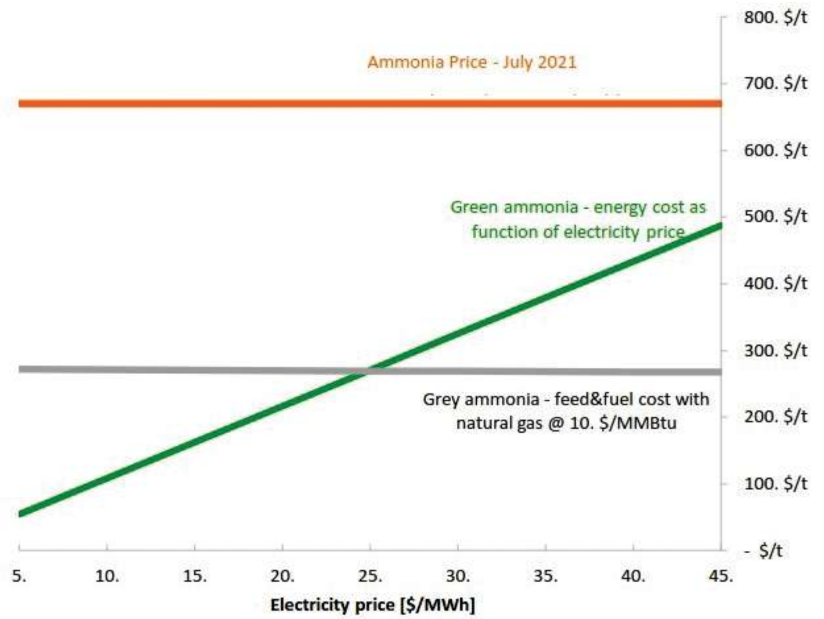

Figure 5. Graph shown cost of production of ammonia from different sources. Cost only includes raw material cost

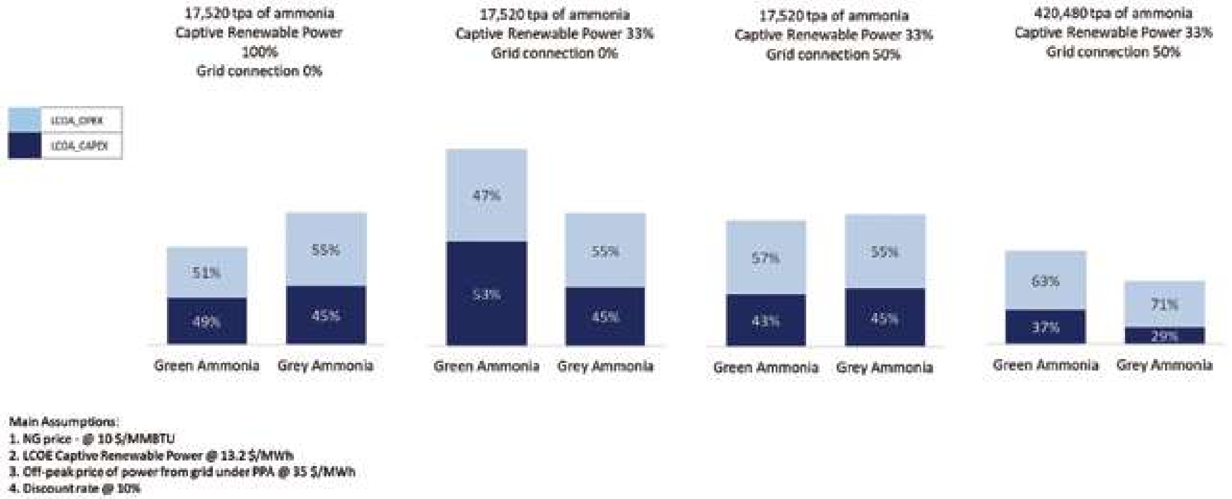

Figure 6. Opex and Capex of LCOA for different scenarios of power availability

ii. Levelized Cost of Ammonia

The energy availability and size of plant has high impact on the levelized cost of ammonia (LCOA) produced. This is depicted in bar charts shown in **Figure 6**, which indicate different scenarios of energy availability and capacity. Assumptions about cost of natural gas and LCOE are in line with the previous paragraph.

In the first case, it is assumed that captive renewable power at very low LCOE is available all the time, so there is no requirement of hydrogen storage and electrolyzers can operate continuously. Assuming a small production of ammonia of approx. 50 metric tons per day (MTPD), which corresponds to approx. 20MW electrolyzer, the levelized cost for green ammonia is lower than for grey ammonia.

In the second case, it is assumed that the captive renewable power at low LCOE is only available during eight hours per day, so hydrogen required for 24 hours of operation is generated in eight hours. This case requires three times the nominal electrolyzer capacity and big hydrogen storage. This significantly increases the CAPEX and OPEX of the plant and even for a small capacity of 50 MTPD grey ammonia becomes more cost-effective.

In the third case, it is assumed that grid connection is possible to top-up the captive renewable power with renewable power available up to 20 hours of day. The renewable power purchased from grid is however at higher cost compared to the captive one. Nonetheless, this significantly reduces the size of electrolyzer from the second case and also lowers hydrogen storage. As a result, the levelized cost to produce 50 MTPD of green ammonia is almost the same of the one for grey ammonia.

The fourth case represents the advantage of achieving economy of scale by higher capacity (approx. 1,200 MTPD). The impact of economy of scale is more prominent in grey ammonia than green ammonia. This is because, in green ammonia process, the economy of scale is currently achieved in ammonia synthesis loop, nitrogen generation unit and offsites, whereas the advantage of higher capacity for electrolyzers are still limited. Nevertheless, it is anticipated that scaling-up of the electrolyzers technology will contribute to a significant saving in the CAPEX, as large as 30% by 2030, making green ammonia competitive even at large scale.

VII. Conclusion

Green ammonia can play a pivotal role in:

- Decarbonizing the fertilizer industry.
- Global energy transition towards lower/zero-carbon fuels.

Green ammonia offers a huge market growth potential as green hydrogen transport vector, shipping fuel and direct energy source.

Grey ammonia is still most competitive option in short-medium term for large capacity; however green ammonia is becoming increasingly competitive. In countries like India, with higher natural gas price and abundant renewable energy, green ammonia could be cost-competitive in the very near future.

KBR offers K-GreeN, its optimized integrated solution for the complete green ammonia plant including electrolyzer, air separation unit, ammonia synthesis and storages.

KBR acts as single-point licensor, providing performance guarantee from power to ammonia production.

KBR offers a Digital Sustainability Suite – solutions for the entire process plant lifecycle, from commissioning and start-up, steady state operation, turnarounds, revamps, right through to plant decommissioning. ■

Energy Efficiency Measures at RCF Thal

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Thal Ammonia - Urea production facility came into operation in the year 1984. Sustainable fertilizer production is a challenge for old plants. Urea being energy intensive industry, specific energy consumption per MT of urea always remained a focus area. Urea energy consists of 80% energy through ammonia and 20 % through utilities. RCF Thal has strategically implemented various energy saving schemes over the period of time to sustain the production.

Reduction in ammonia energy goes a long way in reducing specific energy consumption of urea. Stage wise revamps of ammonia plant over the years for capacity enhancement as well as energy efficiency, retrofitting of urea plants, changes in utility plants have helped in reducing urea plant specific energy consumption from 7.50 to about 5.5 Gcal/MT on daily basis.

Introduction

Stringent energy consumption norms under urea pricing policy, high gas prices and volatile import parity price challenge to viability of old plants.

RCF, Thal was commissioned in the year 1984. It was first mega fertilizer unit set up using natural gas from Bombay High. It was first fertilizer unit in India to implement distributed control system (DCS). The twin ammonia plants had a capacity of 1350 MTPD each. technology supplier was M/s HTA/S. There are three urea plants each with capacity of 1500 MTPD and technology supplier was M/s Saipem (erstwhile M/s Snamprogetti). Energy consumption was around 9.5 Gcal/MT of ammonia and 7.5 Gcal/MT of urea.

The capacity of ammonia plant was enhanced twice with simultaneous target of energy reduction.

First revamp was carried out during 1996-97 to increase capacity to 2 x 1500 MTPD. The energy of ammonia plant reduced to 8.9 Gcal/MT and that of urea plant to 6.6 Gcal/MT. Urea optimization schemes were implemented in the the year 2002-2003 to reduce urea energy consumption of 0.2 Gcal/MT i.e 6.4 Gcal/MT of urea. Second revamp of ammonia plant was carried out in the year 2011-12 and capacity was increased to 2 x 1900 MTPD. Capacity of urea plant was enhanced to a total of 6060 MTPD. The energy of ammonia plant was reduced to 8.15 Gcal/MT and that of urea plant to 5.80 Gcal/MT.

Performance for last ten years :

In the year 2018-19, GTG-HRSG project was implemented in utility plants. Alongwith this project, 10 steam driven turbines in ammonia plant were converted to motors resulting into further energy reduction. GTG-HRSG project saved energy in steam as well as power generation. Thal ammonia plants achieved lowest ever energy of 8.184 Gcal/MT in the year 2018-19 which is lowest ever yearly energy since inception. **Figures 1** and **2** shows the production and energy consumption of ammonia and urea respectively over 10 years period.

Urea Plant

Thal urea plants achieved lowest ever energy of 5.661 Gcal/MT in the year 2018-19 which is the lowest ever yearly energy since inception.

Factors impacting sustenance of vintage plants :

a. Energy saving measures have been implemented from time to time. Further, energy saving measures are difficult to implement as basic technology cannot be changed, space availability is another constraint for new equipment, also configuration of equipment is different for new generation low energy plants.
b. As the ammonia plants have been revamped twice, even small energy saving measures require high capex with long payback period making its implementation unviable.
c. Higher gas prices of both domestic and imported

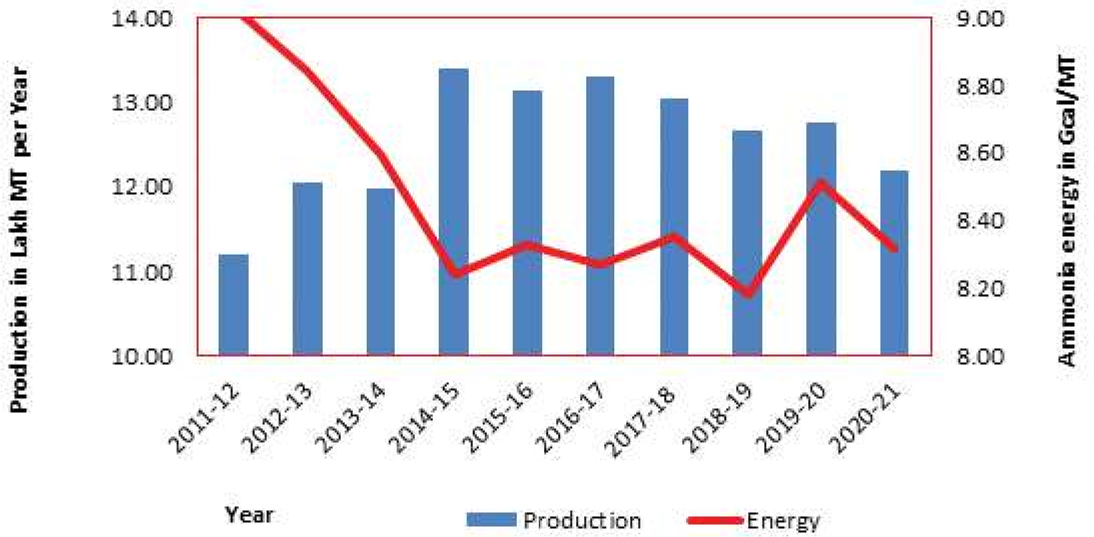

Figure 1. Ammonia production and energy consumption

gas. High gas (energy) cost makes the production beyond reassessed capacity (RAC) unviable.

d. Energy consumption (EC) norms have been revised several times. Recent revision in EC norms for Thal units are as follows:

- 6.938 Gcal/MT for the period 01.04.2008 to 31.05.2015.
- 6.598 Gcal/MT for the period 01.06.2015 to 31.03.2018.
- 6.20 Gcal/MT from 01.04.2018 till 31.03.2025.

Benefits of Revamp and other energy saving schemes have been mopped up due to revision in norms applicable from 01.04.2018.

e. Under NUP-2015, fixed cost is determined in accordance with provisions of NPS-III / Modified NPS-III. This compensation is valid for production up to RAC.

For production beyond RAC, units get variable cost and lowest of fixed cost of all indigenous urea units subject to import parity price (IPP) plus weighted average of all incidental charges incurred by government for import of urea. Due to low fixed cost, profitability is impacted for production beyond RAC when there is a decline in the imported urea prices. The lower fixed cost beyond RAC impacts profitability to greater extent for fertilizer units in Maharashtra where labour costs for bagging of urea contributes to increase in other fixed cost elements.

It is obvious from the above that a number of factors which impact viability of urea units is beyond control

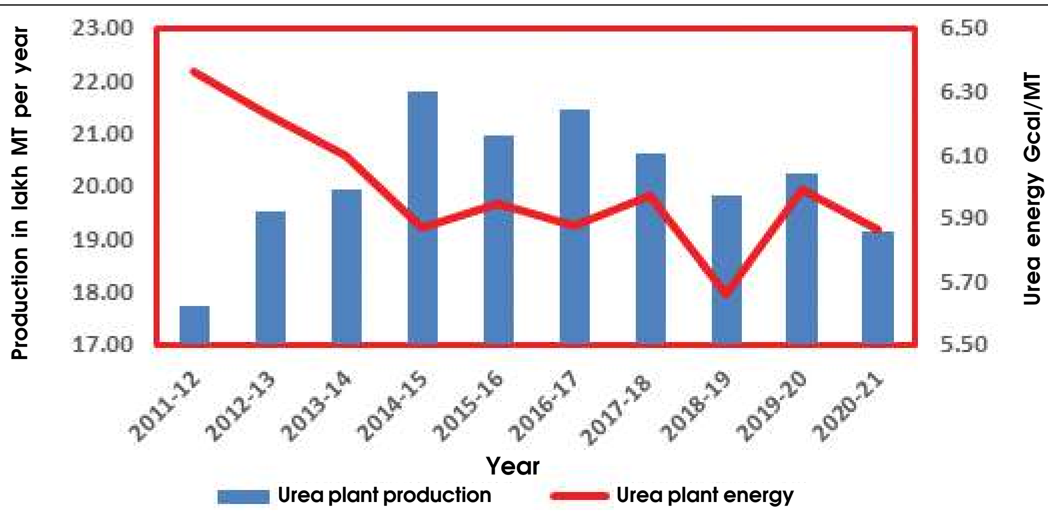

Figure 2. Urea production and energy consumption

of individual units. Urea units have to continue to implement even small energy conservation measures.

As, all above factors are beyond control of an individual unit, the only way forward is implementing in-house energy saving schemes whichever are practically possible with the above constraints and with suitable capex.

4. Implementation of new Energy saving measures :

a. Revamp of Ammonia plants

Ammonia energy for RCF, Thal since inception remained to the tune of 9.5 Gcal/MT. After a decade i.e from the year 1995, new energy efficient plants were being installed. To be in line with the new generation plants, a revamp of ammonia plant was carried out in the year 1996-97 to enhance ammonia plant capacity from 2 x 1350 MTPD to 2 x 1500 MTPD. Also the energy reduced from 9.5 Gcal/MT to 8.9 Gcal/MT on a daily basis. The main schemes implemented were installation of hydrogen gas recovery unit, additional process air compressor, additional ammonia refrigeration compressor, additional cooling tower, retrofitting of synthesis gas compressor and replacement of reformed gas boiler with improved technology.

Even though, plants were revamped to higher capacities, RCF could not reap the benefits due to acute gas shortage. To mitigate gas shortage and to sustain plant operations, ammonia plants were converted for use of naphtha as feed along with available gas in the year 2001. The plants were changed over to 100 % natural gas feed after availability of RILKG D-6 gas in the year 2009.

After the year 2000, the new upcoming plants were having capacity of 1750 MTPD ammonia. So, once again RCF, Thal modernized its ammonia plants by carrying out revamp during the period 2011-12 to 2013-14. Ammonia plant capacity was enhanced from 2 x 1500 MTPD to 2 x 1900 MTPD and energy was reduced from 8.9 Gcal/MT to 8.15 Gcal/MT on a daily basis.

The main changes involved are installation of two stage GV (Technology supplied: M/s Giammarco Vetrocoke) system instead of Benfield system for CO_2 removal. Thus, increasing CO_2 handling capacity and additional new S-50 converter (Technology supplier: M/s Haldor Topsoe) to increase conversion of ammonia per pass and modifications in steam network.

As ammonia plants were revamped twice, there was not much scope left for further energy improvement. Simultaneously, possibilities of reducing energy in urea plant and utility plants were explored.

b. Installation of GTG (2 x 25 MW) & HRSG (2 x 100 MTPH.)

Originally, power requirement of Thal unit was met through 2 x 15 MW steam driven turbo generator (STG) sets since inception. The energy of power produced from STG was to the tune of 3.5 Gcal/MW. An in-house scheme of GTG-HRSG was envisaged to reduce energy of power and to reduce heat rejected to cooling towers. Gas Turbine of capacity 2 x 25 MW (M/s Siemens) along with 2 x 100 TPH heat recovery steam generator (HRSG) (M/s Thermax) and associated facilities were commissioned in March 2018 **(Figures 3 and 4)**.

Implementation of scheme required replacement of 10 nos. of steam driven turbines of ammonia plant with motors as a part of the project viz. 5 no. Cooling tower pumps, 4 nos. GV solution pumps and 1 no. drive turbine of ammonia refrigeration compressor-III. In addition to above, ID (Flue gas blower) and FD (Combustion air blower) of both ammonia streams are required to run on motor drive and turbine drive are kept as standby.

Due to the implementation of GTG-HRSG project, two TG's, one service boiler and two auxiliary boilers of ammonia plant were stopped. Energy saving of 0.30 Gcal/MT of urea was achieved on a daily basis due to reduction in gas consumption.

Figure 3. Project stage

Figure 4. Project after completion

Figure 5. Steam driven ARC-III

Figure 6. Power driven ARC-IV

Cost of the project was Rs. 482 crore.

After commissioning, operation of GTG sets was not reliable & hence desired energy figures could not be achieved. RCF incorporated many operational control measures & site specific modifications in the GTG & auxiliaries in consultation with OEM (M/s Siemens). After this, GTG operation became reliable and envisaged energy savings could be achieved. Operational controls / modifications include periodic washing after every 3 months, mandatory replacement of air filters after 6 months, changing of type of second stage air filter for facilitating fog removal, oil mist eliminator vent pipe diversion, sparger for starter motor, etc.

Installation of motor driven Ammonia Refrigeration Compressor-IV (ARC-IV)

As a part of GTG-HRSG scheme, installation of motor driven ammonia refrigeration compressor-IV (ARC-IV) resulted into stoppage of steam driven ammonia refrigeration compressor-III (ARC-III).

Steam driven ARC-III **(Figure 5)** commissioned in the year 1998 was a back pressure turbine which used approximately 70 MTPH high pressure steam as inlet and produced medium pressure steam as extraction. This compressor catered to requirement of M.P. steam driven turbines and avoided energy loss due to let down of SH steam through the PRDS.

Due to the replacement of cooling tower and GV section turbines with motors, the steam balance changed and hence motor driven ARC-IV **(Figure 6)** was installed and commissioned in March 2020. The power consumption of ARC-IV is around 3.9 MW per hr. This has resulted into energy saving of 0.05 Gcal/MT of urea.

c. Revamping of CO_2 compressor turbine

Compressor train consists of : Steam Turbine (EHNK 40/45-3) + 2MCL 606 + GB + 2BCL 306A.

CO_2 compressor turbine train was installed in the year 1984. Since then CO_2 compressor turbine has given successful service without any modification. Unit-11 CO_2 compressor turbine was manufactured by M/s GE (erstwhile M/s Nuove Pignone) and supplied by M/s BHEL, CO_2 compressor turbine train for Unit-21 and Unit-31 was manufactured and supplied by M/s BHEL.

Figure 7. CO_2 compressor with turbine during revamp

Figure 8. CO_2 compressor with Turbine after revamp

CO_2 compressor turbine revamp was carried out in Unit-11 in January 2018 by M/s GE and in Unit-21 and 31 in October 2018 by M/s BHEL. The total cost of revamp was Rs.137.73 Crores. Savings accrued were 0.108 Gcal/MT of urea. **Figures 7** and **8** show CO_2 compressor with turbine during revamp and after revamp, respectively.

Major components replaced in steam turbine were :

Turbine steam inner casing,turbine rotor, guide blade carriers, dry flexible couplings, bearings, steam glands, oil glands, existing hydraulic speed governor : (Woodward PG-PL type) with electronic governor and dedicated electronic over speed protection system, turbine ejector system.

Major components replaced in compressor 2 MCL 606 were

Compressor rotor, compressor diaphragms/ diaphragm assembly, bearings, internal labyrinth seals including end gas seals for MCL, existing gear type couplings replaced with dry flexible type couplings on both side i.e. TK-1 to MCL and MCL to gear box input shaft.

Major components replaced in compressor 2 BCL 306A were

Compressor rotor, Internal labyrinth seals, existing labyrinth type end gas seals replaced with dry gas seal for HP compressors with it's associated auxiliaries, bearings, barrel end covers suitably modified/ replaced to suit dry gas seal, existing gear type couplings replaced with dry flexible type couplings between 2BCL 306a and gear box output shaft.

In addition to above 3rd stage intercooler (E-26) was replaced with higher capacity intercooler. Surface area of new intercooler is 228 m^2 against 105 m^2 of old intercooler.

Each train revamp required approximately 32 days. For two units i.e Unit-21 and 31, the revamp was carried out parallelly on two machines.

d. Installation of vortex mixer in all three urea plants :

M/s NIIK, Russia studied the parameters of Thal urea plants and suggested installation of vortex mixer and conversion booster at the bottom of urea reactors for saving of medium pressure steam in each Urea unit. **Figure 9** shows picture of vortex mixture. **Figure 10** shows the schematic installation of vortex mixer in urea reactor.

The total cost for all 3 units was Rs.15.60 crore+ applicable taxes and duties. The vortex mixer was replaced in unit-11 in January 2018 and in unit-21 & 31 in October 2018. This has increased urea conversion in reactor from 59.5 to 61.2 %. Increase in urea conversion reduces recycle of ammonia and CO_2, thus reducing steam consumption. Steam saving of 8 MTPH equivalent to 0.027 Gcal/MT of urea was achieved.

e. Installation of Vapour Absorption Machine in Ammonia Plant (VAM)

Process air is used in ammonia plant for providing nitrogen for production of ammonia. Steam driven

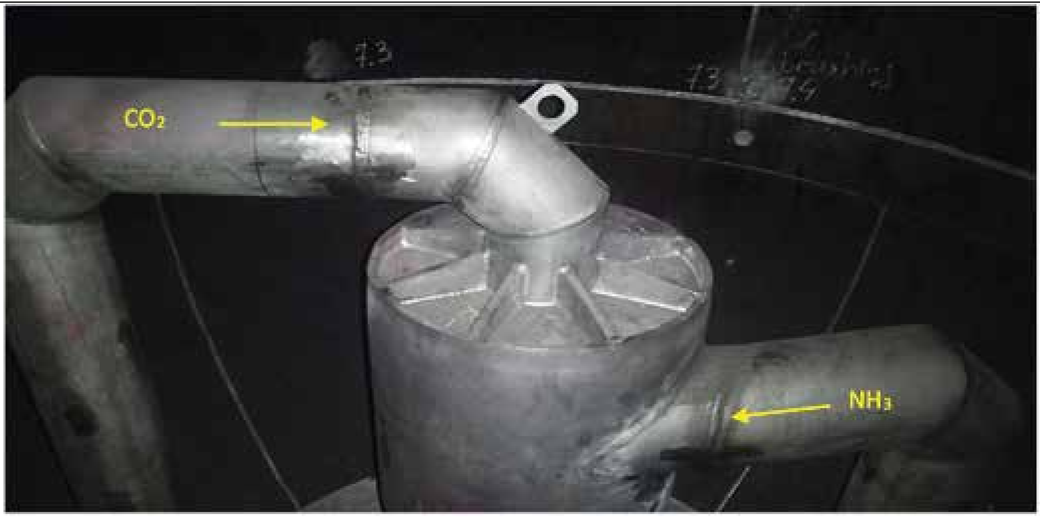

Figure 9. Actual photograph of Vortex Mixer

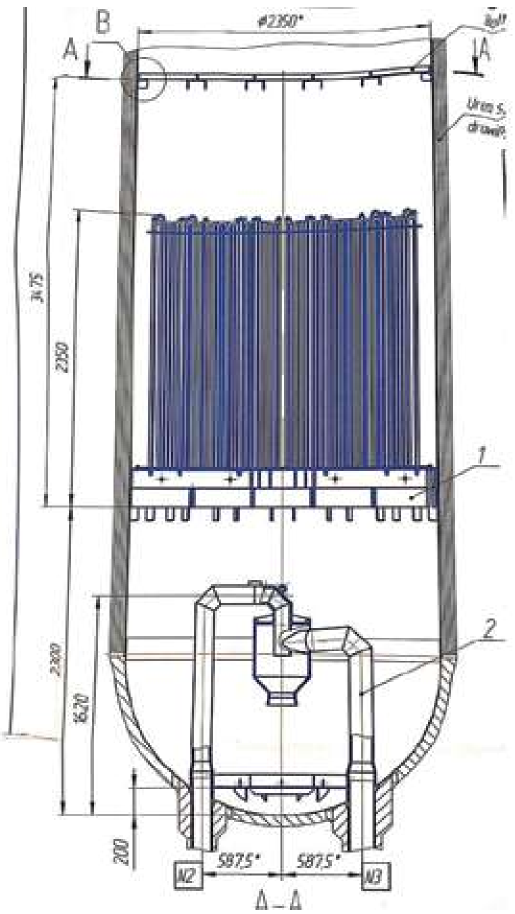

Figure 10. Installation of Vortex mixer at the bottom of the Reactor

process air compressors give higher air flow during winter season and prove to be load limitation during summer season.

Vapour absorption machine (M/s Freudenberg Filtration technologies India) for suction chilling of process air in process air compressor for Line-I & II was commissioned on 27.10.2018 and 27.07.2018 respectively **(Figure 11)**. Air suction temperature was reduced from 35°C to 15 °C. Energy saving of 0.006 Gcal/MT of Urea was achieved.

The heat required for VAM is supplied through saturated M.P. steam at 25 kg/cm^2. Reducing suction temperature of process air resulted into higher air flow at same steam consumption in turbine and consequent increase in production.

f. Installation of Vapour Absorption Machine in Urea Plant (VAM)

Utilising waste heat is the best way to reduce energy consumption. CO_2 from ammonia plant is supplied to urea plant. During summer the temperature of supplied CO_2 is as high as 40 °C impacting throughput of CO_2 compressor. Vapour absorption machine (M/s Voltas) for suction chilling of CO_2 to CO_2 compressors in Urea Plant was commissioned in January 2019 **(Figure 12)**. CO_2 suction temperature has reduced from 40 to 20 °C. Energy saving of 0.009 Gcal/MT of urea was achieved.

The heat required for VAM is supplied through 100 M^3/hr of hot steam condensate which is exported from urea plant at a temperature of 110° C to steam generation plant as DM water.

Figure 11. VAM installed in Ammonia Plant

Figure 12. VAM installed in Urea Plant

g. Operating pressure of Hydrolyser (R-2) in all three urea plants was increased from 22 to 35 Kg/cm² by running two M.P. Hydrolyzer pumps (P-14) in series.

Out of two hydrolyser pumps, 'P-14A' is equipped with variable frequency drive (VFD) and it was always in line. Other pump 'P-14B' was on standby mode.

It was envisaged to operate both MP hydrolyser pumps in series to boost hydrolyser feed to higher pressure **(Figure 13)**. Higher pressure operation is favorable for hydrolysis reaction. This was the immediate and low cost measure for increasing pressure of hydrolyser.

Cost of implementation was Rs. 3.0 lakhs only. This has resulted in HS steam saving of 3 MT/hr (1 MTPH per urea plant). Energy saving of 0.010 Gcal/MT of urea was achieved.

h. Installation of VFD in high pressure ammonia feed pumps (P-1) of urea plant

P-1 pumps installed in 1984 were provided with torque converter system. Torque converter works on hydraulic turbine principle and transfers power to the driven machine. But there is 15-20 % loss of power in transmission. Also, with torque converter speed control, there is always a slight variation in rpm due

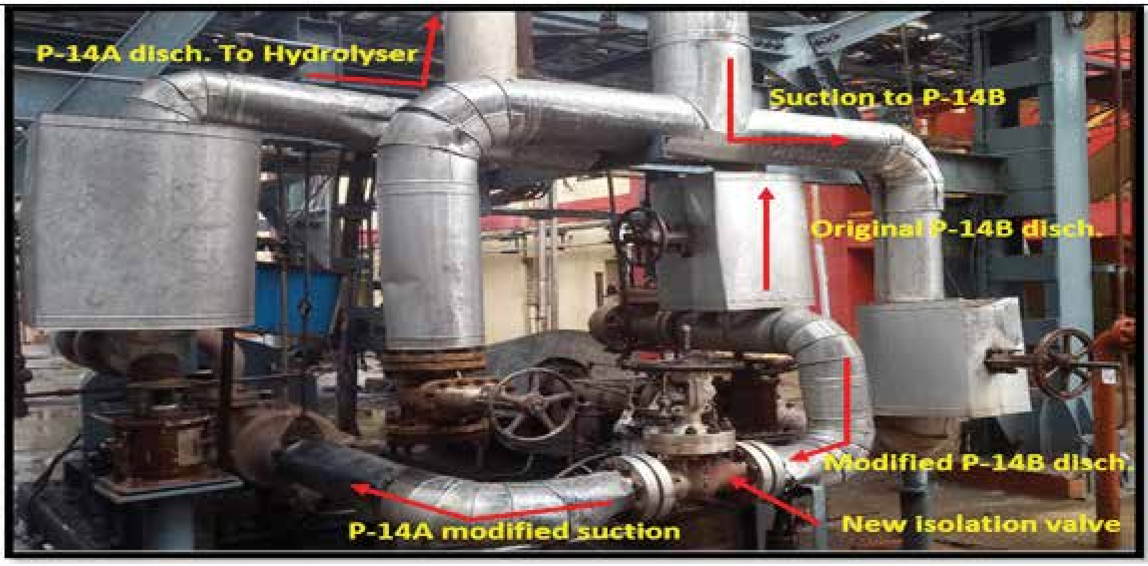

Figure 13. P-14 pumps A & B connected in series in Urea plant

Figure 14. Control panel for P-1 pump VFD in urea plant

to variation in supply frequency resulting into continuous variation of feed ammonia to reactor.

To overcome above issues, it was planned to replace 35 years old torque converters with VFD control **(Figure 14)**. The benefits of VFD control are low power consumption, higher accuracy of speed control and less expenditure on maintenance.

All 9, P-1 pumps have been converted to VFD control (M/s Hitachi) during period May 2019 to September 2021. Total cost of project is Rs.4.02 crore. The VFD's were commissioned online and saving of around 80 kW per pump has been achieved resulting into energy savings of 0.004 Gcal/MT of urea.

5. Safety and Environment Management

Safety of vintage plants and its environment management plays a significant role in its sustenance.

RCF Thal has upgraded its fire and safety systems by installing new facilities such as remote controlled operated high volume long range monitors on both ammonia storage tanks, high velocity water spray system for all electrical transformers, auto dialer system for smoke detectors in unmanned areas in chemical store etc.

For conservation of environment, RCF, Thal has undertaken effluent treatment plant upgradation project which is expected to be completed by December 2022. This project is expected to recycle 5250 m^3/day of effluent as raw water.

6. Conclusion

Keeping in view the high cost of energy, RCF, Thal has implemented strategic energy saving schemes over the period of past 35 years by utilising latest technologies available. It has optimally integrated latest energy saving schemes in ammonia, urea and utility plants to reduce ammonia energy by 14% and that of urea by 23% since inception.

For reliability of equipment, replacement of critical equipment such as urea reactor, carbamate condenser, etc. are planned.

For further energy reduction in ammonia plant discussion with technology supplier M/s HTA/S is in progress.

RCF, Thal has set an example of sustainable fertilizer production from vintage plants.■

Casale Experiences and Revamping Technologies in Ammonia Plants to Improve Sustainability by Reducing the CO_2 Emissions

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The art of revamping has now advanced to the point where it is possible to increase the capacity and improve the efficiency with a reduced environmental impact of an ammonia plant by a really substantial margin. Casale demonstrated this in different successful modernizations according to tailor made solutions to meet the Client targets, also following new routes that are becoming popular in the fertilizer industry. The paper describes different successful examples and strategies focused on plant improvement and reduced CO_2 emission explaining the advantages and commercial benefits based on concrete plant modifications.

Introduction

The importance of ammonia in the world economy is well known considering its paramount role as fertilizer in the world-wide feeding, additionally ammonia is also the hearth of the so-called green revolution. Ammonia is also widely used to produce other chemicals and last, for this chemical, energy or hydrogen carrier is becoming an interesting field of application. In the fertilizer industry, Casale is a process licensor with a wide range of technology solutions covering all the sections of an ammonia, urea, nitric acid, ammonium nitrate and complex fertilizers plants. For an ammonia plant, Casale has a series of unmatched products in terms of overall performances, reliability and efficiency, and hundreds of plants are operated with technology supplied by Casale.

Casale's mission is focused on a continuous enhancement of the supplied products and solutions to achieve the targets of better performances, lower energy consumption, reduction of the CO_2 footprint, and a long and reliable operation of the processes using their products. Different examples of technologies and know-how applications in Casale projects that were applied with the final target to create value for the final customer are discussed.

Development of a Revamping Project

A revamping project is mainly based on the final targets and needs of the plant owner; following this, Casale develops the revamping project according to well defined steps including:

- Identification of the plant limitations and constraints;
- Definition of the right balance between benefits and costs;
- Integration and synergy with other plants within the industrial complex; and
- Use of the latest technologies.

Last but not least, the choice of the right partner for the plant revamping is of paramount importance to get a final successful result of the revamping project; Casale made the revamping project one of the main fields of operation with hundreds of completed projects to achieve the client satisfaction.

Ammonia Plant Revamping from Technology to Accomplishment

The ammonia plant revamping technologies were developed by Casale almost 50 years ago, when the same concept of "revamping" was for most of the ammonia industry unknown; starting from the ammonia converter revamping technology, Casale created a wide portfolio of technologies and know-how embracing whole sections of an ammonia plant. Due to the vast record of cases, this paper is considering the analysis of few modification examples of the primary reformer, the development and use of the most efficient ammonia synthesis converter catalyst the so called Amomax™-Casale, and finally it will be provided a digression of the ammonia plant hybridization philosophy.

Primary Reformer Modifications

The primary reformer modification embraces a large number of cases and several questions can be raised by the analysis of a reforming section related to the current bottlenecks, constraints and limitations, and considering the final targets for the client, for instance:

- Where is the limitation? Flue gas or process side?
- Is there useful space in the reforming unit ?
- Age of the coils ? Maintenance is assessing any ongoing thinning process in the coils ?
- Is there any spare capacity in the machineries and burners ?
- Is repurposing acceptable?
- Is fouling affecting the unit ? and
- Is any green integration planned inside the plant?

The analysis of the previous tips help in the definition of best actions and modifications to meet the client's needs. Very often the reforming units are affected by high temperature to the unit stacks. In this regard, different strategies can be implemented to achieve a mitigation of the previous issue, actually either existing coils can be modified or, if the existing unit is not equipped, a combustion air pre-heating system can be installed. Both the works have been implemented in past projects by Casale. However, the most suitable modification that would maximize the benefits achievable versus a contained economical investment is the installation of a saturation system. The saturation system can be installed in an existing plant according to different arrangements. However, the simplest is the installation of a saturation coil in the (typically) last portion of the reformer convection section regardless of the primary reformer furnace type (top fired, side fired or terrace wall). Additionally, a relatively small saturation column as well as a feed/ effluent gas exchanger plus a condensate exchanger would complete the new saturation section.

In more detail and according to a typical ammonia plant arrangement, the process condensate separated upstream the CO_2 removal section are pumped by a new pump to the new saturation coil after being pre-heated in a saturation tower feed/ effluent exchanger, later on the hot condensate are fed to the top of the saturation column. The desulphurized NG after heat exchange with the saturated NG is fed at the bottom of the saturator and is going to be contacted counter-currently with the hot condensate. The stripped hot condensates after heat exchange are fed to BLs, while the saturated NG, after re-heating is supplied to the mixed feed coil after addition of the balance MP process steam. The typical steam to carbon ratio achieved downstream a saturation section is in the range of 0.5-1 mol/mol. Simplified process flow diagramme of a saturation section installed in an existing NH_3 plant is depicted in **Figure 1**. The installation of a saturation section is an alternative to the combustion air pre-heating system but there are examples of installation of both the systems, achieving a very low temperature (above the dew point) into the reformer stack.

In an example related to a German plant (**Figure 2**), the saturation section was chosen, to provide energy saving and to reduce the CO_2

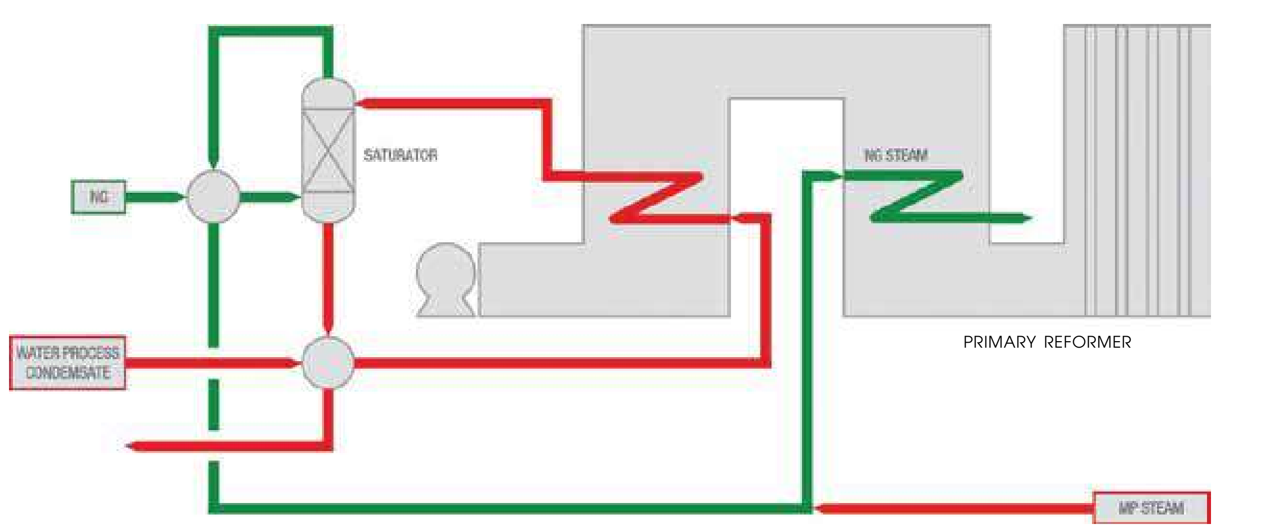

Figure 1. Simplified process flow diagramme of a saturation section installed in an existing ammonia plant

Figure 2. Saturator installation in the German plant

emission of the plant. The installation of this new section was accomplished inside a bigger revamping project involving the whole plant. The plant steam to carbon ratio was reduced from 3.3 mol/mol down to 3.0 mol /mol, while plant capacity was increased from 1700 MTPD up to 1900 MTPD; the installation of the saturation section provided a reduction of the flue gas temperature of the stack up to 170 °C with an estimated energy saving of 0.2 Gcal/MT. Considering a cost of the NG of 6$/MMBtu, the return on investment (pay back time) would be achieved in less than 1.5 years. Thanks to the energy saving provided by the saturation section and therefore to the lower NG consumption, the estimated yearly CO_2 emission was reduced of about 30,000 tonnes.

In another industrial example related to an ammonia plant using a top fired primary reformer with hot and cold leg, the plant owner was considering a complete plant revamping and one of the limitation was related to the superheating temperature of the steam fed to the syngas compressor turbine that was too low, additionally the super-heating burners (these are located in the transition zone between the high temperature and the low temperature steam super-heating coils) were already operated at the maximum. Therefore, there was no additional room to cover the steam super-heating requirement.

The plant owner had already accomplished an extensive coils modification and, therefore, was reluctant to perform other deep modifications of the convection section. For this reason, Casale proposed to accomplish a coil repurposing, by using the last two rows of the BFW coil located in the primary reformer cold leg to be used as low temperature process air coil.

This solution allowed to pre-heat the process air first in the repurposed coil and afterward in the old high temperature existing process air coil; the final effect was a higher operating temperature of the flue gas going to the high temperature steam super-heating coil and, therefore, providing wider operational range to the super-heating burners (**Figure 3**). Thanks to the improved operation, it was also possible to achieve a better use of the heat available in the convection section and, therefore, to achieve an energy saving of 0.05 Gcal/MT with lower temperature to the stack. The material supplied for such implementation were just few elbows, sub-header and connecting pieces and, therefore, the CAPEX for this reformer modification was quite limited.

The plant even if located in Russia and, therefore, operated with a NG having a very low specific cost, could benefit by this modification achieving a pay back time on this section of less than 2 years. The estimated CO_2 emission was reduced of about 7000 tonne/year.

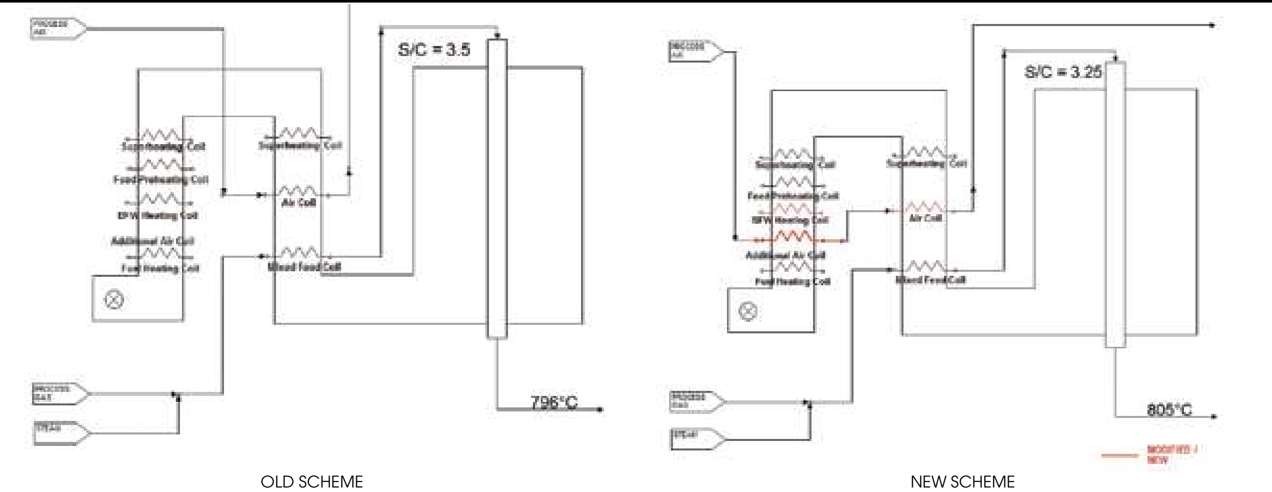

Figure 3. Primary reformer modification with re-purposed coil

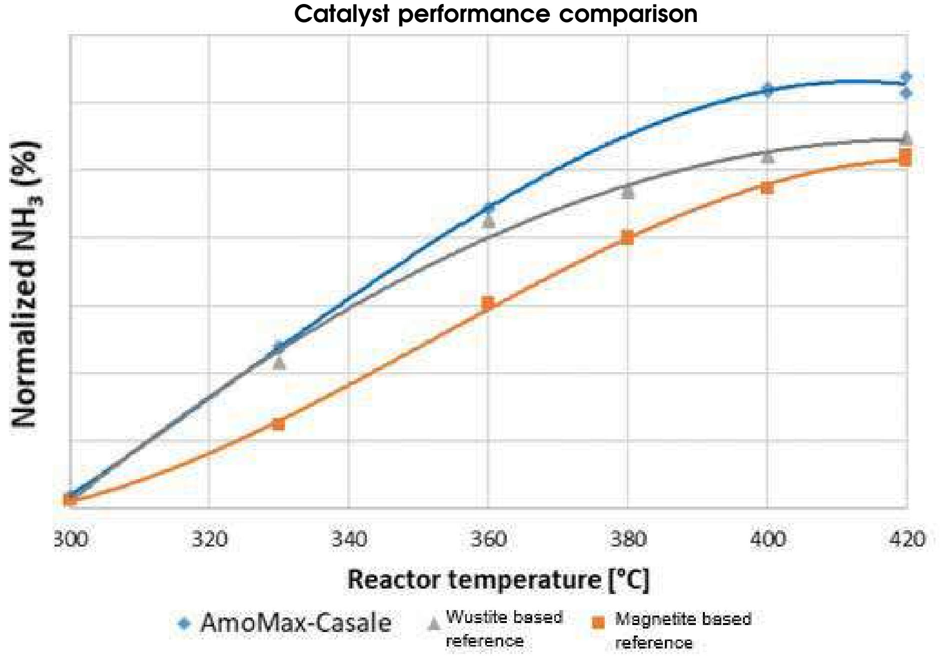

Figure 4. Comparison between state-of-the art magnetite-based catalyst, wustite-based reference catalyst and AmoMax™-Casale

Amomax™-Casale*: *the New Benchmark for Ammonia Synthesis Catalyst

Catalytic ammonia synthesis from H_2 and N_2 represents one of the most important industrial reactions today. The catalyst used in this reaction is made from iron oxide with small amounts of other oxides added as promoters to enhance activity and stability. Despite the Haber-Bosch process being more than 100 years old, only incremental improvements have been achieved until recently. Combining the catalyst expertise of Clariant and the engineering knowledge of Casale, a breakthrough has been realized leading to the new ammonia synthesis catalyst AmoMax™-Casale. The new catalyst is based on Clariant's successful and superior catalyst AmoMax™ 10 with more than 100 references worldwide and is customized for Casale reactors with significantly improved activity compared to state-of-the-art iron-based catalysts (**Figure 4**). When introducing a new catalyst into the market, performance evaluation is of utmost importance, but simple catalytic tests in powder form are not representative enough for industrial applications and only suitable for screening purposes. Therefore, a precise and rigorous methodology must be applied.

Mechanical tests to evaluate the mechanical strength, the shear stress and the pressure drop were carried out showing behaviour at least comparable with the standard 1st class catalysts available on the market, afterward performance tests were performed achieving a significantly higher activity (+30%) compared to reference catalyst, longer life, high resistance to poisoning and higher activity at low operating temperature making this catalyst particularly suitable also for green application. Comparison poison resistance in different oxygen concentrations of the two catalysts is given in **Figure 5**.

The first application of this catalyst was accomplished in 2019 in a KBR vintage plant, having a classical bottle shape ammonia converter; this converter was revamped several years ago by another licensor and more recently, the plant owner approached us to perform a complete internal revamping that was also including the use of the Amomax™-Casale catalyst. The converter was revamped according to the classical configuration of 3 axial-radial beds with interchanger and bottom exchanger. The modification of the internals as well as the loading of Amomax™-Casale was performed according to the usual rules and procedure followed by Casale and was completed in 4 weeks. After catalyst activation and optimization, the plant operated beyond expectation despite an increased inerts content due to operational issues faced in the plant in the primary reforming section that provided to the synthesis loop a make-up gas (MUG) quite methane rich. The converter performance comparison before revamping and use of Amomax™ Casale catalyst is listed in **Table 1**.

Considering that the energy saving achieved by this converter modification was also due to the

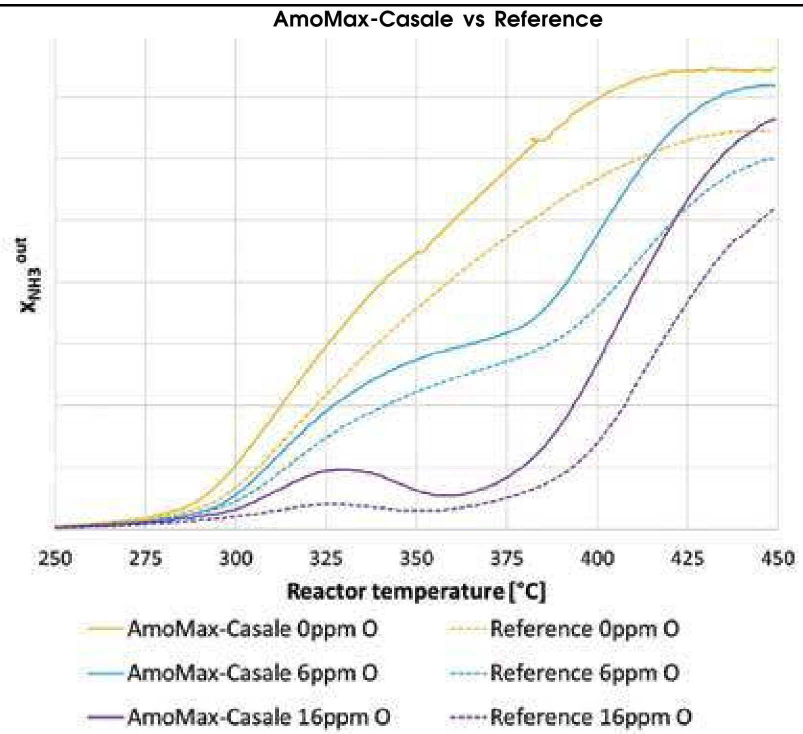

Figure 5. Comparison of poison resistance in different oxygen concentrations

installation of Casale ammonia converter internals, The effect of Amomax™-Casale on such parameter was calculated and discovered that about 0.04 Gcal/MT ammonia was achieved due to this new catalyst release providing a CO_2 savings of more than 85,000 tonnes achieved over a typical lifetime of 15 years. The previous analysis was also possible because in the same industrial complex and at the same time a parallel revamping was performed of another identical KBR bottle shape ammonia converter using the same ammonia converter internals type but with the difference to use a standard Amomax™-10 catalyst. The plant with Amomax™-Casale catalyst was operated at significantly lower pressure. Currently Amomax™-Casale is going to be start-up in several other converters located in North America, Europe, Oceania, Asia and, therefore, other industrial cases will be very soon available.

Plant Hybridization

The concept of plant hybridization is becoming quite popular, thanks to the development of the so called green economy. The most simple arrangement of a hybrid plant is the production of hydrogen, also by a source different than a reforming section and this is commonly identified by a new electrolyzing section that is performing water electrolysis. Injection of hydrogen in an existing plant is not a new concept considering that there are many examples of ammonia plant receiving "grey" hydrogen according to different ranges and Casale has experience of running ammonia plant with a hydrogen injection up to 15% of the total one for ammonia synthesis. In general, the "green" revolution is a big opportunity also for the old fertilizer industry in order to produce part of the ammonia as "green" type, by just installing a

Table 1. Converter performance comparison

Conditions	Amomax™-Casale	Before Revamping
Life	SOR	MOR
Capacity (std)	1788	1776
Syngas compressor discharge pressure (psig) /(barg)	2039/140.6	2206/152.1
Inerts (% mol)	16.7	11.5
NH_3% in	1.4	1.8
NH_3% out	13.5	13.9
△P (bar)/ △P (psi)	3.1/46	4.7/68

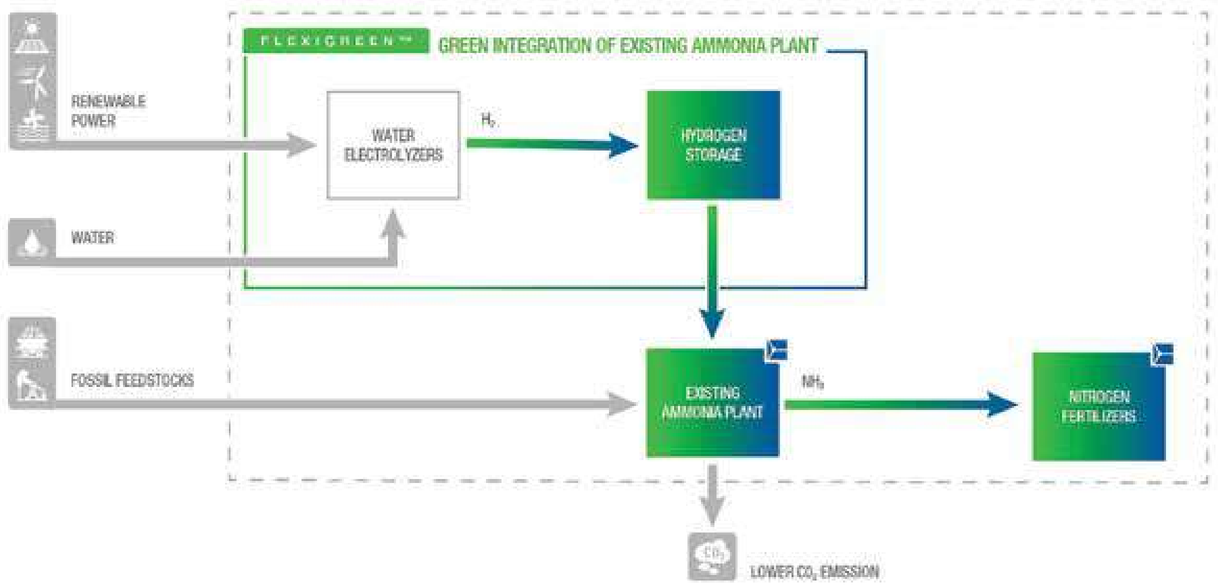

Figure 6. Block flow diagramme for a hybridized fertilizer complex

new electrolyzing section to feed such green hydrogen.

The main advantage for an "old" producer of ammonia is that the plant hybridization is not requiring any new synthesis loop, or nitrogen source (in most of the cases), as well as storage facilities and water preparation system, basically the new installation is limited to electrolyzing units, and hydrogen storage is optional (not always required) because it depends on the availability along the time of the hydrogen from the new source. The block flow diagramme for a hybrid fertilizer complex is illustrated in **Figure 6**.

Different degree of plant hybridization can be implemented by a plant owner, with different economic impacts in the new sections, the typical request is for a plant hybridization in the range 15-40% with some customers that are looking for a complete (100%) conversion of the grey plant to green plant; the previous percentage represent the hydrogen share coming from green sources versus the whole quantity of hydrogen required for the plant production. Depending on the target fixed by the client, the outcomes and modifications required in the existing plant are different. For a low degree of hybridization (typically lower than 15%), no modifications are required to the existing ammonia plant, while a higher degree of green integration could require check and modifications in specific points of the plant. According to a project in a development phase, Casale for a 30% green integration performed a deep analysis of the existing plant to assess the required modifications. For this, plant was available for hydrogen coming from the electrolyzing section with an operating pressure higher than 25 barg, and the ideal injection point for this high purity hydrogen was the suction of the syngas compressor machine. The nitrogen required by the ammonia synthesis was still coming from the process air compressor; the primary reformer load was reduced due to the green hydrogen injection and this condition brought to an excessive temperature at secondary reformer outlet. This situation forced to decrease the outlet temperature from the radiant box, with lower flue gas flow rate in the reformer convection section; the impact of such operational modification created issue in the steam superheating coils suggesting a modification of these coils to make the reformer suitable for the new operating conditions.

The other parts of the plant were in general suitable, in any case, depending on plant configuration and conditions for other critical parts could be:

- WHBs upstream HTS (these could cool too much the process gas in particular for the catalyst end of life conditions;
- Synthesis loop and ammonia synthesis converter (the typical lower inerts content of the MUG generated by a hybrid plant could generate a high

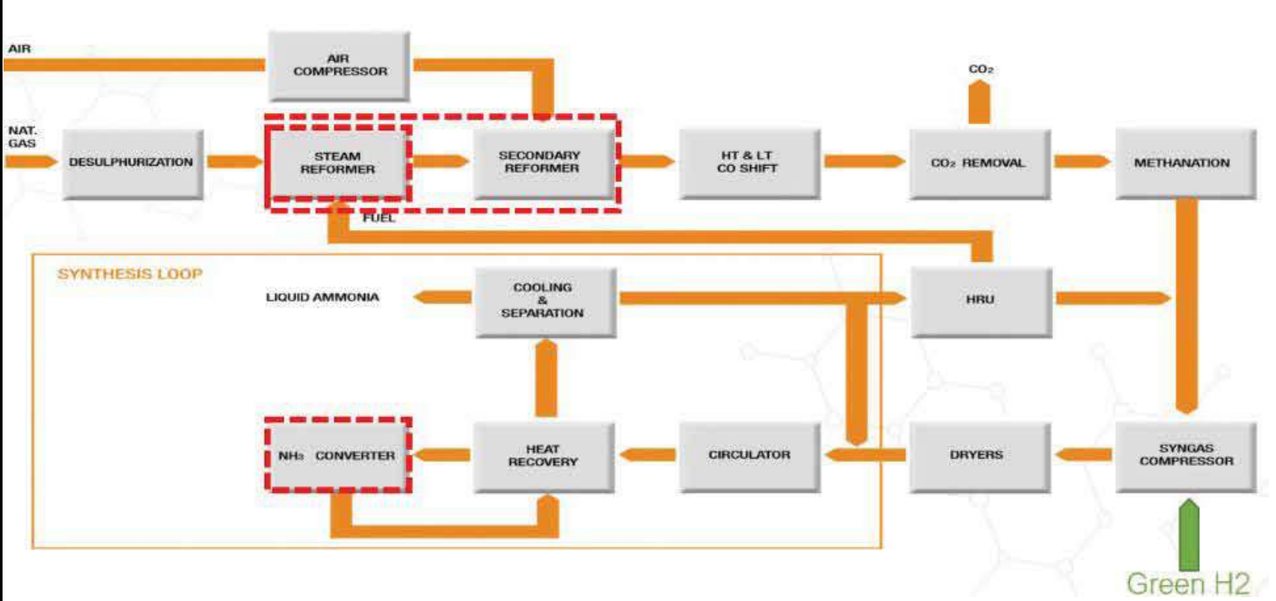

Figure 7. Main ammonia plant area affected by green hydrogen integration

outlet temperature at converter outlet overcoming the temperature limits in specific point of the synthesis loop).

In case of fully PV or fluctuating wind park power generation without a balance provided by the grid, Casale can provide specific solutions to avoid operational fluctuation in the existing plant by adoption of specific buffering arrangement and advanced process control system in order to keep steady the production of the existing facility. In general, this green hydrogen integration is providing energy saving to the plant and the final plant energy consumption depends by the reference energy value considered for the green integrated part, in particular:

- Is the electrolyzing section part of the industrial fertilizer complex?
- Is the green power generation within the fertilizer complex or shall the client buy this energy?

In other words, the injected hydrogen could be completely "free of charge" or a certain energy content should be considered. The main ammonia plant area affected by green hydrogen integration is depicted in **Figure 7**.

Conclusion

More sustainable production would help to lead to a greener and cleaner world. Casale strategy has always been to develop and apply new, advanced technologies to obtain the best possible improvement in plant performance at the minimum cost. It is essential to identify the most critical items to improve for the best return. Casale has done exactly that in many projects and has developed and applied a number of proprietary improvements. Standard schemes but also new solutions for revamping plants based on any existing technology have been developed. Each revamp is tailor-made for the specific situation.

Casale being purely a technology company, it carries out research continuously to develop new technologies. New technologies are typically first applied in revamping projects because these are the fastest route of application for these new solutions, this philosophy makes these products already suitable for application in new plants and ready to take up the challenge for a more sustainable industry. ■

Revamping of Ammonia-Stripping Urea Plant at Rashtriya Chemicals and Fertilizers Limited, Trombay

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The urea plant in Trombay – Mumbai – was commissioned in 1982. After almost 40 years of service, the plant owner, Rashtriya Chemicals and Fertilizers Ltd., committed to the modernization of the plant. Based on Snamprogetti technology, the plant with 1000 MTPD nameplate capacity did not feature any of the heat integration steps which are now commonly applied to modern stripping plants. The specific energy consumption was, therefore, some 30% higher than modern benchmark. In 2016, Casale was awarded the contract for basic engineering and license for the revamping of Trombay plant with the purpose of improving the energy consumption, minimizing pollutant emissions and ensuring a stable capacity at 1350 MTPD. The hook-up of the new equipment was mainly carried-out during plant turnaround in November 2020 and by December of the same year, the revamped plant was put in operation. Notwithstanding the difficulties of covid pandemic, RCF's team, supported by Casales local representative and remotely from the headquarter in Switzerland, managed to rapidly achieve stable production and meet the energy and emissions target. On February 17, 2021, the guarantee test run was successfully completed.

Introduction

Trombay urea plant was designed by Snamprogetti according to its "ammonia" or "self-stripping" technology and put in operation in 1982. As common in many plants of its kind throughout mid 1990s, the process scheme did not implement any heat recovery strategy and relied upon the HP stripper to maximize the decomposition of unreacted carbamate to maintain as low as possible the recycle of carbamate, and consequently water, from the downstream sections. The operating philosophy indeed required the bottom temperature of the Titanium HP stripper to be as high as 210 °C generating a massive quantity of vapours to be condensed in the kettle HP carbamate condenser. Indeed, the production of LP steam in the HP carbamate condenser was such that all the downstream 3.5 kg/cm^{2}g demand was fully covered. By contrast the consumption of 22 kg/cm^{2}g steam in the HP stripper was proportionally high leading to an overall energy consumption above 1.1 Gcal/MT (including also the CO_2 compressor).

The nameplate capacity of the plant was1000 MTPD, even though, RCF operations team used to achieve more than 1200 MTPD during winter season exploiting equipment design margin. During summer, due to increased temperature of the cooling water, maximization of plant capacity was harder mainly due to the performance of the ammonia condensers and condensers of the vacuum system in the urea concentration section.

Concerning the environmental performance, in terms of liquid effluent and emissions, the plant presented margins for improvement. For example, the quality of treated water from waste water treatment section did not meet the standard for boiler feed water. Even though RCF carried out during last years a few modifications to reduce the emissions of ammonia to atmosphere, such as the installation of an atmospheric scrubber or the use of blow-down effluent for carbamate pump flushing, the specific consumption of ammonia was way above 580 kg/MT.

Project Targets

The targets of the revamping project set by RCF were aimed to a general modernization of the plant with the final target to align the performance of a 40-year old plant to the state-of-the-art of urea technology. Quite unusually when it comes to large-scale revamping projects, a massive capacity increase was not sought, as it was requested to debottleneck the plant so to achieve a stable production corresponding to the maximum capacity of the front-end throughout the year.

The targets of the revamping project were thus related to three major areas of improvement:

- Capacity: achieve 1350 MTPD also during the hottest season
- Efficiency: drastic reduction of the steam consumption
- Emissions: reduce the overall specific ammonia consumption
- Effluent quality: treated water to comply with BFW standard

Table 1, values from base case test run are compared with revamping targets.

Regarding the specific steam consumption, the target agreed with RCF was particularly demanding, especially for a 40-year-old plant. Among urea plants with prilling finishing, a specific MP steam consumption of 691 kg/MT, including steam for hydrolysis, only few may declare similar values.

Revamping Scheme

Giving the plurality of project targets, the revamping scheme had to involve all the sections of the plant. The major hurdle was the reduction of the MP steam consumption as it required a drastic shift of load from the HP stripper, which accounted for 90% of the overall MP steam consumption, to the downstream sections. To cut the overall steam demand by 25%, it was mandatory to limit the HP stripper bottom temperature at no more than 202-203 °C. At such temperature, the carbamate fraction to be processed by the MP and LP sections increases by almost 70% with respect to original material balance with HP stripper at 210 °C. If combined with the capacity increase, 1350 MTPD against nameplate 1000 MTPD, the overall amount of carbamate leaving the HP stripper is almost twice the original Snamprogetti design value. Moreover, reducing the HP stripper bottom temperature to 203 °C leads to a production of LP steam in the HP carbamate condenser almost 25% lower. The only possible strategy to balance the lower LP steam production with the increased duty in the downstream sections was to optimize the steam network and maximize the heat recovery.

In the original plant design only two steam pressure levels were foreseen, 26 and 3.5 kg/cm^{2}g. The former level was used in the HP stripper and hydrolyzer, whereas the LP steam was deployed to the decomposition stages, evaporators and distillation tower. With the revamping project, an additional kettle-type HP carbamate condenser was installed downstream the existing one. Following preliminary mechanical evaluation by Casale mechanical specialists, the existing kettle HPCC, with original shell-side design pressure at 5.5 kg/cm^{2}g, was re-rated for 8 kg/cm^{2}g. Existing safety valves were replaced for the new relief set. With a second HPCC, it was possible to generate LP steam at 5.5 kg/cm^{2}g, deployed to users requiring higher temperature, and 3.5 kg/cm^{2}g used for tracing, flushing and in exchangers requiring lower temperature. Additionally, a steam condensate

Table 1. Summary of project process parameters used as targets for the revamping project.

	Base case	Revamping target	Delta (%)
Capacity (1)	1252 MTPD	1350 MTPD	+8
MP Steam (process and hydrolyzer) (2)	922.2 kg/MT	691 kg/MT	-25
Ammonia consumption	589 kg/MT	578 kg/MT	-3.3
Urea in treated water (effluent)	NA	3 ppm wt	
Ammonia in treated water (effluent)	194 ppm wt	5 ppm wt	

1. Base case capacity ranging from 1140 MTPD to 1300 MTPD depending on seasonal effects.
2. Steam extracted from CO_2 compressor turbine at 26.8 kg/cm^{2}g and 290 °C.

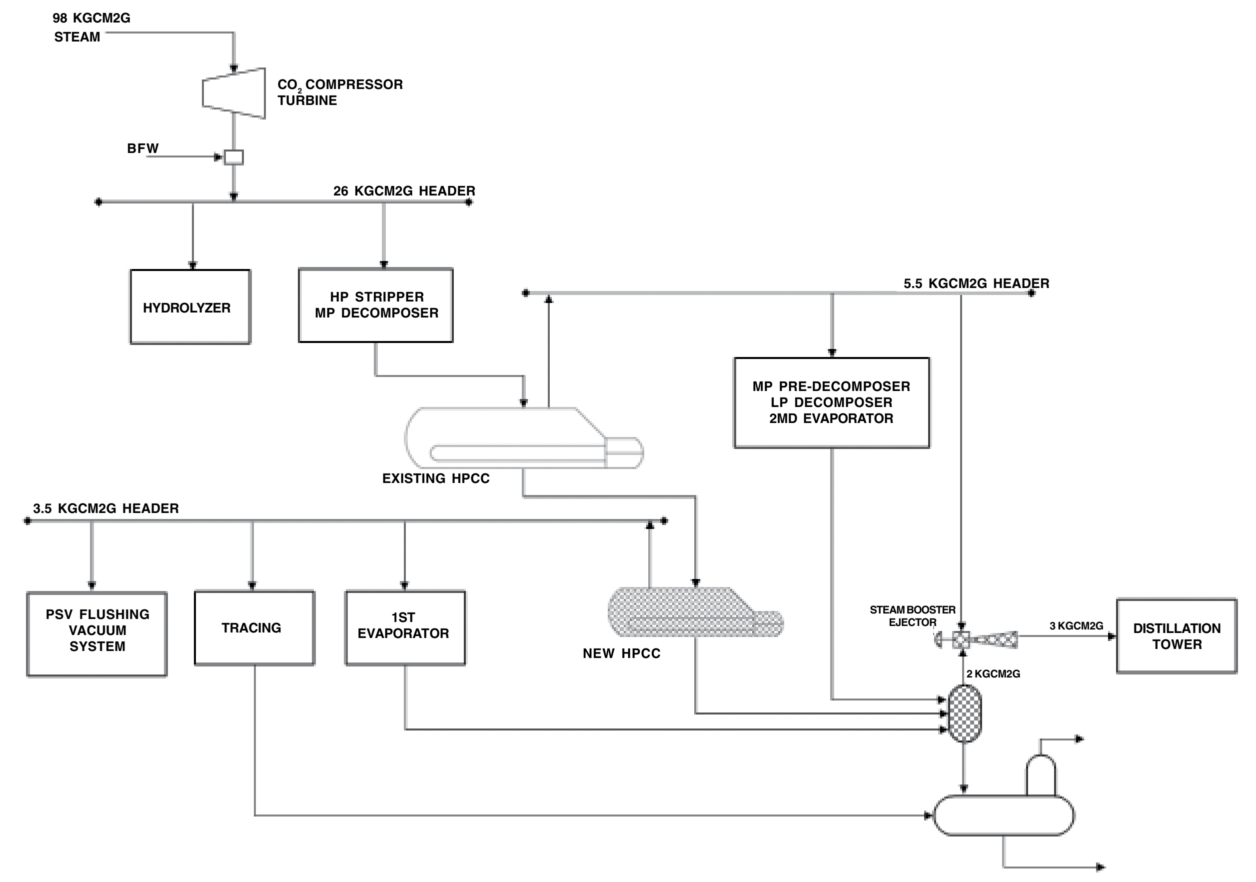

Figure 1. Steam network after revamping (grey pattern for new equipment)

tank at 2.0 kg/cm^{2}g was installed on the LP condensate return header. The low-low pressure generated steam is thermo-compressed in a booster ejector using 5.5 kg/cm^{2}g and delivered to the distillation tower. A schematic of the modernized steam network is represented in **Figure 1.**

The direct advantage of steam internally produced at 5.5 kg/cm^{2}g is the possibility to add a new decomposition step directly downstream the HP stripper. The urea solution from the HP stripper after flashing at 18 kg/cm^{2}g is indeed subject to a new carbamate decomposition step carried out in a medium-pressure pre-decomposer. The pre-decomposer removes the additional carbamate, given by the lower HP stripper bottom temperature and capacity increase, thus debottlenecking the existing MP decomposer. Thanks to the MP pre-decomposer, the MP decomposer can still be operated only with steam condensate from the HP stripper without need of MP steam injection. Casale designed a pre-decomposer with special internals for phase separations which avoids increasing the entrained water in the MP vapours which is typical for similar apparatus.

To reduce the demand of LP steam so that the entire plant consumption could be entirely satisfied with internally generated steam, a vacuum pre-concentrator was installed on the first stage evaporator **(Figure 2)**. This solution has been widely applied in modern ammonia stripping plants where the heat released by carbamate vapours at medium pressure can be conveniently exploited for urea concentration in place of LP steam. Beside steam-saving, adding a vacuum pre-concentrator has also the advantage to drastically reduce the duty required by MP carbamate condenser and consequently the consumption of cooling water.

The heat-recovery performed by the vacuum pre-concentrator reduces the consumption of 3.5 kg/cm^{2}g steam by approximately 200-230 kg/MT urea. This reduction is not enough to close the gap between consumed and produced LP steam. Therefore, two additional recovery steps were added. Namely, a new exchanger was installed to exploit the heat of condensation of low-pressure carbamate vapours and a second heat-recovery exchanger was installed upstream the Reflux condenser in the waste water treatment. The main purpose of these items was to

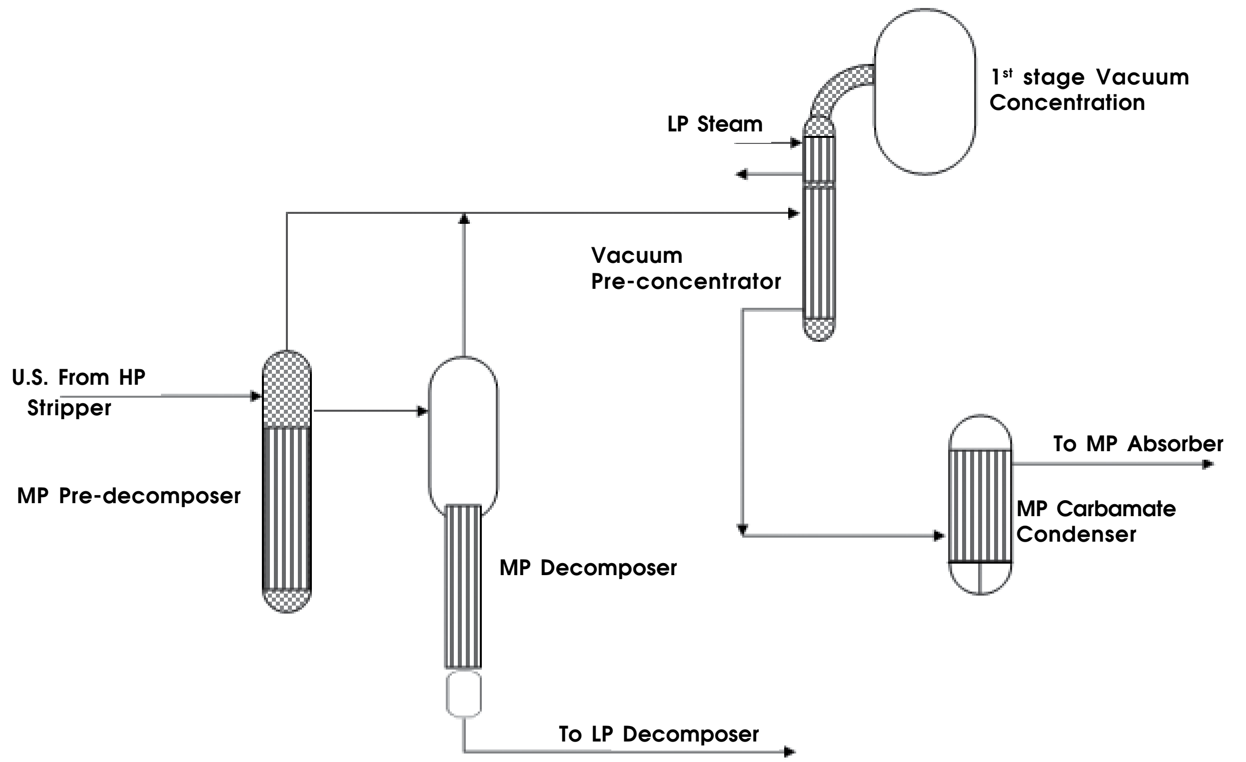

Figure 2. Medium pressure section with new pre-decomposer and vacuum pre-concentrator

increase the production of steam in the HP carbamate condensers and meanwhile debottleneck condensers in LP and waste water treatment sections with consequent saving of cooling water.

To achieve the target regarding the quality of the effluent, the existing waste water treatment section required deep upgrade. In particular, the internals of the distillation tower were replaced with new high fixed-valve trays for high vapour and liquid traffic. The number of trays was increased to improve component separation. The existing kettle-type reboiler was removed in favour of direct LP steam injection to allow use of 3.0 kg/cm^{2}g steam from booster ejector. The existing horizontal hydrolyzer was replaced by a new vertical hydrolyzer column equipped with Casale's proprietary high efficiency trays **(Figure 3)**. The new hydrolyzer features a co-current and counter-current section with direct injection of MP steam. In the lower section process condensate is heated up at temperature favourable for reaction kinetics and hydrolysis is initiated. In the upper section, steam rising counter-current against the descending liquid performs a stripping of NH_3 and CO_2 completing the hydrolysis reaction. Also, hydrolyzer feed pumps and hydrolyzer pre-heater were replaced by new items of larger capacity.

A few additional pieces of equipment were foreseen to maximize plant capacity and reduce ammonia emissions. Namely, an additional ammonia condenser was to be installed in parallel with the existing one to provide larger surface area needed mainly during the hot season. A general upgrade of the vacuum system was also envisaged; together with the original manufacturer it was evaluated to add new condensers to increase the available surface area. To debottleneck the CO_2 compressor and ensure a continuous supply for 1350 MTPD capacity, Casale evaluated to install a cooler at compressor suction using chilled water generated by a vapour absorption machine. Steam condensate from urea plant steam condensate tank was to be delivered to VAM as heat source. During the course of the project, though, RCF decided to postpone the installation of the CO_2 cooler and relative VAM package. As per RCF's request, in view of higher operation flexibility, the existing HP carbamate pumps, which had been facing frequent maintenance issues, were to be replaced with new machines of larger capacity. Based on Casale's specification, RCF decided to install two new reciprocating machines by Uraca rated for 51.5 m^3/hr with variable frequency driver.

Project Execution

The revamping project was initiated by a site survey

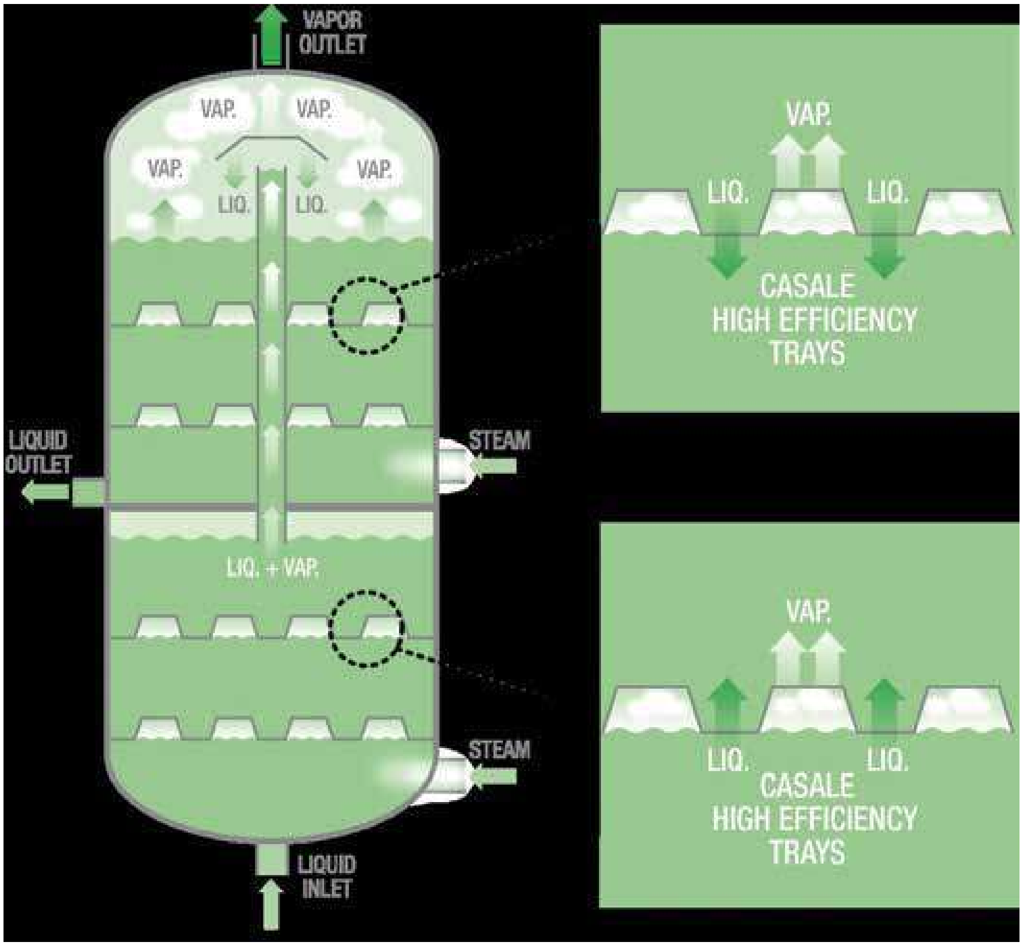

Figure 3. Hydrolyzer with Casale high efficiency trays

followed by feasibility study carried out by Casale. During the study, Casale identified all the plant bottlenecks and presented RCF a revamping scheme supported by a cost analysis. Following the study, Casale was awarded the basic engineering package and the supply of proprietary hydrolyzer internals. The detail engineering was carried out by PDIL and reviewed by Casale. Due to procurement activity that took longer than expected, equipment hook-up could not be executed at the initially scheduled turnaround. Equipment hook-up and tie-ins were completed in 2020 turnaround. These are the project milestones:

- 2014: feasibility study
- 2016 - 2017: basic engineering
- 2017 – 2019: detail engineering
- 2019: hazop
- 2020 November: mechanical completion
- 2020 December : start-up
- 2021 February : guarantee test-run

From the first start-up after mechanical completion in December 2020, the plant was forced to two shut-downs due to activities in the ammonia plant, which delayed the optimization of the operating parameters. Supply of CO_2 and NH_3 from ammonia plant was also constrained and thus, it was not possible for the urea plant to run at the maximum design capacity.

Achieved Performance

As mentioned above, due to feed availability, it was not possible to test the plant at 1350 MTPD, but capacity was limited to 1250 MTPD. Still, operating parameters clearly showed margin for capacity increase. Steam generation occurs at a higher pressure than design case, indicating margin for sustaining a higher duty in the HP carbamate condensers. Additionally, a slight excess of 3.5 kg/

Table 2. Summary of measured performance values during GTR

	Base case	Revamping target	Achieved
MP steam (process and hydrolyzer)	922.2 kg/MT	691 kg/MT	670.2 kg/MT
Ammonia consumption	589 kg/MT	578 kg/MT	571.1 kg/MT
Urea in treated water (effluent)	NA	3 ppm wt	Not Traceable
Ammonia in treated water (effluent)	194 ppm wt	5 ppm wt	3.68 ppm wt

cm^2g steam could frequently be observed. All major control valves operate within the normal range. Once constraints in ammonia plant limiting the supply of reactants are overcome, RCF is committed to steadily run at design capacity.

In terms of steam consumption, during the guarantee test run, the measured MP steam flow rate from turbine extraction (which accounts for all the process users including hydrolyzer) has been even lower than guarantee value. Considering that the production of LP steam at 5.5 and 3.5 kg/cm^2g is enough to cover the demand, make-up from MP header is avoided. The specific consumption is in line with the most modern urea plant which places the revamped process scheme among the best available technology on the market. If compared only with ammonia stripping plants with prilling tower, the achieved specific consumption is the best performance commonly measured in India. From the analysis of the plant data, Casale is confident that consumption of steam could be further optimized, namely, a tight control of the 3.5 kg/cm^2g used for flushing and adjustment of MP steam consumed for hydrolysis according to treated water quality, could further lower the specific steam consumption.

The achieved ammonia specific consumption has drastically reduced with respect to base case. This is a rather satisfactory result considering that the revamping of the vacuum system was not carried out and the additional ammonia condenser was not installed at the time of the test run. The relatively low temperature of the cooling water and a slightly lower plant load, compared to design case, partially mitigated the lack of those additional items. Indeed, during the hottest season, a specific ammonia consumption slightly higher than the value recorded during GTR has been measured by RCF; the summer specific consumption, approximately 575 kg/MT, is still well below the average value before revamping.

Regarding the effluent quality, the measured residual content of ammonia and urea in the treated water were well below the allowed threshold. In particular, the amount of urea was below the detection limit of the lab analysis. The results in terms of ammonia is remarkable since the capacity of the existing distillation tower is at the very limit for the process condensate to be treated. In particular, the narrow internal diameter is drastically smaller than in a new column sized for 1350 MTPD making flooding onset easier. Proper selection of high efficiency trays though managed to match the vapor and liquid traffic necessary for quality achievement with the hydraulic limits of the tower.

Summary of the performance parameters achieved during the guarantee test-run are summarized in the **Table 2**.

Conclusions

The successful revamping of urea plant in Trombay is the result of the strong commitment by RCF towards the modernization of the plant combined with Casale's experience and technical capability in the peculiar business of plant revamping.

The achieved performance parameters are comparable, or even superior, with the most recent and updated urea plants. With reference to Indian fertilizer producers, RCF now operates the most efficient ammonia stripping plant with prilling finishing. Such achievement is due to the deep integration of the process steps to exploit the maximum heat recovery wherever the temperature profiles allowed. Natural consequence of such thorough heat utilization is a drastic reduction of utility consumption which makes the 40-year-old Trombay plant more profitable, more environmentally friendly and more competitive. ■

Improving Productivity of Acid and Complex Fertilizer Plants at PPL

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Paradeep Phosphates Limited (PPL) is one the largest players engaged in manufacturing, trading, distribution and sales of variety of complex fertilizers. Various measures were undertaken to increase the capacity and efficiency of acids and complex fertilizer plants. This paper deals with some of the improvements carried out in the fertilizer plant of PPL. The paper also gives a brief account of measures implemented for improving productivity, efficiency and environment by debottlenecking of sulphuric acid, phosphoric acid, and complex fertilizer plants.

Introduction

Paradeep Phosphates Limited is engaged in manufacturing, trading, distribution and sales of variety of complex fertilizers. It is the third largest private sector in manufacturing of phosphatic fertilizers in India and second largest player in DAP sales. Various grades and manufactured under Zypmite derived from phosphogypsum. Manufacturing facility is located in Paradeep, Odisha.

Capacity of various raw materials and products are: sulphuric acid- 1.39 million MT, phosphoric acid - 0.30 MT and DAP & NPK fertilizers- 1.4 million MT per annum (after revamp - 1.8 million MT).

PPL has a wide network across 17 states covering 11 regional offices, 1324 - stock points, 4529 - dealers, 60257 - retailers and 5 million plus farmers.

Improving Productivity of Acids and Complex Plants

Sulphuric Acid Plant

PPL has taken various measures to improve productivity in sulphuric acid plant by adopting efficient HRS technology for third stream of 2000 TPD sulphuric acid Plant. PPL also upgraded first and second streams of sulphuric acid plants with HRS technology (**Figure 1**). By incorporating HRS technology, the heat recovery improved to 94% from 65% of conventional technology. This enables PPL to produce additional 5 MW captive power from waste heat and also requirement of process steam was fulfilled from HRS low pressure steam. It was not only cost saving but reduction in carbon foot print was also achieved.

Figure 1. HRS tower

To enhance the on stream hours, various modifications and up-gradations were carried out in the plants, few are mentioned below:

i. Replacement of polygon type of mist eliminators with more efficient demister pads in air drying tower (**Figure 2**).
ii. Change of sulphuric acid pipes with Zecor-Z and Zecor-310 M which enabled minimum inventory and low corrosion rate.
iii. Plate acid coolers were replaced with shell and

Figure 2. Replacement of polygon filter with demister pad

tube coolers with anodic protection which reduced downtime due to acid leakages.

iv. Irrigation pipes of cast iron in acid towers were replaced with Sandvik SX which has given a life of more than 20 years.

v. Since inception cartridge filter is used to filter molten sulphur to keep ash content less than 20 ppm.

vi. For energy saving, cooling tower blades were replaced from aluminum to FRP.

vii. DM water is preheated with condensate before feeding to deaerator.

viii. To protect the environment, catalyst loadings in first and second plants were increased to 205 cubic meter from 171 cubic meter to achieve SO_2 emission of less than 1.5 $kgSO_2$/ MT of acid.

ix. Cooling towers blow down are used in the ball mill to conserve water.

x. Hot water of plant is used as cooling tower make up.

Phosphoric Acid Plant

Improving the productivity in phosphoric acid plant is by the philosophy of stretching the plant, experimentation, improvements in equipment material of construction for reliability, timely preventive maintenance of equipment and management of critical spares. Plant is based on di-hydrate process and used various rocks in the reactor since commissioning of the plant in 1992. Rock phosphate and sulphuric acid (98.5% with dilution) reacts in reactor. Total reaction volume is 1900 m^3 and there are different compartments in reactor like annular, vacuum cooler feed tank, vacuum cooler seal tank, and filter feed tank (**Figure 3**).

Various measures taken in phosphoric acid plant to increase the productivity are:

i. Up-gradation of pumps for higher flow.

ii. Increase in pipe line sizes to accommodate higher flow.

iii. Cooling tower extension for evaporators.

iv. Addition of additional evaporator.

v. Installation of new clarifiers.

vi. Replacement of reactor agitators from high flow to high shear in reaction zone.

vii. Height increase in vacuum cooler to control the carryover.

viii. Sulphuric acid dilution with return acid.

ix. Optimization of washing zone in table filter.

x. MoC up-gradation of impeller of vacuum cooler circulation pump, gypsum slurry discharge pump and pond water return pump.

xi. Up-gradation of gypsum slurry discharge line from PN-10 to PN-16.

xii. To improve the environment, manufacturing of flurosilisic acid was started.

xiii. New gypsum pond was made with HDPE liner to protect the ground from leaching acid.

xiv. Effluent treatment plant, treated water is used in ball mill.

A modification is carried in the clarifier bottom by changing the slop. The clarifier was having slope of

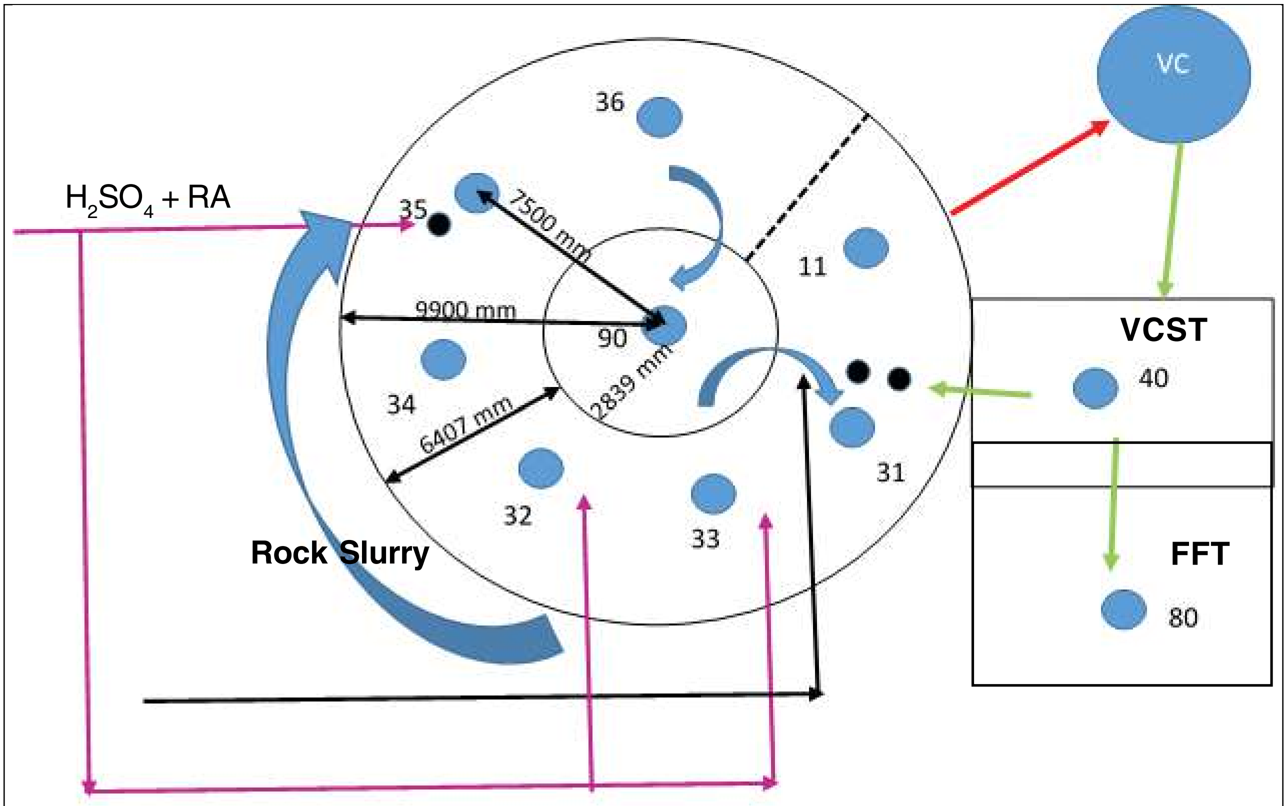

Figure 3. Phosphoric acid reactor overview

2-deg whereas rake arm was having 9.46-deg slope. Sludge used to be deposited at clarifier bottom due to gap between rake arm & clarifier bottom. Clarifier bottom slope is increased to 9.46-deg. This has resulted in no accumulation of sludge in the clarifier and fast cleaning of clarifier if required. Load on rake arm has also been reduced.

Complex Fertilizer Plant

This plant was started in 1986 with imported acid and DAP production. Down the year, various grades were introduced as per market demand and also to optimize the cost of production. Weak acid consumption was increased by installing vaporizers.

Air pre-heater was installed in one train of complex plant after commissioning of third stream of sulphuric acid plant for drying the product from hot air to reduce moisture. This enable to stop FO burning to generate hot air and also resulting in reduction of SO_2 and CO_2 emissions.

To increase capacity and to enhance productivity, all four trains revamp was initiated. Two trains revamp was completed and remaining two trains shall be completed by mid of 2022.

Derived benefits from revamp are:

i. Throughput increase by 12 TPH in all grades of complex fertilizers manufactured in PPL.
ii. Reduction in ammonia emission to 50 mg/ Nm^3
iii. Reduction in solid particulate matters to 50 mg/ Nm^3

Major equipment up-gradation/replacement:

i. Higher capacity fumes fan was installed.
ii. Higher capacity dryer fan was installed.
iii. Dual scrubbing system for better efficiency.
iv. Tail gas scrubber was modified for higher capacity.
v. PN design modification was done for better reaction.
vi. Addition of polishing screen to improve product size.

Process improvement:

i. Installation of polishing screen.
ii. Ammonia vaporizer in all trains of DAP resulted in increase in weak phosphoric acid consumption from 15 to 30%.
iii. Pre-neutralizer design changed from cylindrical type to mushroom type.
iv. P_2O_5 storage tank sludge consumption in complex plant.
v. Addition of urea at initial stage to stabilize the N-20 grade and increase P_2O_5 recovery efficiency and grade balance.
vi. Addition of rock in DAP for higher crushing

Figure 4. Cleaning of phosphoric acid tanks

strength. This modification resulted in increase in crushing strength from 3.26 to 4.24, reduction in moisture in product from 1.42 to 1.33.

Bagging plant Improvement:

To improve the efficiency of bagging plants following measures were carried out:

i. Simplex machine replaced with Duplex machine
ii. Three load cell weighing system installed
iii. NP-20 bags inside liner provided
iv. Bag length increased by 20-25 mm for NP-20 product
v. Anticaking dosing was introduced for NP and NPK product.

Offsite: The phosphoric acid line cleaning is done by 2% sulfamic acid in place of 5% sulphuric acid. This resulted in better line cleaning and no line limitation. Fast cleaning and recovery of sludge P_2O_5 as filler as shown in **Figure 4**.

Figure 5. Ammonia vapour utilization

Energy Improvement Initiatives

i. Incorporation of HRS technology in all three streams of sulphuric acid plants.
ii. Old air compressors (reciprocating) were replaced with energy efficient air compressors (centrifugal & screw type).
iii. Installing HOC air dryer for energy saving.
iv. Ammonia compressor vapour utilization of about 1 TPH in DAP plant. This resulted in steam saving of 4820 tonnes per year **(Figure 5)**.
v. Condensate recovery as DM water.
vi. Replacement of motors with high efficient motors.

Caring For Environment

PPL has always committed to improve the environment of the plant and surroundings. Various measures carried out to improve environment include:

i. SO_2 emission reduction from 4 kg to 1.5 kgSO_2/ MT of acid in old plants by increasing catalyst volume from 171 M^3 to 205 M^3.
ii. Installation of air heater in one train of complex plant.
iii. Plant is upgraded for zero liquid discharge in non-monsoon period.
iv. Recycling of treated effluents to ball mill.
v. Recovery of cooling towers blow down for ball mill usage.
vi. Hot water recycle as cooling tower make-up water.

Conclusion

PPL has implemented a number of measures over the years to improve the productivity of acids and complex fertilizer plants. The measures resulted in increased production, saving in energy consumption, improved raw material recovery efficiency, product quality and improvement in environmental performance. ■

Sulphuric Acid Plant Revamped with SS304H SS Convertor, Commissioned Oct 2018

Phosphoric Acid Concentration Unit, Commissioned Oct 2021

Sulphuric Acid Plant, Commissioned Oct 2020

SESSION – IV

STRATEGIES FOR FERTILIZER MARKETING

Chairman : **Mr. S. Narayanan**
Whole Time Director - Marketing
Greenstar Fertlizers Limited
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KRIBHCO
Cooperative and beyond...
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Effective Logistics Strategy
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Cooperative and beyond...
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Flow of Presentation
Introduction
Characteristics of Logistics in Fertilizers
Nature of product, volume and movement of fertilizers
Modes of transport
Warehousing
Handling and Port operations
Distribution management
Cost Optimization
Information Technology
Suggestions


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Logistics
Logistics is the management of flow of goods and services between point of origin and the destination to meet the needs of companies and customers.
Broadly, logistics comprises of four major components i.e. transportation, storage, handling and distribution.
TRANSPORTATION
STORAGE
DISTRIBUTION
LOGISTICS
3


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Goals of Logistics
Freight Economy
Reduce Response Time
Reliable Delivery Performance
Reduce Inventory
Preserve Product Quality
Logistics
4

	Production/ Import of Fertilizers	Consumption of Fertilizers
Geographical Spread	· Production is concentrated in some states · Imports arrive at ports	· Consumption is spread over a very large area of the country
Temporal Pattern	· Production is continuous throughout the year	· Consumption is seasonal (Kharif - 4 months; Rabi – 3 months)


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Production, Import and Sales Trends
Urea, DAP, NP/NPKs & MOP (million MT)
10
8
6
4
2
0
Apr-20 May-20 Jun-20 Jul-20 Aug-20 Sep-20 Oct-20 Nov-20 Dec-20 Jan-21 Feb-21 Mar-21
Production (mMT) Import (mMT) Sales (mMT)
➢ Production and imports occur round the year.
➢ Consumption of fertilizers confined to few months in a year.
➢ Fertilizers are applied mainly during June to August and November to January.
➢ Consumption is dependent on monsoon and cropping patterns of areas.
9


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Fertilizer Production and Distribution Areas
Urea
➢ Production is concentrated mainly in Gujarat and UP.
➢ The consumption is pan India
DAP & NP/NPK
➢ Production is concentrated in states of Orissa, Gujarat, A.P and T.N.
➢ Consumption is pan India
10


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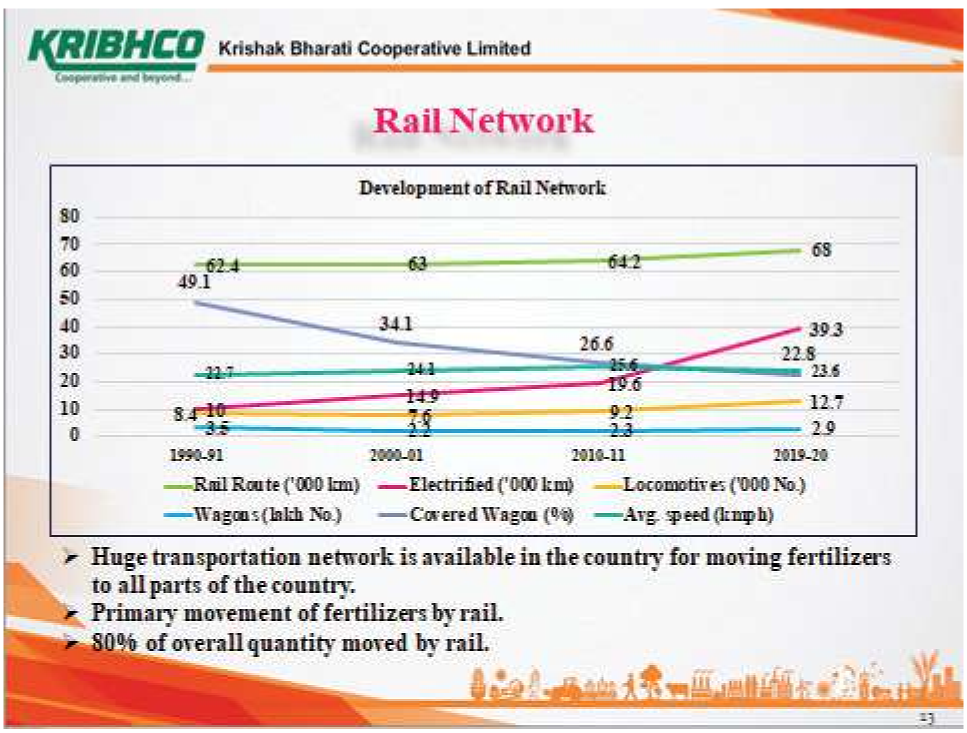
Fertilizers Import and Distribution Areas
➢ Import of fertilizers through major ports located on coastal areas.
➢ Consumption takes place all over India.
➢ Consumption areas are far from point of imports – huge movement involved.
21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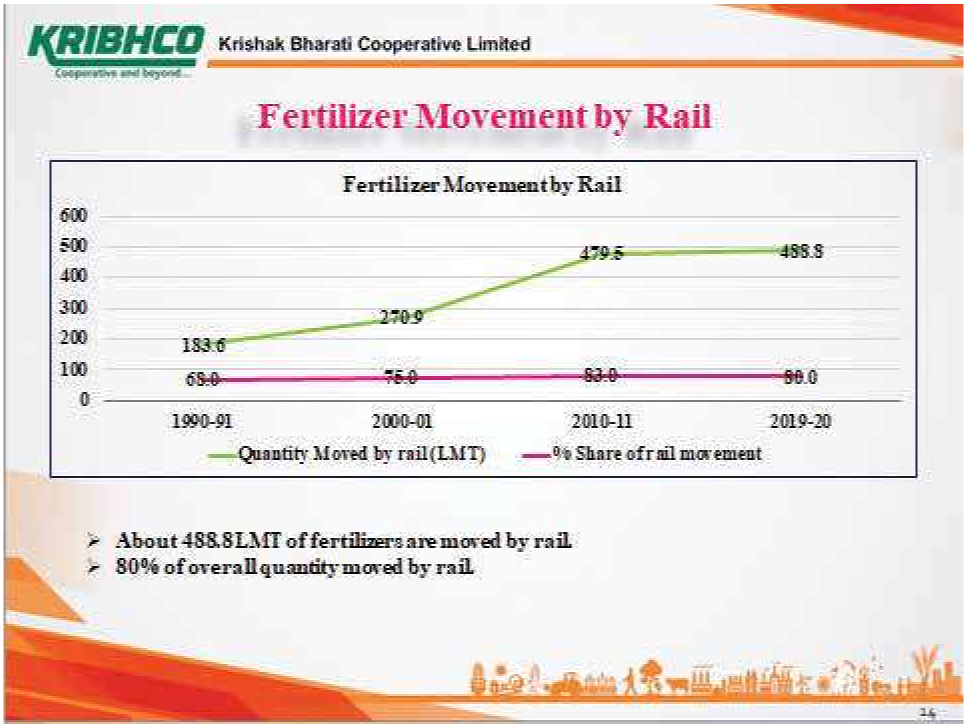
Rail Network
Development of Rail Network
80
70
60
50
40
30
20
10
0
1990-91
2000-01
2010-11
2019-20
62.4
63
64.2
68
49.1
34.1
26.6
22.8
39.3
22.7
24.1
25.6
23.6
8.4
10
14.9
19.6
7.6
9.2
12.7
3.5
2.2
2.3
2.9
Rail Route ('000 km)
Electrified ('000 km)
Locomotives ('000 No.)
Wagons (lakh No.)
Covered Wagon (%)
Avg. speed (kmph)
➢ Huge transportation network is available in the country for moving fertilizers to all parts of the country.
➢ Primary movement of fertilizers by rail.
➢ 80% of overall quantity moved by rail.
23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Fertilizer Movement by Rail
Fertilizer Movement by Rail
600
500
400
300
200
100
0
183.6
270.9
479.5
488.8
68.0
75.0
83.0
80.0
1990-91
2000-01
2010-11
2019-20
Quantity Moved by rail (LMT)
% Share of rail movement
About 488.8 LMT of fertilizers are moved by rail.
80% of overall quantity moved by rail.


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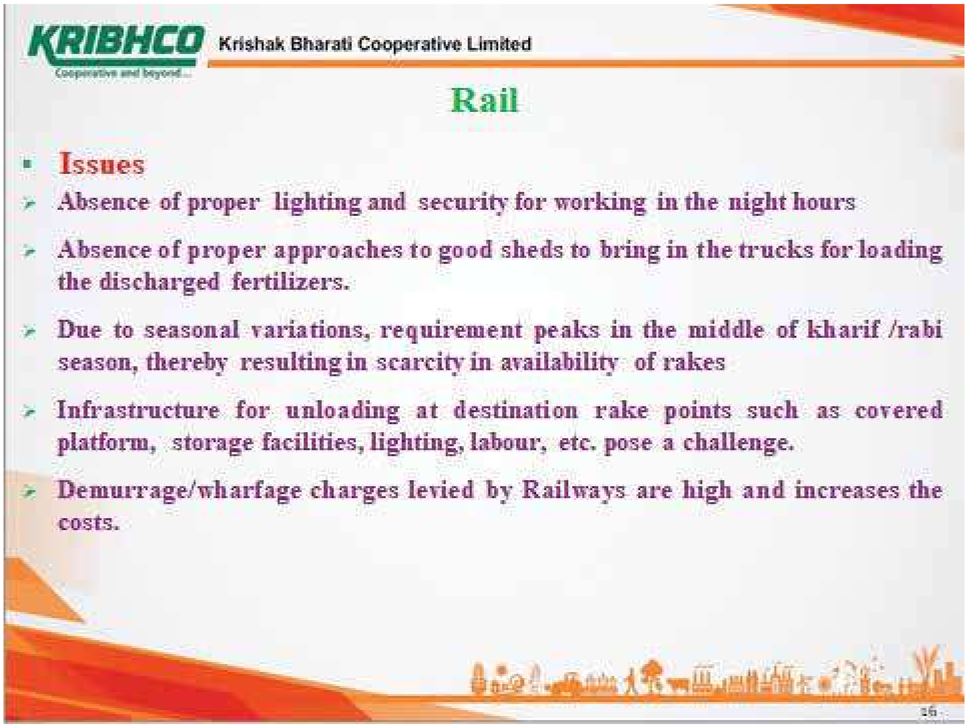
Rail
Issues
Route bottlenecks
Congested terminals
Poor condition of rake handling terminals
Shortage of covered wagons
Lack of Users' friendly Rules
Transit losses due to pilferage, etc.
Non-availability of rakes for short lead destination
Absence of information about two-point rake combinations, restrictions, congestion, etc.
Inadequate platform for unloading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Rail
Issues
Absence of proper lighting and security for working in the night hours
Absence of proper approaches to good sheds to bring in the trucks for loading the discharged fertilizers.
Due to seasonal variations, requirement peaks in the middle of kharif /rabi season, thereby resulting in scarcity in availability of rakes
Infrastructure for unloading at destination rake points such as covered platform, storage facilities, lighting, labour, etc. pose a challenge.
Demurrage/wharfage charges levied by Railways are high and increases the costs.
26


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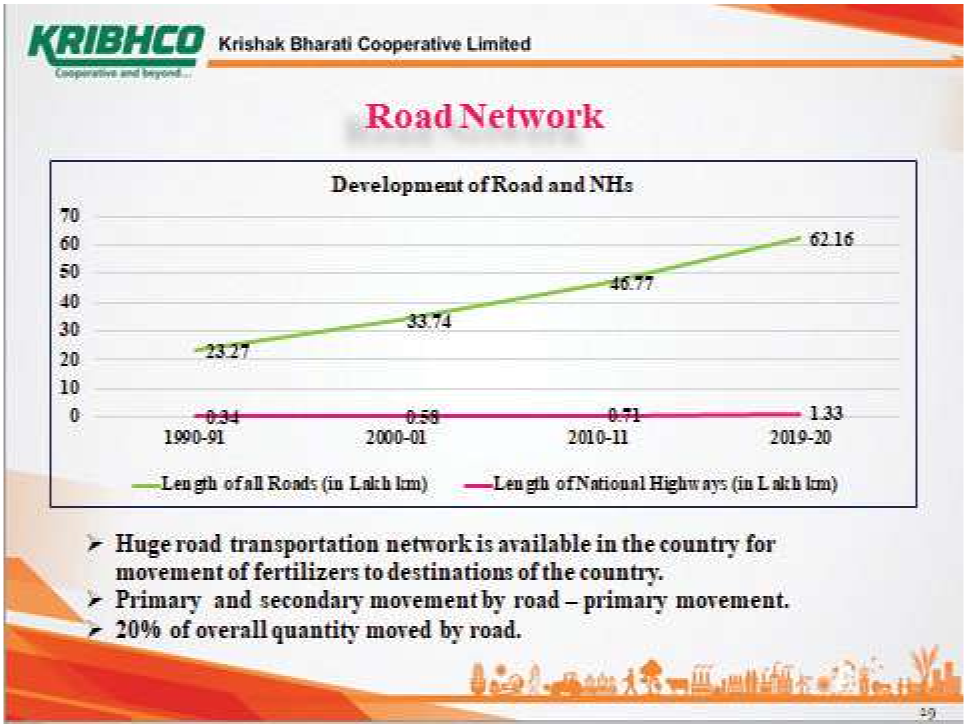
Rail
Strategy
Long distance Trains
High Powered Locomotives
Electrification of more routes
Upgradation of Gauge
Increasing average speed - save time
Development of dedicated freight corridors.
Deployment of more number of rail heads for fertilizer handling.
Permitting two point rakes.
Permitting mini rakes.
Development of infrastructure at some of the rail heads handling fertilizers to improve the efficiency and speed.
Deployment of clean and sound wagons to ensure quality of fertilizers during transit.
27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Cooperative and beyond...
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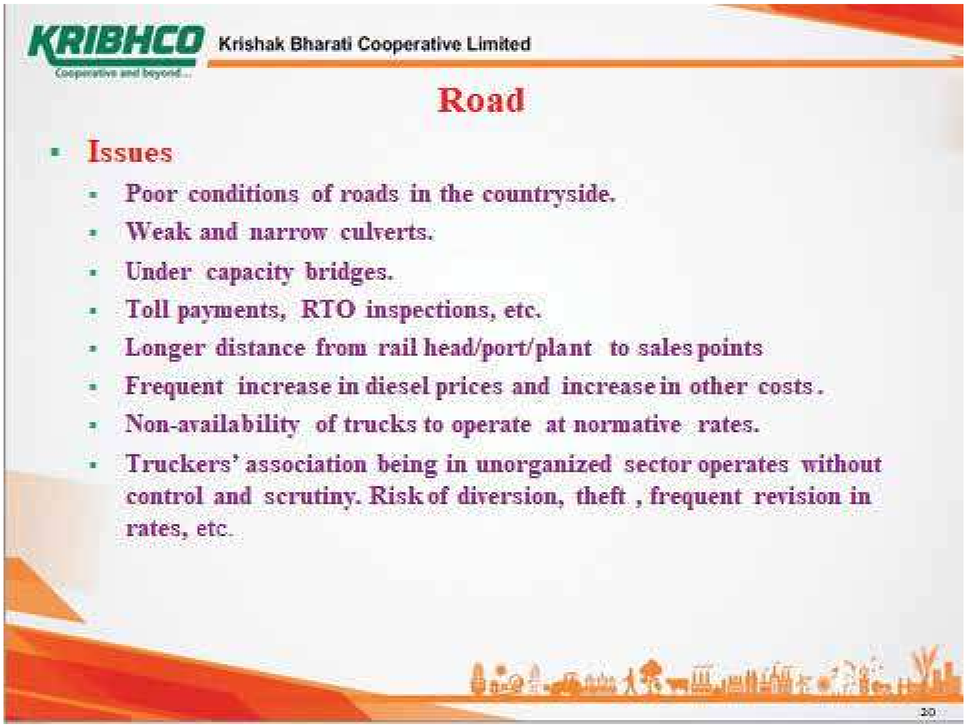
Road Network
Development of Road and NHs
70
60
50
40
30
20
10
0
62.16
46.77
33.74
23.27
0.34
0.58
0.71
1.33
1990-91
2000-01
2010-11
2019-20
Length of all Roads (in Lakh km)
Length of National Highways (in Lakh km)
➢ Huge road transportation network is available in the country for movement of fertilizers to destinations of the country.
➢ Primary and secondary movement by road – primary movement.
➢ 20% of overall quantity moved by road.
19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Road
Issues
Poor conditions of roads in the countryside.
Weak and narrow culverts.
Under capacity bridges.
Toll payments, RTO inspections, etc.
Longer distance from rail head/port/plant to sales points
Frequent increase in diesel prices and increase in other costs.
Non-availability of trucks to operate at normative rates.
Truckers' association being in unorganized sector operates without control and scrutiny. Risk of diversion, theft , frequent revision in rates, etc.
20


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Road
Strategy
Upgrade National Highways with a provision of 4 to 6 lanes.
Improve quality of rural roads.
Modify primary freight reimbursement system of P&K fertilizers in conformity with urea.
Increase Rail : Road mix in favour of road.
Allow primary road coverage beyond 500 km.
Develop company owned fleet of trucks.
Deploy a mix of large capacity and small capacity trucks.
Develop multi-product/multi-point delivery system.
21


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Warehousing
Warehousing of fertilizer is an essential part of logistics as-
About 43.5 mMT of fertilizer is produced and 20.5 mMT is imported which needs to be stored.
Limited storage can be done at plants/ports.
Fertilizer demand is seasonal (Kharif & Rabi).
Limited storage space available at intermediate places and consumption points.
Transportation of fertilizers is not very quick, hence the need for more storage.
Demand is based on cropping pattern of the area.
Competition with other goods for space.
23

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Warehousing

- Fertilizers require large storage space.
- Highly fragmented warehousing industry - 85% in unorganized sector.
- Warehousing space is often blocked with a fixed quantity round the year. Due to seasonal requirement and limited availability, facilities of warehouses need improvement.
- Warehousing for fertilizers is mainly provided by CWC, SWCs, MARKFED, cooperative societies, etc. and other agencies in private sector.

24

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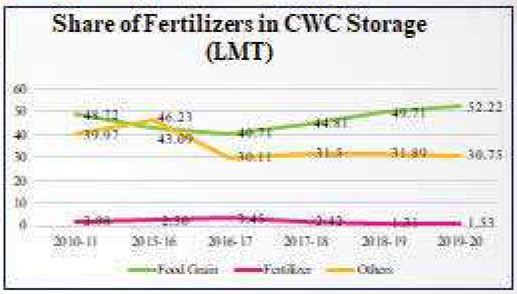
Warehousing

Year:2019-20	CWC	SWC
No. of warehouses operated	415	2093
Storage capacity (LMT)	99.62	397.24



- Inadequate skilled labour
- Inefficient material handling with outdated handling equipment
- Limited technology penetration and innovation
- Lack of world-class standards and specifications
- Inadequate availability of space at CWC/SWC.

25

25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Warehousing Strategy
Requirement of warehouse spaces as per consumption pattern of the area
Schemes incentives for retailers and farmers to lift material ex-railhead
Avoid overstocking and stock-out events – inventory management
Adoption of new and improved technologies for inventory management
Development of buffer stocking points near high consuming areas
Improve standard of warehousing to avoid deterioration in quality of fertilizers
Encourage hiring of warehouses on actual utilization as far as possible
Increase storage at ports
Make more storage available from CWC/SWCs
Skill development of labour to avoid hooks
Mechanization of loading, unloading and stacking operations to reduce labour requirement and cost
26


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Handling
About 20 mMT of fertilizers is handled at various ports annually.
Ever increasing volumes require efficient handling and evacuation from ports
Delays in handling can attract demurrage
Rake loading and unloading is handled by labour. Labour unions at many places, affect man productivity
Increasing handling cost due to labour shortages
Use of hooks impacts the quality of packing and product
Skill development of manpower needed for efficient operations.
28
28


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Handling
▪ Low level of mechanization- Fertilizer as a product is handled primarily by manual system at many units/ports.
▪ Low level of mechanization at many plants/ports, railway sidings and warehouses increases handling costs and turnaround time of rakes.
▪ Mechanization can improve handling operations efficiency at plant, rail heads and warehouses.
29


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Port Operations
Issues
▪ Inadequate infrastructure at port to handle large vessels
▪ Long waiting time for berthing
▪ Lack of mechanized discharge and handling at some ports
▪ Cumbersome customs/GST clearance procedures.
▪ Insufficient warehousing for storage space.
▪ Inadequate rake loading facilities.
▪ Insufficient rake availability at certain times
▪ Low availability of vessels
▪ Low preference for road movement
30


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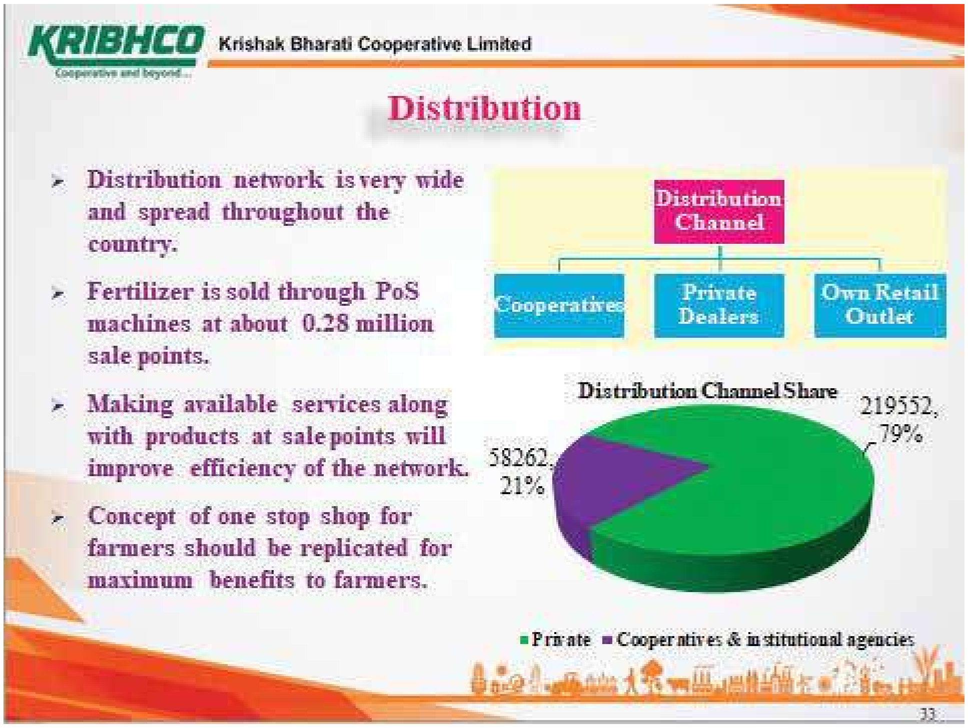
Port Operations
Strategy
Mechanization at ports for discharge and handling to improve efficiency.
Development of additional berths.
Dredging should be done to increase port drafts.
Upgradation of rail / road transportation network near ports.
Port infrastructures, warehouses, truck waiting area etc to be created at the port for efficient delivery.
Simplify procedures for various clearances.
32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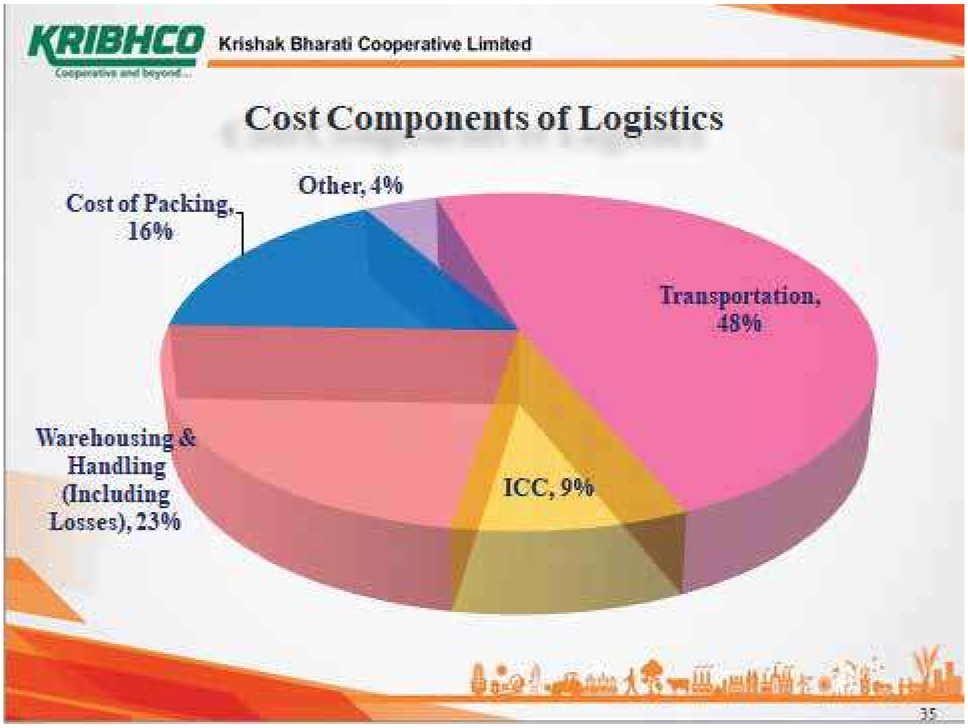
Distribution
Distribution network is very wide and spread throughout the country.
Fertilizer is sold through PoS machines at about 0.28 million sale points.
Making available services along with products at sale points will improve efficiency of the network.
Concept of one stop shop for farmers should be replicated for maximum benefits to farmers.
Distribution Channel
Cooperatives
Private Dealers
Own Retail Outlet
Distribution Channel Share
219552, 79%
58262, 21%
Private
Cooperatives & institutional agencies
33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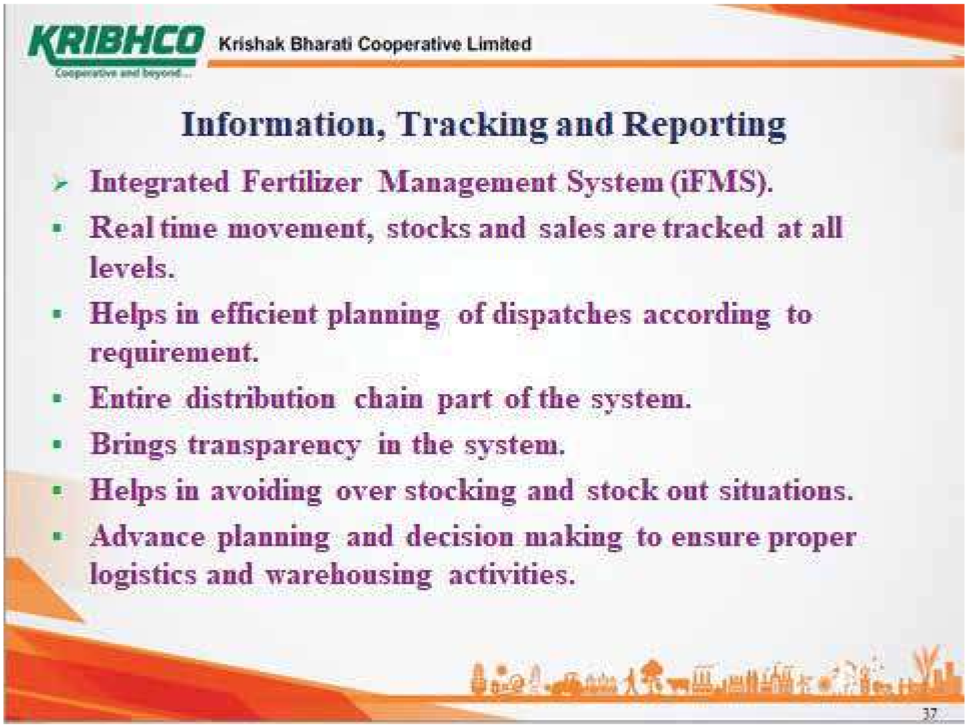
Cost Components of Logistics
Other, 4%
Cost of Packing, 16%
Transportation, 48%
Warehousing & Handling (Including Losses), 23%
ICC, 9%
35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Information, Tracking and Reporting
Integrated Fertilizer Management System (iFMS).
Real time movement, stocks and sales are tracked at all levels.
Helps in efficient planning of dispatches according to requirement.
Entire distribution chain part of the system.
Brings transparency in the system.
Helps in avoiding over stocking and stock out situations.
Advance planning and decision making to ensure proper logistics and warehousing activities.
37


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Digitization of Logistics system
Industry needs to digitize end to end logistics system for proper monitoring of fertilizers.
Can further build on iFMS system.
Will bring efficiency and cost optimizations.
To provide real time information to management for timely decision making.
Develop the mechanism to evaluate logistics performance indices such as efficiency of clearance process, quality of transport, cost of transportation, speed of movement, warehouse space utilization, stock turnaround time, inventory management, etc.
38


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Suggestions for Improvement in Logistics
Mechanized handling of goods.
Palletization of fertilizer bags.
Direct delivery to retail points.
Extensive use of IT for real time information.
Robust MIS system through IT.
Introduction of QR code for end to end tracing of information.
Increase in Road movement.
Efficient utilization of resources.
Just in Time delivery to reduce warehousing, inventory and handling cost.
40

DBT/iFMS – Issues and Suggested Measures

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Fertilizer Monitoring System (FMS) was introduced with the objective to monitor the import, production and movement of various subsidized fertilizers in 2007. The procedure for release of fertilizer subsidy was amended in November 2012 with introduction of Mobile Fertilizer Monitoring System (mFMS). The balance payment of subsidy to the fertilizer companies *i.e.* 5% in case of urea and 10/15% in case of P&K fertilizers was linked to acknowledgement of receipt of fertilizers by the retailers. Further, for direct benefit transfer (DBT) of subsidy, an integrated fertilizer management system (iFMS), a more comprehensive system, was developed integrating both FMS and mFMS to enhance the features of system. It was introduced in 2016. The current iFMS provides a platform for DBT on fertilizers where subsidy is paid to producers/ importers based on sales of fertilizers by the retailers through POS devices to farmers installed at retail points across the country. The system is working well, and the iFMS can be extended to implement Direct Cash Transfer (DCT) to bank account of the farmers.

History

History of Fertilizer Monitoring System (FMS) can be traced way back to 2007. The inaugural ceremony of the FMS was held on 13th January 2007; and FMS was formally launched by the then Hon'ble Minister of Chemicals and Fertilizers and Secretary, Department of Fertilizers on 22nd January 2007. It was a path breaking IT initiative undertaken by Department of Fertilizers (DOF). Availability and movement of fertilizers till district level used to be tracked on real time basis through the system. Subsidy payment including freight subsidy was processed with the help of this system.

The then, Hon'ble Finance Minister, in his budget speech of 2009-10 stated that in due course of time, the Government intends to move to a regime of direct transfer of subsidy to the farmers. Subsequently, he in his in the Budget Speech of 2011-12, he referred to constitution of a Task Force in order to work out the modalities for the proposed system of direct transfer of subsidy. The Task Force was constituted under the chairmanship of Chairman, Unique Identification Authority of India, Mr. Nandan Nilekani in February 2011. The Task Force recommended that beneficiaries of all social safety net programmes (MGNREGS, SSP, JSY, IAY, Scholarships, etc.) and recipients of direct subsidy transfer payments (LPG, fertilizers, kerosene, etc.) can greatly benefit the stakeholders by electronically transferring the payments directly into their bank accounts or post office.

In another press note issued in November 2012 titled as "Procedure for Release of Fertilizer Subsidy to Farmers", the Government amended the procedure for release of fertilizer subsidy. For this, the DOF developed mobile Fertilizer Monitoring System (mFMS) through National Informatics Centre (NIC). The mFMS aimed to provide end to end information on the movement of fertilizers up to the last mile delivery and subsidies to the manufacturers/ importers.

In June 2014, it was decided by DOF to develop a more comprehensive by integrating the FMS and iFMS to enhance the features of both the earlier systems. The system tried in the two pilot districts of Andhra Pradesh from 1st October, 2016. Subsequently, more districts of other states were included. These were under direct benefit transfer (DBT) system as a precursor to fertilizer subsidy. DBT scheme was rolled out in states starting from 1st October 2017, PAN India roll out was completed by March, 2018. The scheme is not DBT in true sense. Subsidy payment is made to the industry on the basis of sale of fertilizers to farmers through point of sale (POS) machines.

Need for FMS, mFMS and iFMS

The mandate of the DOF is to make available fertilizers to the farmers at affordable prices. The "affordable prices" part of the mandate gets translated into subsidized fertilizers. The subsidy portion of fertilizers which ranges from 30% to 75% of the cost of the fertilizers is reimbursed to the companies, so as to make available fertilizers for the farmers at subsidized MRP. The requirement of fertilizers is projected by the state governments to the Department of Agriculture, Cooperation and Farmers Welfare, Government of India, which in turn, coordinates with DOF for finalizing the requirement of fertilizers for the seasons (*kharif and rabi*) in the country. Department of Fertilizers prepares state-wise supply plan, issue movement order to manufacturers/importers. State Governments prepare district-wise supply plan and issue quantity and quality certificates. With the objective to monitor the import, production and movement of various subsidized fertilizers and processing subsidy claims and for ultimate aim of introduction of DBT scheme on fertilizers, different software systems were introduced by DOF over the last decade *viz.* FMS in 2007, mFMS in 2012 and iFMS in 2016.

Fertilizer Monitoring System

The FMS was launched in May 2007 to capture dispatch of fertilizers from plants/ports to district warehouse of companies. It had web interface for entry/access of information and used for payment of subsidy. It provided login IDs to companies, state agencies and DOF for enter/view/process information. Companies used to provide information about production, consumption of raw materials, dispatches, receipts and first point sales of fertilizers to wholesalers/retailers. Company-wise availability of fertilizers in a district was available in the public domain. It helped the DOF in planning import and ensuring equitable distribution of fertilizers across the country. It was initiated for the first time in the fertilizer sector and proved to be a well-established and credible source of information to all stakeholders *i.e.* industry, policy makers at central government, state governments and the public at large. The subsidy used to be reimbursed to companies after receipt of fertilizers in the districts of the states. FMS was in the organized sector and, therefore, implementation and post implementation response was good.

Mobile Fertilizer Monitoring System

To achieve more visibility and transparency in the fertilizer supply chain from plants/ports to receipt at the last point sale (retail point), a mFMS was introduced in the year 2012 by the DOF through NIC as a developer of the system (www.mFMS.nic.in). It facilitated the retailer to acknowledge the receipt of fertilizers through mobile as well as web. The mFMS was also implemented for all subsidized fertilizers in the country. The subsidized fertilizers namely urea, ammonium sulphate and 20 grades of phosphatic and potassic (P&K) fertilizers were covered under the mFMS in 2012 (DOF, 2020). A portion of the subsidy *i.e.* 5% in case of urea and 10/15% in case of P&K fertilizers used to be reimbursed to manufacturers/importers after acknowledgment of receipt of fertilizers by the retailers in the system pertained to wholesalers and retailers who were not so equipped to handle the new system. Therefore, implementation of the system was a challenge. Concerted efforts of the DOF and the industry prompted the retailers for acknowledgement of receipt of fertilizers by organizing need based training to them.

Integrated Fertilizer Management System

In June 2014, it was decided by DOF to develop a more comprehensive, all-inclusive system which integrates, incorporates and enhances the features of both the earlier systems *i.e.* FMS and mFMS (DOF, 2020). Accordingly, the software programme *i.e.* integrated fertilizer management system (iFMS) was developed by NIC. It was developed in consultation with the industry and other stakeholders. The software was on parallel run from June 2016 and became fully operational *w.e.f.* 1st October 2016 in certain districts as pilot project. The system was rolled out in all states from 1st October 2017 to March, 2018. The system provides single-window interface for tracking movement of fertilizers from plants/ports to buyers. It has web and mobile and POS interface for entry/access of information and uses e-sign, biometric authentication, e-KYC for security/authenticity of information. System is used for subsidy payment. Presently all fertilizer manufacturers/importers, nearly 30,000 wholesalers and 0.25 million retailers are registered in iFMS. More than 11.28 crore farmers are making purchase of fertilizers. Payment of subsidy and freight is made to the industry after sale of fertilizers which are under subsidy scheme by the retailers through POS machines to farmers. The products being not under subsidy scheme are also monitored through the system. It was really an uphill task to implement this system as the retailers have to sell fertilizers to farmers through POS machines and farmers have to get themselves authenticated by Aadhaar cards. Therefore, lot of efforts went in for educating them about the operation of the new system by organizing various programmes across the country by the fertilizer companies. There were challenges in the operation of the system itself. Industry remained in constant touch with the NIC and DOF for solving the glitches of the system. The Fertiliser Association of India also helped the industry in taking up the issues with the DOF on sustainable basis. Now the system has more or less stabilized but certain problems still persist which are narrated in the later part of this paper. The system also monitors raw materials, production, import, energy consumption norms, revision in urea concession rates, natural gas projections/requirement (demand/supply) and distribution and movement information system - ECA, supply plan *vs.* actual movement.

Advantages of Integrated Fertilizer Management System

- System monitors the production, dispatches, receipts and sales of subsidized fertilizers.
- It is used to track the actual supplies against the planned supplies.
- The State Governments use the system to monitor the availability of fertilizers at the districts.
- Fertilizer subsidy disbursement process moved towards greater transparency and uniformity.
- The diversion of fertilizers to non-agriculture use and its black marketing, etc. is reduced.
- The subsidy is disbursed to fertilizer producers and importers based on sale of fertilizers to farmers through POS devices and farmers Aadhaar card which is linked to UIDAI and iFMS system.
- The subsidy can be disbursed directly to the farmers Aadhaar linked bank accounts as when actual DBT is introduced.

Key Stakeholders in Fertilizer Sector

- Department of Fertilizers, Ministry of Chemicals & Fertilizers
- NIC
- Ministry of Agriculture and Farmers Welfare
- Ministry of Finance
- State Governments and District Administration
- Fertilizer importers, manufacturing companies/units/plants covering public, private as well as cooperative sectors
- The Fertiliser Association of India, a representative body of fertilizer companies
- Fertilizer dealers namely wholesalers, retailers, marketing federations, societies, agro-industry business centers, company's own retail outlets, etc.
- Farmers – the ultimate users of fertilizers

The success of scheme depends on close coordination among all stakeholders robust monitoring and evaluation mechanism.

Functionalities in iFMS

Integrated Fertilizer Management System is a path breaking IT initiative undertaken by the DOF to improve the functioning of the Department in not only monitoring the movement and managing supplies of fertilizers but also processing of the subsidy claims. Various functionalities of system are:

- ***Transactions/Modules:*** Following transactional details are captured on the system. These are entered by the companies on a daily basis and thus system always provides latest information to the Department of Fertilizers and state governments at all points of time:
  - Import of raw materials/finished goods
  - Customs clearances
  - Receipts of raw materials in bulk including natural gas in the plant
  - Production of subsidized fertilizers, including installed capacity data
  - Supply plan
  - Dispatches from plants and ports and returns
  - Receipts in the districts
  - District warehouse details, losses/adjustments.
  - Wholesaler details
  - Capturing retail sales with farmers data
  - Tracking and capturing sales till retailer level
  - Product and freight subsidy claim generation module
  - Bills processing
  - MIS report generation

The above transactions in the system capture information in detail and facilitate the department in monitoring the movement of fertilizers and settlement of claims.

- ***Requirement & Supply Plan:*** The distribution of fertilizers in the country is linked to the requirement given by states for every season. The states also facilitate the fine-tuning of the supply plan for a month, in consultation with the lead fertilizer supplier (LFS) and the department. Thus the state governments provide and view the information about fertilizer distribution online. Payment of freight subsidy is limited to supply plan. Any deviation in supply plan has to be regularized by the competent authority of the DOF and in absence of the same, freight subsidy payment is not released.
- ***Subsidy Claims & Freight Subsidy:*** The weekly product subsidy claims are generated automatically based on the data entered in the system throughout the month. The claims once generated on the system as per the guidelines and format prescribed by the Department of Fertilizers are approved at different levels within the department according to the set norms. The freight claims are generated as per the uniform freight subsidy policy and also approved on the system.
- ***Certification of the States:*** Provision has been made for the State Departments of Agriculture to enter the following information:
  - Product-wise and company-wise material received in the state

- Certification of short or substandard quantity and uploading of Proforma B1 directly on the system
- Provision has also been made to upload quality certificate (Proforma B2)

♦ ***Processing Claims within the Department:*** The entire process of approval of claims (both controlled and decontrolled) within the department has been mapped in the iFMS. Provision has been made for the following:

- Tracking of budgets both for P&K and urea (cash, bond, special banking arrangement)
- Generation of noting and sanction advice in the prescribed formats
- Provision to split claims and generate supplementary claims
- Provision to split the sanction advice depending on the amount being actually disbursed
- Provision to link the companies bank guarantee and the amounts already utilized and available
- Provision for linking the registration certificate given by the state for the sale of fertilizers to prevent processing of claims if the same has not been submitted to the department

♦ ***Generation of MIS Report in iFMS:*** The MIS report provided on iFMS gives up to date information about the fertilizers. Some of the indicative reports are:

- State-wise/district-wise/product-wise - dispatch report
- State-wise/district-wise/product-wise - sales report
- District-wise/distribution-wise - sales report
- Supply plan *vs.* actual receipts
- Requirement *vs*. supply plan
- Subsidy settlement

Current DBT System in Fertilizers and Subsidy Payment

The POS device plays an important role in implementation of the DBT project. The sale of fertilizers by retailers to farmers is done through POS devices only. Software version is updated from time to time. Presently the software version 3.1 is in use throughout the country.

The POS software provides for a one-time registration of retailers in the system. Retailer can register and authenticate himself by entering his user ID of iFMS and Aadhaar card number. Once one-time registration is done and the retailer is having more than one machine, in such cases there can be 4 shop users with the same ID and can sell fertilizers to the farmers through the additional machines. The POS software has provision of sale of fertilizers to the farmers or buyers whose identity is verified through Aadhaar based biometric authentication. Each successful sale transaction will generate two sale receipts, one for buyer and other for retailer for record purpose. The generated bill also automatically informs the buyer the exact amount of subsidy that has been paid by the Government of India on behalf of the farmers to the manufacturer or importer for such purchase. Online sale transactions through POS machines by retailers to famers are tracked company-wise, plant-wise, product-wise in the iFMS, on real time, which enables DOF to process the weekly subsidy bills raised by the manufacturing units. The 100% subsidy claims are being remitted to the company's bank account through electronic mode but not paid in 7 days after sale is made. Further, Aadhaar based biometric authentication is linked to soil health card of the farmer. This would enable recommendation of appropriate mix of fertilizers compatible to the soil health profile of the agricultural land held by the beneficiary. However, the recommendation is not binding on the beneficiary and the sale of fertilizers is on a "no denial mode".

Reports Generated in POS Software

♦ *Fertilizer stock report:* A retailer may click this module to generate fertilizer stocks available as on date at his end.

♦ *Fertilizer sale report for a week*: It provides record of sale of fertilizers on weekly basis.

♦ *Fertilizer receipt report*: It is used to generate report on fertilizers received at the retailer. This report shows the company name, receiving date and quantity of fertilizers received.

♦ *Print bill in duplicate:* Its use is to print a duplicate bill in case of any requirement.

Requirement for Release Order Module (R.O. Module)

Release Order Module/Vehicle Challan Module was incorporated in the iFMS on 17th May 2017. The objective of this module is to track the movement of fertilizers across the country on a real time basis. This module enables companies, wholesalers and retailers to generate vehicle challans in the iFMS application itself. It is now mandatory to generate vehicle challans whenever there is a movement by road and only those transactions for which vehicle challan is generated, will be available to the receiver for acknowledgment.

Details Captured in the R.O. Module

♦ The information of truck carrying the fertilizer consignment

♦ Movement of fertilizers from plant/port to rake point

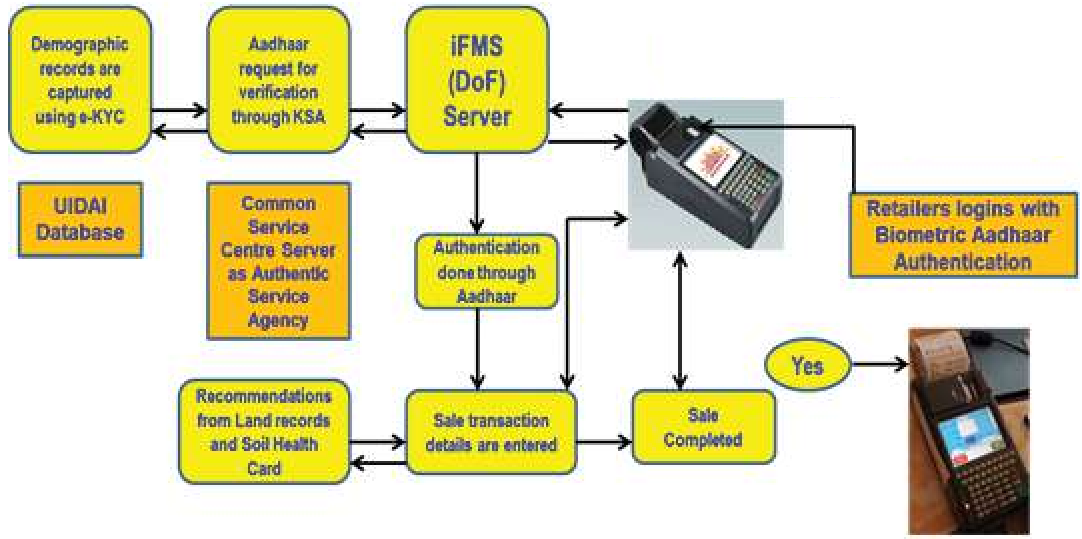

Figure 1. Mechanism of sale of fertilizers through POS machine

- Movement of fertilizer from plant/port to district warehouse
- Movement of fertilizer from rake point to district warehouse or directly to wholesale or retailer
- Movement of fertilizer from district warehouse to wholesaler/retailer
- Movement of fertilizers from wholesaler to wholesaler/retailer

The POS user module is further divided into the following sub-modules

- Sale of fertilizers
- Receipt acknowledgement
- Initial stock reporting
- Bill receipts
- Reports

New initiatives of DBT

Software Version

Keeping in view the various operational challenges *viz.* limited POS vendors, rush of sales due to peak season, etc., Department of Fertilizers, through NIC being the developer of iFMS, launched DBT 2.0 on 10th July, 2019 *i.e.* an advanced multi-lingual desktop version of POS software as an alternative or added facility of POS devices. Retailers having computers or laptops are using this for sale of fertilizers. The Desktop software is more robust and secure. The original version in the POS machines was in English only. Now the software is in many regional languages. Further the new software version 3.0 was also multi-lingual having facility of Aadhaar virtual ID option and fertilizer recommendation based on soil health card. Now the POS 3.1 software version is in place. The details of sale through POS device are illustrated in **Figure 1**.

DBT Dashboards

In order to provide accurate information about the position of supply/availability/ requirement of various fertilizers at National, State and District levels, the DOF had developed various dashboards (https ://fert.nic.in). These dashboards can be accessed by general public by clicking the e-urvarak website of DOF (www.urvarak.nic.in). There are dashboards for the stakeholders as given below:

i. DOF Dashboard
ii. State Dashboard
iii. District Dashboard
iv. Markfed Dashboard
v. Kisan Corner

These dashboards provide various reports such as:

i. Fertilizer stock positions at plants, ports, states and district levels
ii. Proportionate requirement for the season and availability of stocks at various levels
iii. Top buyers' list
iv. Most frequent buyers
v. Retailers not selling fertilizers

In kisan corner, a farmer can know about the retail outlets in the district, availability at the nearest retail outlet and MRP of each fertilizer. The DOF/ movement division can monitor the product-wise availability of fertilizers on day-to-day basis at ports/ plants and also in various states and districts, stock in the country, requirement *vs.* availability, bill tracking module, payment status and can also do the analysis of import *vs.* indigenous production and of subsidy expenditure. The state dashboard helps the state governments to understand about gap between requirement and supply on day-to-day basis, retail sale and top buyers of fertilizers. District dashboard is helpful to the district administration about fertilizer requirement, sales and stock, material in transit, numbers of active wholesalers/ retailers, expiry of letter of authorization of dealers, top buyers, frequency of purchase by beneficiaries and further analysis. The companies can know about production and inventory at various levels and bill generation and its status of payment. Fertilizer availability at their retail outlets and stock acknowledgement report can be accessed by marketing federations with the Markfed dashboard. In reality, generation of voluminous data can be used by stakeholders for understanding of market dynamics/response and farmers' behaviour as the same can be of great help for analysis to all concerned. A screenshot of the same is given in **Figure 2**.

SMS to Buyers

The Department of Fertilizers has implemented short message services (SMS) to farmers for the sale of fertilizers to them in the DBT system. Buyer receives a receipt on his mobile through SMS on every purchase of fertilizers. Department of Fertilizers has introduced SMS system on 30th September, 2020 in POS 3.1 version.

i. The SMS contains the details viz. invoice number, name of retailer, quantity purchased, total amount to be paid, subsidy borne by the Government of India. etc.

ii. SMS module is used to send periodic SMS to farmer about availability of fertilizer at retail outlet from where he purchased fertilizer last.

iii. Farmer can get information about availability of fertilizer at any retail outlet by sending SMS to +917738299899 with sending retailer ID of the concerned outlet he is interested in.

Direct Cash Transfer to Farmers

Direct Cash Transfer (DCT) to farmers has been under discussion at various forum such as PMO, Cabinet Secretariat and Niti Aayog. A Committee of Secretaries (COS) headed by Cabinet Secretary was setup to develop the broad contours of the DCT framework under which DCT to farmers can be implemented. The meeting was held on 16th January, 2020. The COS *inter-alia* had recommended to constitute a Nodal Committee to be co-chaired by Secretaries of Department of Fertilizers and Department of Agriculture, Cooperation & Farmers Welfare to formulate and implement DCT in fertilizers. Accordingly, a Nodal Committee was constituted by DOF on 1st June 2020 to formulate policy relating to implementation of DCT of fertilizer subsidy to farmers.

On 4th June, 2020, Department of Fertilizers, Ministry of Chemicals and Fertilizers, Government of India,

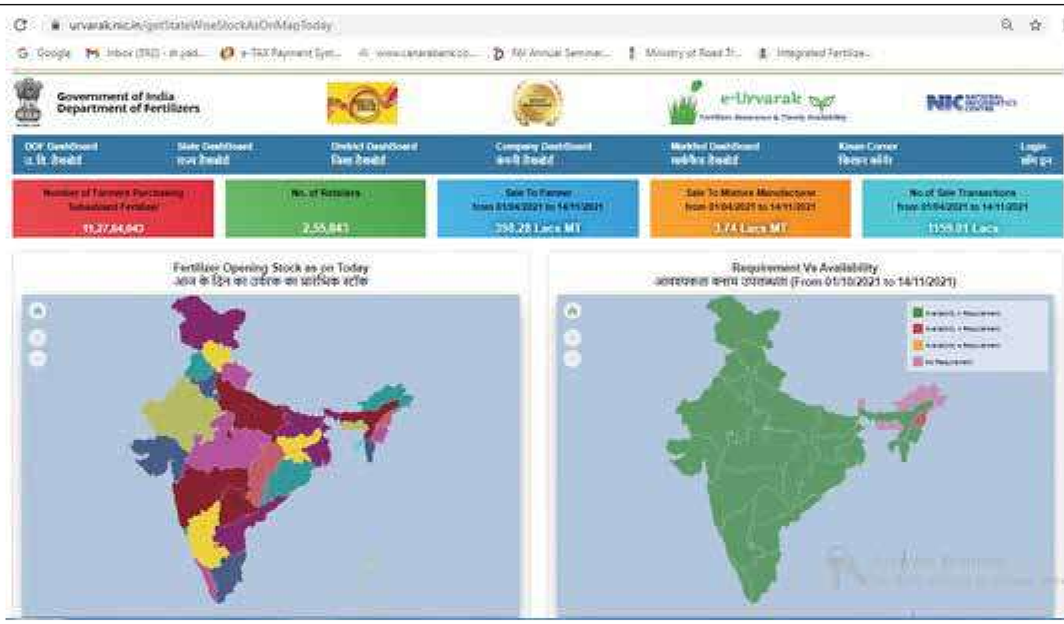

Figure 2. Screenshot of urvarak.nic.in

constituted five high level Working Groups for Chintan Shivir headed by Union Ministers/MOS of concerned Ministries to deliberate on challenges facing the fertilizer sector and to prepare knowledge report for five years' roadmap. The Working Group on Direct Benefit Transfer to farmer (Direct fertilizer subsidy to farmers account instead of an industry) was headed by Hon'ble Minister for Chemicals and Fertilizers (fert.nic.in/dbt). Two meetings of the Group were held in 18th May and 13th July, 2021. Five members from fertilizer companies and DG, FAI were part of the Group. There seems to be consensus amongst the members on implementation of Nutrient Based Subsidy (NBS) scheme for urea and gradually shifting to a system of DBT where subsidy is transferred directly to the bank accounts of farmers.

Current Issues iFMS /POS Machines /DBT

- Dealers are closing their fertilizer business without informing to companies/ State Departments of Agriculture. Non-clearing of such stocks, which is lying in the POS machines, results in blockage of subsidy of the industry.
- There is no mechanism in the system to account for the stock lying in the POS machines of the retailers whose authorization letter have been cancelled by the officials of the state governments.
- Retailers are not updating their mobile numbers (especially societies where CEO term ends after certain tenure period) and unable to approach such retailers over telephone. Towards this, a mechanism for confirmation of retailer mobile number may kindly be developed during login in POS on quarterly basis with OTP authentication.
- Due to COVID19, few cases have come up where dealers expired. The Aadhaar names were registered in the name of the concerned proprietor in POS machines, and other persons cannot login the machines. There is a need to have a mechanism for addressing such issues immediately so that farmers are not deprived of fertilizers in the peak seasons. Companies/LFS/ State Department of Agriculture may be allowed for updating of Aadhaar names from their respective iFMS logins with proper documentation upload. Post verification of uploaded documents can kindly be done by DBT Cell at New Delhi.
- A farmer can purchase only 50 bags in a month of all fertilizers put together as per the guidelines issued by the Department of Fertilizers on 21st January, 2021. Farmers, having more land and raising high fertilizer consuming crops, are facing lot of challenges in complying with the requirements of the crops during the peak seasons. A limit of 50 bags is insignificant for such farmers. Further the district administrations in some states direct the retailers to sell 3-10 bags to a farmer at a time. This is creating difficulties for the farmers and the retailers. Clear guidelines from the Department of Fertilizers will go a long way to sort out such issues. Further the limit should be enhanced to 100 bags per month per farmer.
- Automatic logout is happening after 15-20 minutes of login of POS devices by the dealers. The expiry of login session can be increased to 1 hour for ease of operation of POS devices by dealers.
- In case of damaged stock due to floods/any other reason, dealers are claiming the insurance as per the MRP but the stock held up in their retailer POS / iFMS is lying in the system, for such cases companies could not claim subsidy. A way out has to be there.
- Ensure transfer of entire stock to other wholesalers or retailers and EPOS machine to LFS or dealer, in case of closure of dealership.
- A mechanism for confirmation of retailer mobile number during login in POS may be developed on quarterly basis with OTP authentication.
- Companies/LFS/State Departments of Agriculture may be allowed for up-dation of Aadhaar names from their respective iFMS logins with proper documentation upload. Post verification of uploaded documents up-dation be done by DBT Cell of DOF.

Way Forward

Over the one and half decades, FMS has gone into transformation in mFMS and iFMS and fulfilling the purpose of introduction and implementation of the software system. The transformation into iFMS was with ultimate objective of introduction of DBT on fertilizers. The current iFMS caters the purpose of hybrid DBT, where the subsidy is paid to fertilizer producers and importers based on sales of subsidized fertilizers by the retailers to farmers through POS devices, which is captured in iFMS. The system is working well and now the time is to extend and implement the software system for the real DBT *i.e.*, payment of subsidy directly in the bank accounts of the farmers.

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Effective Marketing for Innovative Fertilizer Products

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The world is changing and so is the agriculture. Megatrends such as climate change, water stress, soil degradation, food industry integration, dietary shifts, circular economy, and digitisation are influencing the way our industry will work in future. Developing innovative solutions that support and enhance climate-smart agriculture help maximize yields and quality while minimizing environmental impact and losses will be a key success factor. India is blessed with an agro-climatic environment which enables us to produce almost all crops in the country round the year. This gives us a huge opportunity to be a player in the agri-export markets. However, we have not been able to take full advantage of the nature's advantage that we have as India remains at the lower end of the global agri export value chain. To improve our presence in the US$ 1500 billion agri-output markets, we need to understand the demands of the international consumer and improve the produce quality up to globally accepted levels. Fertilizer companies have been adopting innovative marketing strategies to serve Indian farmers. Government policies need to support industry efforts, such as the general specifications for water soluble fertilizers. This approach needs to be extended to the entire fertilizer range of products and general specifications of fertilizers (primary-, secondary- and micro-nutrients). The right policies and right marketing strategies will help India to become a leading player in the global market which in turn will lead to higher farm income.

Mega Trends Shaping Industry and Markets

The world has just 8 more years left to achieve the ambition to reach zero hunger, no poverty, good health and well-being by 2030 as laid out in the sustainable development goals. Agriculture globally faces multi-pronged challenges due to ever-growing population, soil health degradation, water scarcity, climate change and ever-increasing production cost. Global population is expected to reach 10 billion by 2050. To feed such a high population means that food production would need to be ramped up putting significant pressure on the environment. From now itself, we need to produce more from less through optimal use of resources to achieve the common goal of feeding the world. Even today, 815 million people are hungry with every third person being malnourished clearly reflecting a food system operating at sub-optimal level. Malnutrition affects the development potential and reduces the work efficiency of the population. Accelerating efforts to address all forms of malnutrition will unlock human potential and stimulate positive change.

The global environment is rapidly evolving and as per our understanding, seven key megatrends are emerging as discussed here.

Key Agriculture Megatrends

Climate Change

Changing climatic patterns are set to impact agricultural production throughout the world, mainly impeding plant growth. Across most sectors, there are increasing pressures and expectations for climate actions and reduction of greenhouse gas (GHG) emissions. More than 20% of global GHG emissions stem from agriculture, forestry and land use change.

Water Stress

Water is crucial for plant growth. There is no substitute. Agriculture is a huge consumer of water and it accounts around 70 per cent of the freshwater usage and lack thereof is a major stress factor in crop production. Climate change disrupts precipitation patterns, while extensive irrigation taps aquifers and reduces water quality through salination. If there is scarcity of water in the soil due to non-irrigation or no

Photo 1. Cracks in soil due to water scarcity

rain in rainfed areas, particularly in heavy textured soil, cracks are developed (**Photo 1**).

Soil Degradation

Roughly one third of the world's soil is degraded, and soil erosion, biodiversity loss and pollution are high on the list of causes. Farming without adequate replenishment of nutrients adds to the problem. Best farming practices, however, focus on soil health, carbon capture and regenerative agriculture. Towards this, integrated nutrient management comprising of all available resources with the farmers inclusive of vermi-compost (**Photo 2**) needs to be given more impetus.

Food Industry Integration

Agriculture and the food value chain is becoming increasingly integrated. Input providers are joining hands, farms are growing in scale and professionalism, the food industry is moving upstream, and the whole industry is under pressure to achieve new levels of sustainability.

Photo 2. A snapshot of vermi-compost

Dietary Shifts

Conscious consumers, particularly in high income countries, are increasingly driving diets towards healthier and sustainable choices, and more plantbased nutrition. Globally, however, the trend towards higher calorie and animal protein intakes continues.

Circular Economy

Resource scarcity, growing sustainability awareness and increased consumer pressure is creating a push towards a circular economy. It creates a push for recycling of nutrients in agriculture and food value chains, as well as for organic fertilizers.

Digitalization

Digital innovation and technological transformation are fundamentally changing strategies and practices in decision making, fertilizer application, farm automation and traceability. It has started to impact the entire food value chain.

Global policies will increase pressure for more sustainable and efficient farming. European Union (EU) put forward plans for the world's first 'carbon border tax' on imports. We need to manage and measure our value creation along the three axes of people, planet and prosperity, we need to have a holistic approach for performance management to integrate sustainability, mitigating GHG emissions and drive towards climate neutral is critically important.

It is important to focus on climate-compatible agriculture which maximizes yields while minimizing environmental impact and losses. This involves optimizing land use by way of increasing yields and efficient water use, while avoiding soil degradation/ depletion or nutrient losses. Developing solutions that support and enhance climate-smart agriculture will be a key success factor. In addition to light, carbon dioxide and water, plants need essential nutrients to grow, which can come from the soil and organic and mineral fertilizers. Mineral fertilizers contain concentrated, consistent, and readily available nutrients, and enable farmers to grow more on less land. Without these fertilizers, world agricultural production could fall by as much as half and it would not be possible to feed the increasing global population.

Boosting India's Agri-export

The Indian agriculture sector, with more than 146 million farm holders, holds tremendous potential for contributing much higher than the current 19% to the

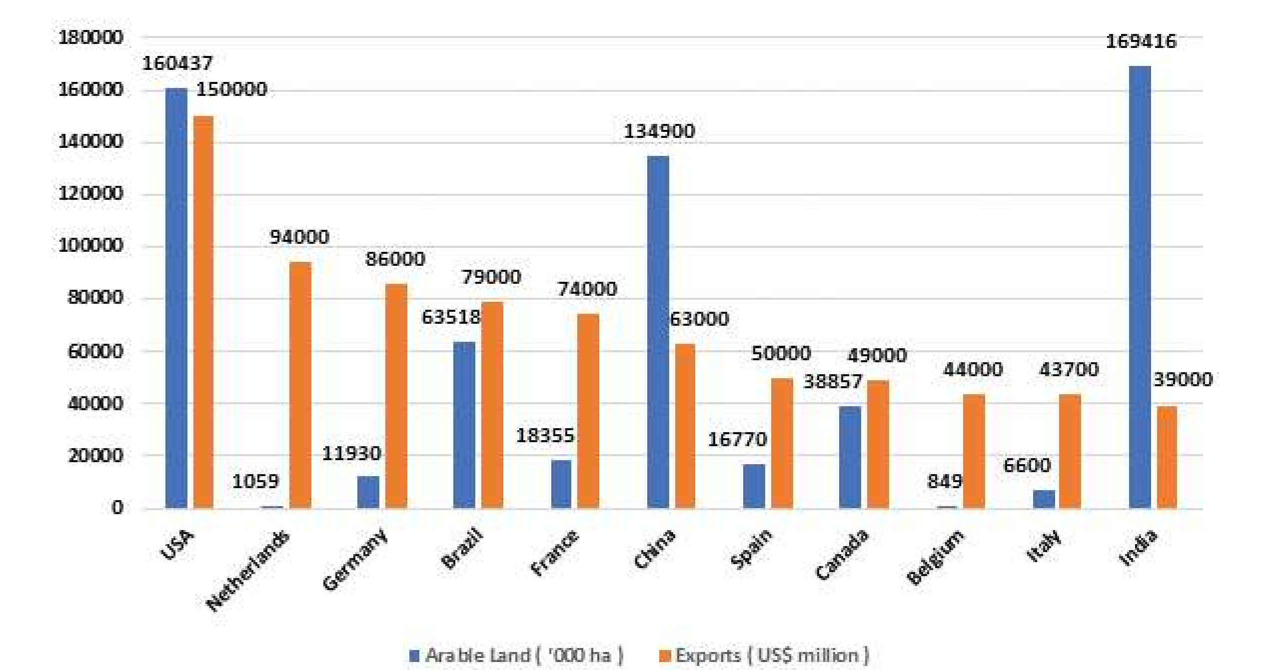

Figure 1. Comparison of India with other countries in relation to arable land and export of agricultural commodities (Source : https://humboldt.global/top-agricultural-exporters/)

Indian GDP. Agriculture continues to remain the only sector that has a direct combined impact on poverty, rural livelihoods, health, and nutrition. With net cultivated area of about 141 million hectare, India has one of the largest arable land resources in the world. With 20 agri-climatic regions, India also possesses 46 of the 60 soil types in the world presenting a unique opportunity to produce almost every crop in the country and potentially supply to the global markets round the year. The focus on climate compatible agriculture and use of innovative fertilizer products will improve yields as well as raise produce quality to international standards.

The country lags other counties in export compared to other countries despite of having largest arable land (**Figure 1**).

Importance of Specialty Fertilizers to Boost Agri-export

The global fertilizer sector has undergone a revolution, and a new category of fertilizer generally known as specialty fertilizers have emerged. Specialty fertilizers are fast-growing and varied group of products with different characteristics containing essential primary-secondary - and micro-nutrients. Harvest of mango after use of specialty fertilizers is given in **Photo 3**.

Controlled release fertilizers, water soluble fertilizers and secondary & micronutrients as well as customized fertilizers come under specialty fertilizer's ambit. The water soluble fertilizers segment is one of the fastest growing specialty fertilizers worldwide. Water Soluble fertilizers go a long way in reducing excessive use of fertilizers as well as improving nutrient use efficiency. Further, the yields of crops and quality improvements are significant helping improve crop export prospects as well as farm incomes **(Photo 4)**.

Photo 3. Harvest of mango after use of specialty fertilizers

Photo 4. Quality produce with use of water soluble fertilizers

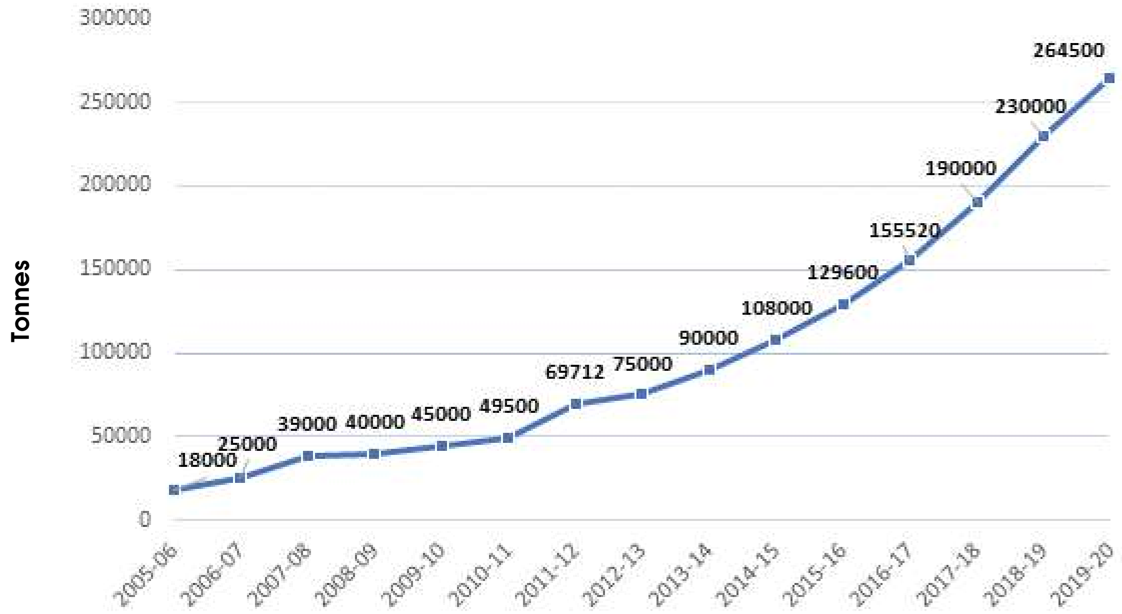

Figure 2. Estimated consumption of water-soluble fertilizers in India (Source : FAI, 2020)

Consumption of Water-soluble Fertilizers and Related Areas

Among innovative fertilizer products, use of water-soluble fertilizers is of vital importance. Consumption of such fertilizers has increased by a compound annual growth rate (CAGR) of 21.1 per cent in the country from 2005-06 to 2019-20 (**Figure 2**). The growth is driven in part by the applicability of water soluble fertilizers across all crop types; in particular, horticultural crops which not only are the biggest constituent of the market but also are the fastest growing. The growing population and thus, rising demand for fruits and vegetables is fuelling the growth of horticultural crops. Water soluble fertilizers are applied in the crops by foliar and through drip irrigation. Use of such fertilizers through drip irrigation, generally known as fertigation, is considerably more than foliar application as per the data available for 2017 given in tonnes (**Figure 3**). Moreover, the increasing acceptance of micro-irrigation and precision irrigation techniques is a major driving factor for the fertigation application. Application of such fertilizers through drip irrigation results in enhancing fertilizer use efficiency considerably (**Table 1**).

Figure 3. Use of water-soluble fertilizers through foliar (tonnes) and drip irrigation (Source : E&Y, 2019)

Drip irrigation also increases water use efficiency to a great extent as water is applied in the root zone as per the demand of the crops. Realizing the importance, Government of India is giving lot of emphasis in promotion of micro-irrigation comprising of drip and sprinkler in the country. The area has increased from 3.1 million ha to 2005 to 11.4 million ha in 2019 showing a CAGR of 9.8%. Per Drop More Crop Scheme initiated in 2015 under Pradhan Mantri Krishi Sinchai Yojana and corpus of fund increased from Rs. 50 billion to Rs. 100 billion for the current year to expand the area under micro-irrigation. Government target is to cover additional 10 million ha in next 5 years. More than 85 per cent area under drip irrigation is in the states of Andhra Pradesh, Maharashtra, Gujarat, Tamil Nadu and Madhya Pradesh. For sprinkler irrigation, leading states are Rajasthan, Karnataka, Gujarat, Haryana, Maharashtra, and Andhra Pradesh (FAI, 2020)

Other Innovative Products

In addition to water soluble fertilizers, there are other innovative fertilizer products such as micronutrients, fortified fertilizers, customized fertilizers, nano

Table 1. Fertilizer use efficiency (Source : FAI, 2020)

Nutrient	Fertilizer use efficiency (%)	
	Soil Application	Fertigation
Nitrogen	30-50	95
Phosphorus	20	45
Potassium	50	80

fertilizer, organic fertilizers, etc. Micronutrients are needed by the plants in small proportion as compared to primary nutrients but are indispensable for the life cycle of a plant. Fortified fertilizers are multi-nutrient carriers and there are 30 zinc, boron, sulphur and magnesium based fortified fertilizers in FCO, 1985 but market is not expanding. Farmers' acceptance needs to be created on importance of value added fertilizers in agriculture. Production of zincated urea is not cost effective. Customized fertilizers are area and crop specific, but production is not picking up. These products certainly help in improving crop yields with better quality (**Photo 5**). Market size of the specialty fertilizers in the country is given in **Figure 4**.

Water Soluble Fertilisers – Impact on Exports

Water Soluble Fertilizers offer multiple benefits in the Indian context. Fertigation is an effective tool to increase productivity as well as quality of the crops. Increased area under fertigation has helped raise the horticulture production in India in the past decade. Further, we do see that increase in consumption of water soluble fertilizers has helped farmers improve the yield quality (**Photo 6**) and improve exports as in the case of grapes. Grapes exports have increased by nearly 25%, over a three-year period from 2017 to 2019, primarily due to better crop quality as result of using of innovative crop nutrition products (APEDA). Higher exports, in turn, imply better returns to the Indian farmers. Many similar stories, for other crops, such as bananas and pomegranates have also been documented

Marketing Strategy for Innovative Solutions (Specialty Fertilizer)

India's potential offers scope and opportunity for

Photo 5. Rice crop with use of innovative products

capturing overseas markets to earn foreign exchange and enable producers to earn higher prices for farm produce. In order to boost our agri export, we need to focus on maximizing yields and quality while minimizing environmental impact and losses. This is possible when farmers access innovative solutions to meet the ever-changing requirements of the global consumers. Companies cannot sell whatever solutions they have, it's important to work with farmers, understand their pain points and provide solutions that work. Marketing of innovative fertilizer solutions has become the necessity to the economic system of the country.

Photo 6. Grapes of export quality

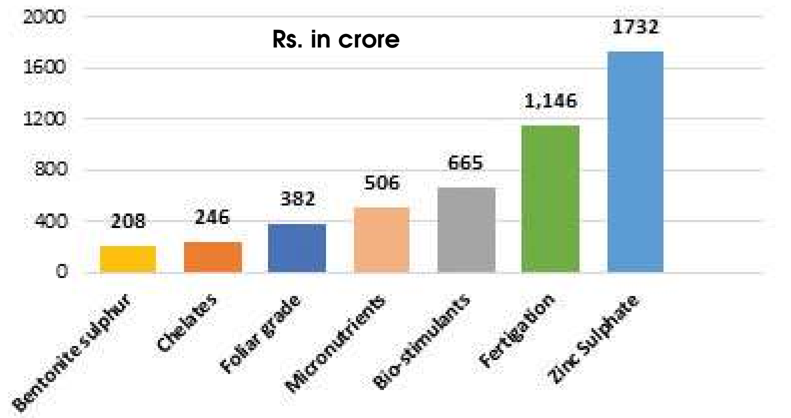

Figure 4. Category-wise market size of specialty fertilizers in India (Source: EY, 2019)

The marketing strategy for the innovative fertilizers should be such that the farmers are helped to overcome the challenges that have been discussed earlier. Some of the ideas that we have been using to help create awareness amongst the Indian farmers are given for the benefits of the readers.

- **Crop-Clinic and Crop Demo**

Organise crop clinic and crop demo to help and educate farmers for using proper Innovative fertilizer for their crop and demonstrate its impact.

- **Mini Kits to the Small and Marginal Farmers**

Distribution of mini kits to the small and marginal farmers is also an important element of the promotional programme. The productivity of different crops at the small and marginal farmers' fields is so low that even a marginal increase in investment on the right type of inputs would give better results. Each mini kit contains a pack of fertilizers, improved seeds and plant protection chemicals, etc.

- **Small Farmers Meetings**

Meet the farmers at regular intervals. Sensitise them how innovative fertilizers can increase their crop productivity (yield and quality). Highlight the salient features of specialty products and convince them to buy and use such fertilizers.

- **Connect with Dealers and Retailers**

Agronomists and sale executives need to get in touch with dealers and retailers selling agricultural products in and around locality. It is important to regularly sensitise about the benefits of innovative fertilizers and their impact on increasing yield, quality, and other related advantages. Also, product-wise business plan for dealers and retailers needs to be developed. Displaying promotional materials and brochures at dealers' and retailers' outlets will also be useful for the visiting farmers to know about such products.

- **Sponsor a Local Event**

Sponsoring a local event helps in building a strong relationship with the local farming community. Display of products, distribution of leaflets as well as some live demonstrations (if possible) would also go a long way in helping farmers to understand the new products and their usefulness in agriculture.

- **Participate in Agricultural Trade Shows**

Participation in agricultural trade shows especially in the Agricultural Universities/ICAR Institutes/State Departments of Agriculture gives a good opportunity to showcase innovative products to the scientific community as well as the farmers.

- **Advertisements**

Advertisements play an important role in creating awareness of the product as well as brand. Traditional media such as newspapers/FAI Journals and now digital media are extremely useful in reaching out to large groups of farmers. Strategically placed hoardings help catching the attention of the farming community. Advertisement on TV is expensive, but the impact is significant in raising the awareness among farmers.

- **Crop Seminars and Webinars**

Organizing seminars and webinars are important tools for sensitizing groups of farmers about innovative solutions. The seminars and webinars should focus not only on products and solutions but also best practices to be adopted.

- **Model Plots**

Creating of model plots to demonstrate the best agricultural practices and use of innovative products and solutions for any particular crop.

- **Digital Tools**

Digital technology enables us to address a key problem in smallholder markets, which is how to bring know-how to remote farms, and reach millions of farmers. Imagine a world where such farmers can arrive at an informed decision and we can unlock the tremendous potential it has. Technology, of course, is a part of a holistic system. Certainly, high quality physical inputs, optimized seeds, infrastructure, etc. need to be further optimized.

Facilitating Access to Innovative Fertilizer Products

While marketing strategies ensure easy warehouse-to-local market access to innovative fertilizers for farmers, the broader issue is encouraging companies to introduce innovative fertilizers into the Indian market. Given the critical role of innovative fertilizers play in ensuring our country's food and nutrition security, the government must create conducive policy environment to spur supply. In India, the fertilizer sector is heavily regulated, and all products must be registered under the Fertiliser Control Order (FCO), 1985 before introducing to the Indian farmers. India has a rather long-winded process for registering new fertilizer products in FCO.

In India, product sample of the new product either imported or produced is taken and multi-location trials are conducted by Indian Council of Agricultural Research or State Agricultural Universities for one season and then results of the same are communicated to Ministry of Agriculture & Farmers Welfare. There is a Central Fertilizer Committee (CFC) and the results are reviewed in the meeting of CFC. After lot of deliberations if the committee feels that the product is good for Indian farmers, the same is approved and notified in Official Gazette for inclusion in FCO, 1985. The important point is that the entire process takes lot of time and considerably time consuming compared to other countries as illustrated

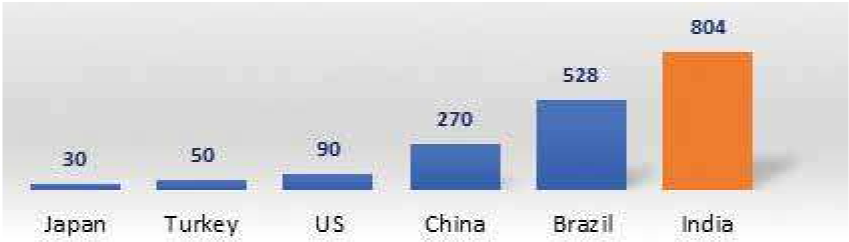

Figure 5. Time taken (days) for approval of a new grade in top agriculture producing countries (Source - World Bank, 2019).

in **Figure 5** and **Figure 6**.

In a study done by World Bank on the time taken to register fertilizers, India came at 98th position out of some 101 countries surveyed (World Bank, 2019). The delay means that Indian farmer is deprived of accessing the latest developments in the global market in the field of crop nutrition. On the other hand, his counterparts in other countries producing the same crop are accessing as well as benefiting from the latest technological developments in crop nutrition. This delay is one of the reasons for the huge productivity gap that we see between India and the rest of the world.

As an illustration of the powerful outcomes that emerge consequent to an enabling policy environment which encourages the introduction of innovative fertilizers, consider the case of water-soluble fertilizers. In a landmark reform the Ministry of Agriculture and Farmers Welfare, Government of India introduced general specifications of water soluble fertilizers NP/NPK (WSF NP/NPK) grades in 2014. The guidelines spelt out the minimum level of nutrients that have to be in these grades for sale of the fertilizers in India. This reform helped suppliers create and make available crop stage specific grades to the farmers without a time lag.

Conclusion

The world is changing fast. Agriculture, the food value chain and industries are also undergoing profound changes. Megatrends like climate change, water stress, soil degradation, food industry integration, dietary shifts, circular economy, and digitisation

Figure 6. Time taken (days) in India compared to SAARC countries for approval of new grade (Source: World Bank Report, 2019)

significantly shaping our industry and markets. Global policies will increase pressure for more sustainable and efficient farming. Developing innovative solutions that support and enhance climate-smart agriculture maximize yields while minimizing environmental impact and losses will be a key success factor. Innovative fertilizers play an important role in enhancing farm productivity with quality produce. There is a sea change in behaviour of the consumers to go in for quality diet. The potential of agri-export is tremendous. In order to enable various market players to introduce more innovative products which help the farmers produce high quality crops and improve their farm incomes, it is essential that the Ministry of Agriculture and Farmer Welfare allow for label claim on all fertilizers (primary-, secondary- and micro - nutrients). This will go a long way in helping develop innovative products which will help the farmers meet the challenges of climate change, soil degradation as well as improve the nutrition content of the crop. It is important for farmers to access innovative products and solutions in order to ensure our country's food and nutritional security. Fertilizer companies have been adopting innovative marketing strategies to serve Indian farmers. The right policies and right marketing strategies will definitely help India to become a leading player in the Global market. *Farmers can "Responsibly Feed the World" by producing more from less – we need to provide the right tools.*

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