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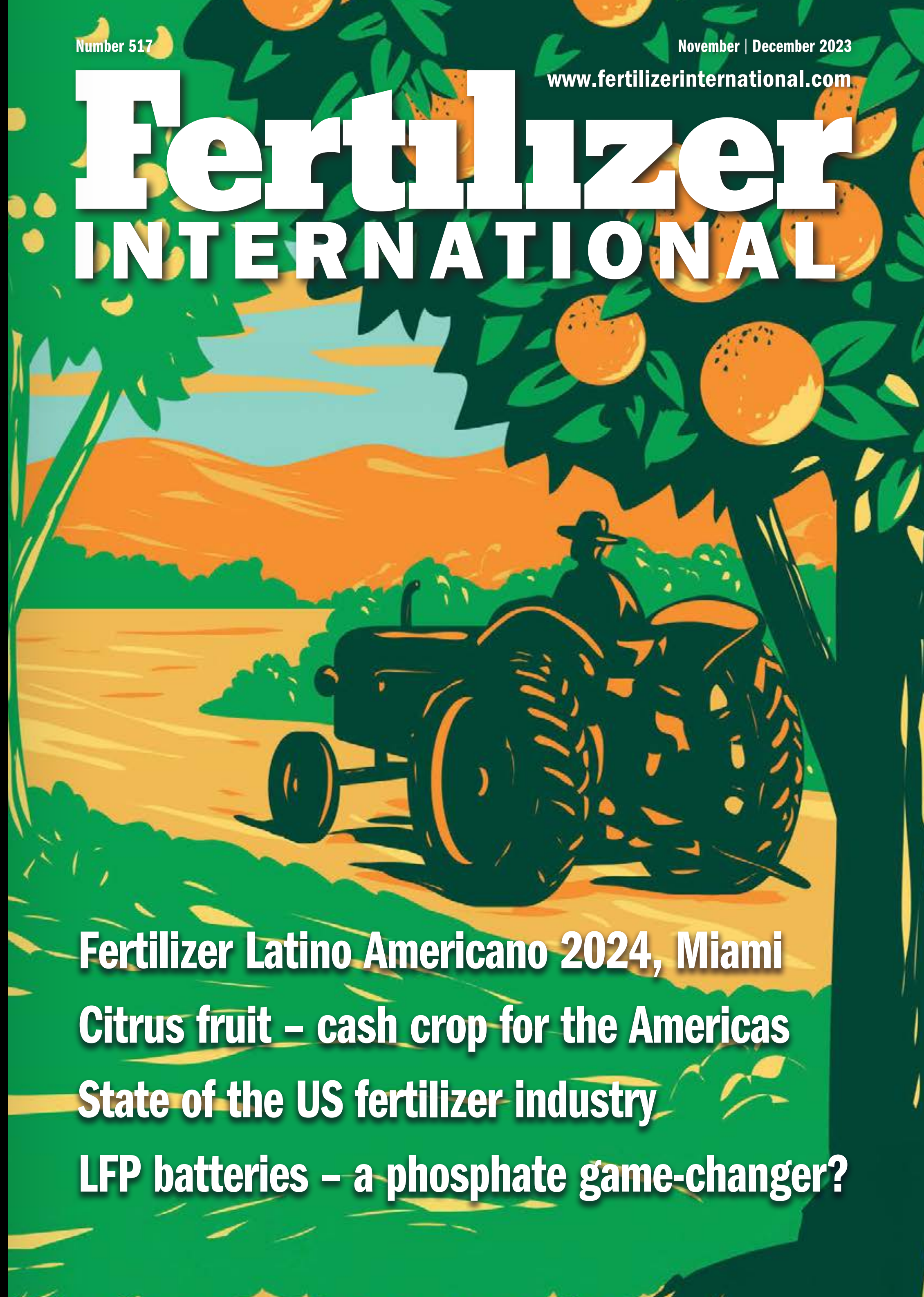

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Cover: An orange grove in Central Florida.
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Editorial

Brazil's grand plans

Brazil is a powerhouse agricultural economy, ranking as a top three global exporter of soybeans, corn and sugar. It is also the world's number one producer and exporter of oranges and orange juice – as highlighted in our current issue (p18).

Yet, to maintain production on this enormous scale, the country is highly reliant on imported agricultural inputs – this dependency being most acute for fertilizers. Annually, Brazil imports 85 percent of its total fertilizer needs. Imports of crop nutrients at this scale are essential for maintaining its powerhouse status, with more than 70 percent of all fertilizer consumption going to the cultivation of just three crops: soybeans (44 percent), corn (17 percent) and sugar cane (11 percent).

In March 2022, Brazil launched its National Fertilizer Plan to great fanfare. Designed to reduce its overdependence on fertilizer imports, the plan was released with some urgency at a time of great market uncertainty.

The preceding 12 months had been a truly unprecedented period for the global fertilizer market characterised by record breaking (and volatile) fertilizer prices and supply security fears. The latter were focussed on sanctions-hit Belarus and Russia, two key fertilizer suppliers to the Brazilian market. It was this combination of factors that gave the national plan added impetus.

The plan's overall goal is to reduce Brazil's total fertilizer import dependency to around 60 percent by 2050 – with specific targets for nitrogen, phosphate and potash imports.

Brazil is targeting a reduction in phosphate dependency from around 70 percent currently to between 25-35 percent by 2050. For nitrogen, the ambition is to cut reliance on overseas supplies by 61-71 percent. The target for potash is even more ambitious – the aim being to cut import dependency from 98 percent of consumption at present to around 40 percent over the next three decades.

So, how to get there?

One major objective is to incrementally increase installed nitrogen capacity to 2.8 million metric tonnes by 2050. Brazil's government has set out grand plans to help achieve this. It wants to draw in more than $10 billion of private investment and attract at least six more domestic nitrogen producers – two by 2030 and then another four by 2050.

Brazil currently has five operational nitrogen fertilizer plants. Unigel's Camacari site in Bahia has a urea unit with an installed capacity of 475,000 t/a, while two units at its Laranjeiras site in Sergipe offer 650,000 t/a of installed urea capacity and 320,000 t/a of capacity for ammonium sulphate. Yara Brasil also operates 416,000 t/a of domestic ammonium nitrate capacity.

Yet, due to poor natural gas supply and low operating rates, Brazil only produced 224,000 tonnes of nitrogen fertilizers in 2020, just 4.3 percent of domestic demand. The priority, therefore, is to improve access to natural gas – to allow existing plants to fully function and to improve the natural gas availability needed for any future expansion in nitrogen fertilizer production. Brazil is therefore seeking new bilateral natural gas agreements with its neighbours, Bolivia and Argentina, to improve its supply access.

For phosphates and potash, Brazil's focus is on pathfinder mineral exploration work. The government is aiming to boost domestic phosphate rock production to 27 million t/a by 2050 and, over the same timescale, gradually raise national potash production capacity to six million t/a. Ultimately, the fertilizer plan wants to increase the number of domestic phosphate producers to 10 and the number of potash producers to 20 by 2040.

In the near term, EuroChem's one million tonne capacity Serra do Salitre phosphate fertilizer project in Minas Gerais state (*Fertilizer International* 507, p58) is scheduled for completion in April 2024. The project could supply up to 15 percent of Brazil's demand, according to EuroChem.

Mosaic Fertilizantes, which operates the Taquari mine in Sergipe state, is Brazil's only major potash producer. The company is investing $154 million and installing new production machinery at Taquari with the aim of boosting potash output to 450,000 tonnes in 2024, compared to 300,000 tonnes last year.

New entrant Brazil Potash, meanwhile, is developing the 2.2 million t/a capacity Autazes potash project in Brazil's Amazonas state (p51).

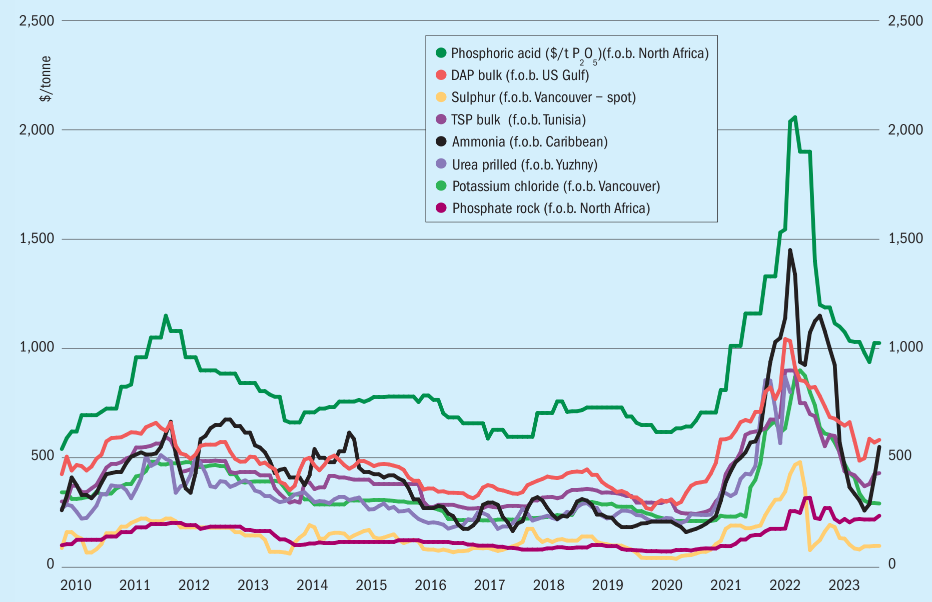
S. Inglethorpe

Simon Inglethorpe, Editor

"Brazil wants to reduce its total fertilizer import dependency to around 60 percent by 2050 – with specific targets for nitrogen, phosphate and potash imports.

Market Insight

Historical price trends $/tonne



Source: BCInsight

Market Insight courtesy of Argus Media

PRICE TRENDS

Urea: Prices in general fell further in late October. Suppliers in most regions were forced to accept lower than expected netbacks due to low import demand and high producer inventories. India was the exception with IPL securing 1.7 million tonnes of urea at $400-404/t cfr under its 20th October tender.

Prices in the other major import markets fell back. Brazil mostly traded at $390-405/t cfr while US prices slipped and Europe was inactive. Most trading activity instead focussed on securing cargoes for India — with firm deals done from the Middle East at $386/t f.o.b., Egypt at $375-380/t f.o.b. and Indonesia at $380/t f.o.b., along with several provisional trades from the Baltic in the $320s/t f.o.b. range.

Key market drivers: Ambiguities around China's urea exports restrictions — particularly those to India — continue to cause market uncertainty. After difficult conditions in recent months, urea trading remans sporadic due to the low appetite for price risk among both importers and traders.

Ammonia: The $50/t rise in the Tampa contract for November has kept the short term outlook relatively stable. Price ranges have been narrowing across most regions with sellers unable to achieve prices above last business.

Seasonal demand from the fertilizer sector is compensating for below average industrial demand in Asia, Europe and the Americas.

Key market drivers include: Yara and Mosaic's Tampa monthly contract price settling at $625/t cfr for November, a $50/t increase on the previous month. This nets back to $575-580/t f.o.b. Caribbean. Pupuk Indonesia is looking to issue an early November sales tender with about 25,000 tonnes of ammonia from Bontang and 6,000 tonnes of ammonia from Lhokseumawe.

Phosphates: Market activity remained subdued at the end of October. Short-term supply availability was limited and demand was waning in major markets. The Indian cabinet has now approved a subsidy cut for October-March. Indian importers, meanwhile, bought 95,000 tonnes of Saudi DAP and 30,000 tonnes of Russian product, with prices mostly in the mid $590s/t cfr for November delivery.

European DAP offers remain firm despite limited demand in most major markets. West of Suez, MAP cargoes to Brazil held at $560/t cfr for November loading, while activity in Argentina remained sluggish. In the US, DAP and MAP barge prices were under pressure due to a late October seasonal lull.

Key market drivers: As expected, the Indian government has agreed the DAP nutrient-based subsidy at Rs22,541/t for the rabi season, down by 31 percent from the kharif season rate.

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Market price summary $/tonne – Late October 2023

Nitrogen	**Ammonia**	**Urea**	**Ammonium Sulphate**	**Phosphates**	**DAP**	**TSP**	**Phos Acid**
f.o.b. Caribbean	550-600	345-375**	f.o.b. E. Europe 140-195	f.o.b. US Gulf	561-594	-	-
f.o.b. Yuzhny	Port closed	Port closed	-	f.o.b. N. Africa	565-640	411-480	975-1,075
f.o.b. Middle East	445-550	340-405	-	cfr India	590-600	-	985*
Potash	KCl Standard	K_2SO_4	**Sulphuric Acid**		**Sulphur**		
f.o.b. Vancouver	263-320	-	cfr US Gulf	50-85	f.o.b. Vancouver	94-100	-
f.o.b. Middle East	300-415	-	-	-	f.o.b. Arab Gulf	100-115	-
f.o.b. Western Europe	-	560-650	-	-	cfr N. Africa	90-127	-
f.o.b. Baltic	245-315	-	-	-	cfr India	119-135+	-

Prices are on a bulk, spot basis, unless otherwise stated. (= contract ** = granular). Phosphoric acid is in terms of $/t P_2O_5 for merchant-grade (54% P_2O_5) product. Sulphur prices are for dry material. (+ Quotes for product ex-Arab Gulf). n.a. = not available.*

Potash: The Indian government has rubber stamped the proposal to cut MOP subsidies by 85 percent to Rs1,427/t for the rabi season, reducing import margins to around $45/t.

In the Chinese market, ex-warehouse prices rose around $7/t as demand for winter storage ramped up. More plantation potash tenders, meanwhile, emerged in southeast Asia. Sarawak Oil Palm awarded its 13,000-tonne standard MOP tender in the $300-315/t cfr range. West of Suez, buy tender offers for 100,000 tonnes of MOP were in the range $350-375/t cfr. European demand for granular MOP is healthy but less so for standard product.

Key market drivers: ICL says there are no impacts to potash supply currently, despite the worsening Israeli-Hamas conflict, with port logistics at both Eilat and Ashdod normal. The Canadian dockworkers strike that began on 22nd October, affecting the trade route between Montreal and Lake Erie, has not had much of an impact on potash movements so far.

NPKs: Prices for complex fertilizers in three key markets, China, Southeast Asia and Europe, were steady towards the end of October. Prices for 20-20-0+13S deliveries to India did, however, soften slightly to $404-407/t cfr. The purchase of another 20-20-0+13S cargo is expected for November loading. This NPS product is expected to be sourced from Indonesia, where Petrokimia Gresik has sold 30,000 tonnes to a trading firm at $10/t lower than its previous sale.

Key market drivers: China's NPK imports totalled 962,000 tonnes for January-September 2023, up from the 645,000 tonnes imported in the same period last year, but in line with imports during first nine months of 2021.

Sulphur: Lower Middle East prices together with lower demand from key import markets weighed on market sentiment towards the end of October. Price drops in China, Brazil and Africa mean there is no longer a delivered market where a price of $130/t cfr is achievable.

Middle East supply tenders have attracted bids in the high $90s to low $100s/t f.o.b. range. Demand from China softened as its sulphur inventory reached a two-year high of nearly three million tonnes. This caused port delays as storage capacity has now reached its limits. A trade for 60,000 tonnes from the Middle East was concluded at $120/t cfr south China.

West of Suez, there is some demand in East Africa and Brazil. A delivery of 35,000 tonnes, priced in the low $120s/t cfr Beira, was booked to Mozambique through a buy tender.

Key market drivers: Chinese domestic prices have softened and eroded due to the release of port stocks to buyers. Spot sales tenders from Middle East suppliers have attracted bids in high $90s/t to low $100s/t f.o.b.

OUTLOOK

Urea: Barring any external market shocks, the cautious buying behaviour of importers looks set to continue – a factor which is likely to limit the extent and duration of any price rally. Countering this, strong sales commitments to India and impending improvements in European and Brazilian demand should limit downside risks.

Ammonia: December prices look like heading lower as seasonal fertilizer demand wanes and buyers wind down stocks ahead of the year's end.

Phosphates: Latent DAP demand in India and Pakistan should support prices in the short term, although buyer interest for cargoes loading in December-January is expected to subside quickly. A correction in finished phosphates prices looks likely, if raw materials prices drop in the east. The US market remains quiet for now and Brazilian importers also have time to spare before making more purchases.

Potash: No real downside to the Indian subsidy cut is expected globally with the change unlikely to affect prices much. Chinese domestic demand, meanwhile, is building for winter storage. Additionally, Brazilian Safrinha demand should arrive at some point and more plantation tenders are also emerging in Asia.

NPKs: A combination of factors should keep the market steady in the short term. These include competition for sales, a stubbornness among buyers to accept higher prices, and the willingness of some suppliers to sell lower than others. Sellers are, however, likely to push for price rises again once demand increases in some key markets, including Europe, helped by the limited availability expected in coming weeks.

Sulphur: A softer DAP trend, linked to lower operating rates in China and declining demand, is contributing to falling sulphur prices. However, west of Suez, healthy November bookings for Moroccan and Brazilian markets are expected to provide market support and limit any downside. A softening in freights assessments should also support supplier f.o.b. prices.

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Fertilizer Industry News

CANADA

BHP commits $4.9 billion to Jansen Stage 2

PHOTO: BHP

The Jansen project is located 140 kilometres east of Saskatoon, Saskatchewan, and is BHP's most advanced under-development project.

BHP has approved an investment of $4.9 billion (CAD 6.4 billion) in stage two of its Jansen potash project (Jansen Stage 2) in Saskatchewan, Canada.

The investment, announced at the end of October, will transform Jansen into one of the world's largest potash mines, doubling production capacity to approximately 8.5 million t/a.

This latest tranche of investment follows BHP's final investment decision in Jansen in August 2021 and the approval of $5.7 billion (CAD 7.5 billion) for the project's first stage (Jansen Stage 1) (*Fertilizer International* 504, p8). Prior to this, the company had invested a preliminary $4.5 billion (CAD 4.9 billion) in developing the project.

"This is an important milestone that underscores our confidence in potash and marks the next phase of the company's growth in Canada," said Mike Henry, BHP's CEO. "We believe Jansen will deliver long-term value for shareholders and the local community, and will position BHP as one of the leaders in the global potash industry."

The Stage 2 investment in Jansen is part of BHP's strategy to focus on commodities that will grow strongly in future in response to global megatrends, such as population growth, urbanisation, rising living standards and decarbonisation.

"Potash, used in fertilisers, will be essential for food security and more sustainable farming," commented Henry. "We are advancing our sustainability and economic development priorities for Jansen and we are pleased with the progress of our ongoing work with the Governments of Canada and Saskatchewan, as well as local and Indigenous communities."

Jansen Stage 1 is progressing on schedule and is now 32 percent complete, with first production from this stage expected in late 2026. Construction of Jansen Stage 2, meanwhile, is due to take around six years and is expected to deliver its first production tonnages in 2029. This will be followed by a three-year ramp-up to full output.

Jansen Stage 2 is expected to deliver approximately 4.36 million t/a of potash at a capital intensity of approximately US$1,050/t. This is lower than Stage 1 costs due to the advantages of existing and planned infrastructure.

BHP approved an initial funding commitment of $188 million for Stage 2 in October 2022. This was to procure long lead equipment and finance the start of the process plant foundation works.

The extra $4.9 billion of Stage 2 investment will be used to:

- Develop additional mining districts
- Complete the second shaft hoist infrastructure to handle higher mining volumes
- Expand processing facilities
- Add more rail cars.

Stage 2 investment also includes funding to increase storage at Westshore Terminals in Delta, British Columbia. This remains BHP's main port for shipping potash from the Jansen mine to its overseas customers.

Jansen has been designed with sustainability in mind and is expected to have approximately 50 percent less operational (Scope 1 and 2) greenhouse gas (GHG) emissions per tonne of product, and use up to 60 percent less fresh water, in comparison to the average Saskatchewan potash mine

Jansen Stage 2 is expected to have an internal rate of return of 15-18 percent and a payback period of approximately six years from first production, according to a BHP evaluation. The company is also forecasting underlying earnings (EBITDA) margins for Jansen Stage 1 and Stage 2 of approximately 65-70 percent due to the mine's low cost position ($105-120/t).

The overlap of Stage 2 of the project with continuing Stage 1 construction is expected to offer operational benefits. These include fully capturing the experience of the integrated project team, the continued use of existing contractors, reduced overheads, and savings on mobilisation and demobilisation costs. These should help deliver potential cost saving of $300 million.

The Jansen mine has the potential for two additional expansion stages over the longer term – subject to further studies and company approvals – enabling the mega project to reach an ultimate production capacity of 16-17 million t/a (*Fertilizer International* 515, p54). ■

MOROCCO

OCP commits to green ammonia ramp-up

Phosphates giant OCP secured a €100 million ($106 million) loan in October for two large-scale solar power plants from the International Finance Corporation (IFC), the World Bank's investment arm. These will be used to help generate green ammonia as a raw material for low-carbon fertilizer production.

The two solar photovoltaic (PV) plants will have a combined capacity of 400 megawatts (MW) and a storage capacity of up to 100 megawatt-hours. They will be located in the mining areas of Khouribga and Benguerir. The large scale solar photovoltaic project will be the first in Morocco to include integrated storage infrastructure – as well as being the largest project of its kind in North Africa.

This is the second green loan secured by OCP from IFC. It follows a similar €100 million IFC loan granted in April 2022. This was earmarked for the construction of four solar plants with a combined capacity of 202 MW in the same two mining areas.

In June, OCP announced plans to invest $7 billion in a green ammonia production plant in Tarfaya in southern Morocco, using hydrogen generated from renewable electricity sources such as solar. This plant could produce 200,000 t/a of green ammonia by 2026, increasing to one million t/a by 2027, and ultimately three million t/a by 2032, *Reuters* have reported.

The investment in green ammonia is part of an overall $13 billion strategy by OCP to shift to renewable energy and construct a domestic supply chain for ammonia. The aim is to increase OCP's green fertiliser production and fully convert its production operations to renewable power. The strategy's other goals are to achieve full carbon neutrality within the business by 2040 and reach a water desalination capacity of 560 million m^3 in 2026.

"Today's agreement is a major milestone towards our target of using 100 percent renewable energy in our fertilizer production by 2027," said Mostafa Terrab, OCP Group's chairman and CEO. "Our deepening collaboration with IFC reflects our alignment on the urgency of addressing the global challenges of food security and climate change simultaneously".

"IFC is proud to support OCP in its journey to reduce its carbon footprint, a strategy that will have long-term positive effects not only in Morocco, but also on the global food supply," said Makhtar Diop, IFC's managing director. "The fertilizer industry needs leading companies like OCP to embrace a sustainable path forward, and IFC is committed to supporting this important shift."

OCP is one of the world's biggest ammonia importers, spending $2 billion on imports of this basic chemical last year. The company consumes ammonia on a large scale as a raw material in diammonium phosphate (DAP) and monoammonium phosphate (MAP) production. The company is the largest phosphate fertilizer producer globally. It also operates the world's largest phosphate fertilizer complex at Jorf Lasfar in Morocco.

Prior to the war in Ukraine, OCP's ammonia demand was partly sourced from Russia via a pipeline through Ukraine and then by shipments through the Black Sea. However, this ammonia supply route has been closed since February 2022 and, to offset the resulting deficit, OCP struck an ammonia supply deal with North America during 2023, according to *Reuters*.

WORLD

Fertilizer affordability hits six-month low

Fertilizer product affordability dropped to a six-month low at the end of September, according to Argus Media, with fertilizers becoming more expensive as a result of high demand, while crop prices also retreated following grain and oilseed harvests in the northern hemisphere.

The Argus fertilizer affordability index is a global assessment calculated from the ratio between fertilizer and crop price indices. It fell to 1.09 points in September, down from 1.24 points in August. An affordability index above one indicates that fertilizers are more affordable compared to the base year (2004), while values below one indicate lower affordability.

The fertilizer index – which includes international prices for urea, DAP and potash adjusted by global usage – rose sharply in September to its highest level since April 2023, supported by increases in diammonium phosphate (DAP) and urea prices. At the same time, wheat, soybeans and corn prices all fell on the month due to high stocks following the start of northern hemisphere harvests.

High DAP prices, in particular, have pressured affordability. Phosphate prices in September were pushed upwards by firm demand in south Asia, as buyers from the subcontinent competed for the available supply. Strong phosphate demand, for example, caused Chinese DAP prices to rise by $113/t between the beginning of August and 25th September.

Firm urea prices also weighed on fertilizer affordability, with the Middle East benchmark rising by 11 percent month-on-month in September to $388/t f.o.b. Global MOP prices, meanwhile, entered a period of stability following strong demand from Brazil earlier in the third quarter. Consequently, the Brazilian granular MOP cfr price dipped slightly to $358/t in late September, equivalent to a three percent fall on the 24th August price.

CHINA

Stamicarbon wins another low energy urea plant contract

Stamicarbon has signed contracts for a new Ultra-Low Energy urea plant in Shouguang, Shandong province, China. This will be the eighth urea plant worldwide to use Stamicarbon's Ultra-Low Energy design.

The contracts, awarded by Shandong Lianmeng Chemical Company, cover licensing and equipment supply for a 2,334 t/d capacity urea melt and prilling plant. They cover technology licensing, proprietary equipment – including high-pressure super duplex stainless steel equipment – and associated services.

Stamicarbon's Ultra-Low Energy design allows heat supplied as high-pressure steam to be used three times instead of the usual two. This reduces steam consumption by about 35 percent and cooling water consumption by about 16 percent, versus traditional processes.

Stamicarbon was awarded a contract for a 3,850 t/d capacity Ultra-Low Energy urea plant – its largest to date – in Jiangxi province, China, earlier this year (*Fertilizer International* 514, p10).

"We're excited to launch a project using our Ultra-Low Energy design, which has shown itself to be the top choice for energy

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efficiency and sustainability in urea production. With this project, we are further expanding our footprint in China, aiming to address the region's growing demand for urea," said Pejman Djavdan, Stamicarbon's CEO.

UNITED ARAB EMIRATES

Fertiglobe strengthens collaboration with AD Ports

Fertiglobe has signed a memorandum of understanding (MoU) with AD Ports Group. This sets out the scope for logistics and supply chain collaboration on storing and shipping urea and ammonia at ports in Egypt and the UAE.

The two companies plan to explore the opportunities for using AD Ports Group's state-of-the-art cargo handling and storage infrastructure more fully. This will assist Fertiglobe as it moves to strengthen its urea and ammonia storage and shipping capabilities, reduce its greenhouse gas (GHG) footprint, enhance operational efficiency and further automate its logistical activities.

Fertiglobe – a strategic partnership between ADNOC and OCI Global – is the world's largest seaborne exporter of urea and ammonia, the largest nitrogen fertilizer producer in the Middle East and North Africa (MENA) region, and an early mover in low-carbon ammonia.

Ahmed El-Hoshy, CEO of Fertiglobe, commented:

"We are pleased to partner with AD Ports Group, a UAE national champion and a global leader in maritime trade and logistics. Through this MoU we will identify compelling opportunities across our logistics and supply chain management requirements, enabling us to bolster our ability to store and ship urea and ammonia from Egypt and further optimize our logistics' cost structure.

"Today, our strategically located production facilities benefit from direct access to international ports and distribution hubs, allowing us to easily access major end-markets and regions with high demand. This MoU will enable us to expand our partnership beyond Egypt and the UAE, as well as to the shipping and storage of green ammonia, in line with our commitment to deliver more sustainable products to the world."

The two companies say that they will also explore opportunities for collaboration in other regions. The development of

EUROPE

Yara and John Deere launch digital farming partnership


PHOTO: JOHN DEERE/YARA

Connected John Deere tractor during crop fertilization.

John Deere and Yara have formed a new partnership to increase fertilization efficiency. The collaboration will integrate Yara's agronomic expertise with John Deere's use of precision technology and advanced machinery.

The aim is to help farmers increase their yields and optimise fertilizer use. These objectives will also help achieve the agricultural policy goals of the EU's Farm to Fork Strategy.

The digital partnership will connect two powerful apps: John Deere Operations Center™ and Yara's Atfarm digital platform. Better connectivity will ensure crops receive the right amount of nutrients, where and when these are needed, by providing farmers with tailored crop nutrition recommendations and then delivering these precisely.

"To be able to produce more efficiently and sustainably, farmers need high-quality, actionable data and the technology to put these insights into practice. This is where digital farming will play a big role in helping farmers optimize the productivity of their fields," the two companies said in a statement.

Yara's Atfarm app enables farmers to monitor the biomass development and nitrogen uptake of their crops throughout the season and access field-specific variable rate application maps for fertilizers. These data can now be seamlessly shared as a WorkPlan with John Deere Operations Center™. This will enable farmers to wirelessly synchronise fertilizer prescriptions to any John Deere farm machine featuring a Gen4 or G5 Display.

Delivering crop nutrients though variable rate application maps is sometimes viewed as complex and laborious. The John Deere-Yara partnership should, however, make the task of achieving higher yields with less fertilizer inputs much easier. Trials have shown that farmers, if they can implement Yara's agronomic advice, should achieve yield increases of up to seven percent with a 14 percent saving in nitrogen fertilizer use.

The seamless connectivity between Yara's Atfarm and John Deere Operations Center™ will be piloted from spring 2024 with a group of farmers in Germany, France and the UK. Yara and John Deere will also collaborate on other opportunities for improving nutrient use efficiency.

"Achieving the ambitious goal of the Farm to Fork Strategy to reduce nutrient losses by 50 percent in 2030 requires the industry to work together. Through partnering with John Deere, farmers will be able to use our recommendations in an easy, practical way. This contributes to more sustainable food production without adding complexity for farmers," said James Craske, VP Digital Solutions Europe at Yara International.

Katharina Nies, Marketing Manager Precision Ag at John Deere, said: "For small grain producers, crop nutrition is one of the largest opportunities for optimisation. We are excited to partner with Yara, as this is a unique combination of science-based fertilization recommendations together with John Deere's connected, highly precise & intelligent machines. With that farmers can achieve highest levels of nutrient use efficiency."

Yara created Atfarm in 2018 to help farmers use nitrogen fertilizers more efficiently with the help of advanced satellite technology and vegetation indices. Although precision techniques have been used in agriculture for decades, Atfarm is designed to be easy to use and as simple to understand as possible.

The web and mobile versions of Atfarm reduce complexity by combining variable rate applications, nutrient planning and satellite monitoring into one app. This helps farmers to make informed decisions about crop nutrition from seeding to harvest, says Yara. ■

supply chain solutions for green ammonia is also an area of mutual interest, given that Fertiglobe's existing operations are strategically located near key shipping routes.

Fertiglobe has also announced that it will install a 10 t/d carbon capture unit, manufactured by UK-based company Carbon Clean, at its ammonia plant at Ruwais. The unit will be installed at Ruwais by Fertiglobe's partner ADNOC.

INDONESIA

Pusri to build new urea plant

Pupuk Sriwidjaja Palembang (Pusri), a subsidiary of state-owned Pupuk Indonesia, has approved the construction of the new Pusri-IIIB ammonia and urea plant at its existing production complex at Palembang, south Sumatra.

The company has secured the funding and agreed an engineering procurement and construction (EPC) contract to build the 1,350 t/d (445,000 t/a) capacity ammonia and 2,750 t/d (907,500 t/a) capacity urea units – using technology licensed from KBR and Toyo, respectively. Wuhuan Engineering and Adhi Karya will construct the plant, while a syndicate of eight state-owned and private-sector companies will provide the necessary funding.

Once complete, Pusri-IIIB will replace the existing Pusri 3 and Pusri 4 plants at Palembang. By incorporating the latest low-energy production technology, the new units will consume natural gas feedstock much more efficiently and also increase the reliability of fertilizer production at the site.

Pusri has yet to announce the start-up date for the new plant.

UNITED STATES

Atlas Agro receives $325 million investment

Macquarie Asset Management (MAM) has invested $325 million in Atlas Agro Holding AG (Atlas Agro).

This investment will help finance Atlas Agro's project portfolio of industrial-scale green nitrogen fertilizer plants in the US and Latin America. These will use green hydrogen as a substitute for the fossil fuels conventionally used in nitrogen fertilizer production.

The company's business model is based on locally supplying competitive carbon-free nitrate fertilizers in agricultural regions, thereby displacing standard imported products and eliminating the carbon footprint associated with their production and transport.

"MAM, with their experience in projects and infrastructure, ability to initiate support investments with a wide range of expertise and their commitment to accelerate decarbonization of hard-to-abate-industries, is an ideal partner for us as we approach construction of our first plants in the United States," said Petter Østbø, CEO of Atlas Agro.

Atlas Agro says the investment is a significant step forward in delivering its expansion across the Americas – and realising its vision of providing a sustainable alternative to conventional fossil-fuel based fertilizers and moving away from the large volumes of greenhouse gas (GHG) emissions these produce.

In October, Atlas Agro announced it had been selected by the US Department of Energy's Office of Clean Energy Demonstrations (OCED) to begin negotiating an award to develop the Pacific Northwest Hydrogen Hub. This hub is expected to receive up to $1 billion in Bipartisan Infrastructure Law funding.

The selection and subsequent negotiations should enable Atlas Agro to work in partnership with OCED to establish the Pacific Northwest Hydrogen Hub. OCED funding will support Atlas Agro's participation in the hub by helping expedite planning, detailed design, environmental permitting and the procurement of long-lead equipment.

BRAZIL

Brazil to export green ammonia to Croatia

Project developer Green Energy Park (GEP) has announced a large-scale green ammonia project in Brazil. This will supply GEP's other planned project, a 10 million t/a capacity import terminal on the Croatian island of Krk.

The one million t/a capacity green ammonia project includes around 5GW of dedicated renewable power generation capacity. The project is located in the special economic zone of Luis Correia in Piaui state in the northeast of Brazil. The state's first major port is scheduled to open in Luis Correia in December and will target exports to European markets.

GEP plans to export green ammonia generated by its project via this port and then ship this to the recently-announced Krk ammonia import terminal. ■

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PHOTO: EUROCHEM

Bruce Bodine will become Mosaic's new CEO at the start of 2024.

Bruce Bodine will become the new CEO of The Mosaic Company from the 1st January 2024. He was unanimously elected by the company's board of directors at the end of August. His appointment followed the announcement that the current CEO **Joc O'Rourke** will retire next year. Mr Bodine was also elected company president in August and appointed as a member of Mosaic's board with immediate effect. He was previously the company's SVP - North America.

In a synchronised move, Mr O'Rourke relinquished the title of president at the end of August. He will stand down as CEO at the end of December and resign from Mosaic's board at the same time. Joc will, however, continue to serve as a senior advisor to Mosaic until mid-2024.

"Joc's leadership over the past 8 years strengthened Mosaic," said Greg Ebel, chairman of Mosaic's board of directors. "The company today is larger, more geographically diverse, more resilient and in excellent financial condition. My fellow directors join me in wishing him all the best as he transitions to a well-deserved retirement. The board has full confidence in Bruce and the other members of Mosaic's talented Senior Leadership Team. Together they will build on Joc's legacy of success on behalf of all Mosaic stakeholders."

"I am proud of Mosaic's accomplishments over the past decade, and I know Bruce will lead the company to still greater success," Mr O'Rourke said. "It has been a tremendous privilege to serve as President and CEO alongside Mosaic's thousands of exceptionally talented people around the world."

Mr Bodine has worked for Mosaic and its predecessor company for many years in executive roles. These have included SVP - Potash, SVP - Phosphates, and VP - Supply Chain. In his most recent role as SVP - North America, Bruce headed up the North American Sales team. He also managed the integration of Mosaic's North America businesses and led on company-wide operations.

"I am grateful for the support of the Mosaic board of directors and my extremely talented management team colleagues," Mr. Bodine said. "Joc's leadership made Mosaic stronger. We will continue to meet Mosaic's noble mission – to help the world grow the food it needs-while operating safely and responsibly."

CF Industries has elected **Susan A Ellerbusch**, a global leader in chemicals and energy industries, as an independent director. Ms Ellerbusch has been in leadership roles at Air Liquide since 2015, including as CEO, Air Liquide North America, LLC. She held several increasingly senior roles at BP prior to joining Air Liquide.

"We are pleased to welcome Sue to the CF Industries' Board," said Stephen J Hagge, chairman of the board, CF Industries Holdings, Inc. "With her extensive leadership experience, global perspective and deep expertise in hydrogen, industrial gases and chemicals, Sue will be a voice the Board and our management team can rely on as we advance the Company's mission to provide clean energy to feed and fuel the world sustainably. We look forward to her contributions as we work together to create long-term value for our shareholders."

Ms Ellerbusch is a board member of Summit Materials. She has a BSc in genetics from the University of Illinois Urbana-Champaign and an MBA from the University of Illinois Chicago. The election of Ms Ellerbusch brings the total membership of CF Industries' board of directors to 12.

Gerald Marinitsch is Solex Thermal Science's new CEO. With a background in process engineering, Gerald joined Solex in 2014 and has led the company's global business development efforts in chemicals, metals, minerals and sands. Most recently, he championed Solex's energy portfolio. This role included creating tailored and integrated solutions designed to improve the energy utilisation and energy efficiency of Solex customers.

Marinitsch said: "I am excited to be taking on the role of CEO at Solex Thermal Science, effective immediately. I look forward to sharing our progress and achievements with you in the coming months and years." ■

Calendar 2023/2024

NOVEMBER

28-30
IFS Strategic Forum 2023, DOHA, Qatar
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

DECEMBER

6-8
IFS 2023 Conference, CAMBRIDGE, UK
Contact: Steve Hallam, International Fertiliser Society
Tel: +44 (0)1206 851819
Email: secretary@fertilser-society.org

FEBRUARY

5-7
Argus/CRU Fertilizer Latino Americano 2024, MIAMI, Florida, USA
Contact: Argus Media
Tel: +44 (0)20 3923 0741
Email: conferencesupport@argusmedia.com

26-28
CRU Phosphates 2024 Conference & Exhibition, WARSAW, Poland
Contact: CRU Events
Tel: +44 (0) 20 7903 2444
Email: conferences@crugroup.com

MARCH

4-6
Nitrogen+Syngas Conference 2023, GOTHENBURG, Sweden
Contact: CRU Events
Tel: +44 (0)20 7903 2159
Email: conferences@crugroup.com

MAY

20-22
IFA Annual Conference, SINGAPORE
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

Fertilizer Latino Americano welcomes you to Miami!

Argus in collaboration with CRU will convene the 2024 Fertilizer Latino Americano conference at the Hilton Downtown Miami, Miami, Florida, 5-7 February 2024.

PHOTO: ARGUS

The last FLA event in Miami in 2022 was attended by more than 745 delegates.

Argus in conjunction with CRU are hosting Fertilizer Latino Americano (FLA) 2024. We are delighted to be returning to the vibrant and exciting US city of Miami on 5-7 February for Latin America's biggest fertilizer industry networking event.

With more than 700 delegates due to attend, FLA 2024 is not to be missed. The conference, as always, takes place at a crucial time of the year for the market. Professionals from across Latin America's fertilizer value chain are therefore expected to attend – to network, negotiate, and learn about the latest trends and opportunities.

The last two years have seen fertilizer markets adjust to new trade flows and unforeseen circumstances, with Latin America continuing to play a central role in global markets. Topics up for discussion at FLA 2024 include the impact of geopolitical events on fertilizer trade flows, sustainability and decarbonisation.

FLA provides unrivalled networking opportunities, with an expanded and sold-out exhibition hall that includes a barista cafe, networking bar and — new for 2024 — a golf simulator sponsored by Nutrien. These improvements ensure there will be more opportunities than ever to meet up with contacts, both old and new, to discuss and make deals for the business year ahead.

Main conference highlights

The presentations and panels at FLA 2024 will feature executive speakers from Yara Brasil, IFA, Mosaic, Lavoro, Argus, Fertilizar AC and many more companies. This year's main conference programme provides the ideal opportunity to hear about the latest trends and gain insights into new regulations, the impact of geopolitics and changing trade routes.

On the third day of the conference, you can join the **Buyer's Masterclass**. This will bring together leaders in blending, retail and banking to discuss the biggest challenges facing the industry as we enter a new year.

Our main conference featured speakers:

- **Jason Newton**, Chief Economist, Nutrien
- **Alzbeta Klein**, Director General, International Fertilizer Association (IFA)
- **Ruy Cunha**, CEO, Lavoro
- **Marcelo Altieri**, SVP, Yara Brasil
- **Eduardo Monteiro**, Country Manager – Brazil, Mosaic

New sustainability forum – upgrade you pass!

This forum will showcase key sustainable fertilizer technologies and highlight how the industry is working towards carbon neutrality goals. Hear from Heliae Ag, Syngenta, Verdesian, EDPR, Stamicarbon, Phospholutions and other companies.

Change within the fertilizer industry is accelerating. Carbon markets are becoming increasingly important, for example, while the clean ammonia market is also developing at a rapid pace. Similarly, next-generation nutrient products are now playing a key role in sustainable development. Please join FLA's interactive discussions to understand how the fertilizer industry is evolving alongside these emerging markets.

Our sustainability forum speakers:

- **Andre Savino**, CEO, Commercial Platform, Syngenta
- **Hunter Swisher**, CEO, Phospholutions
- **Walter Sandoval**, Chief Science Officer, Microbios SA
- **Cassidy Million**, VP of Ag Science, Heliae Agriculture
- **Ana Quelhas**, Managing Director, Hydrogen, EDP Renewables

Revamped fertilizer fast-track

New to the market or looking for a refresher? Then join our fertilizer fast-track to hear from Argus market experts who will provide you with all the essential market basics plus an overview of the primary dynamics. This year's fast-track will focus on the key products for Latin America:

- MOP – Potash
- MAP – Phosphates
- Urea – Nitrogen
- Clean ammonia

Whether you are new to the market or an old hand, this is the perfect opportunity to sharpen your product knowledge and identify new opportunities. Simply upgrade your pass to benefit from face-to-face interaction with our five Argus experts who will be on hand to answer your most pressing questions.

We would like to thank our speakers, sponsors and exhibitors for their continuing support, and look forward to seeing everyone in Miami in early February for FLA 2024! ■

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State of the US fertilizer industry

We report on fertilizer production, consumption and pricing in the US market. The country's fertilizer industry, ranked fourth globally in terms of total production capacity, has grown and developed alongside its increasingly sophisticated domestic agricultural sector.

PHOTO: CF INDUSTRIES

CF Industries' Donaldsonville site, Louisiana, is the world's largest nitrogen fertilizer complex.

The US fertilizer industry contributes almost $131 billion to the domestic economy and directly employs more than 100,000 full time staff, according to trade body The Fertilizer Institute (TFI).

In 2021, US fertilizer producers:

- Invested a total of $1.2 billion in capital expenditure
- Captured and reused 31 percent of their greenhouse gas (GHG) emissions
- Sourced 39 percent of their total energy from waste heat
- Used 10 percent less water in nitrogen production, compared to 2017
- Reported a lost time incident rate of 0.46, making US fertilizer manufacturing 2-3 times safer than comparable industries nationwide.

These performance indicators are updated yearly in TFI's annual sustainability report. The 16 fertilizer manufacturing companies who contributed to the latest report collectively accounted for 92 percent of total US nitrogen, phosphate, and potash production capacity.[1]

Overview

The United States is the world's third-largest fertilizer consuming region, being responsible for almost 11 percent of global consumption and ranked behind only China and India globally (Figure 1). On an individual nutrient basis, the country is the world third largest nitrogen and potash consumer and fourth largest consumer of phosphates (Figures 2-4).

The United States has developed a large-scale and technologically advanced domestic fertilizer industry to satisfy the demand generated by its equally sizeable and sophisticated agricultural sector. By capacity, the country is the world's third and fourth largest phosphate and nitrogen fertilizer producer, respectively (Figures 5-6), as well as being the ninth largest potash producing nation globally.

Despite having a stable output, US fertilizer production is in relative decline with the country's capacity for phosphate and nitrogen fertilizers being overtaken by Morocco and India, respectively, in recent years.

Overall, the US fertilizer industry, is ranked fourth globally, in terms of total production capacity (22.4 million nutrient

Fig. 1: **Top five fertilizer-consuming countries*, 2021**

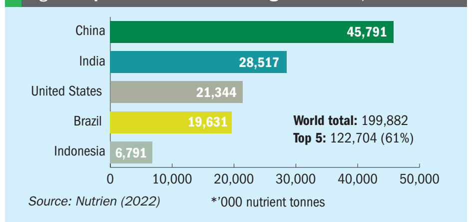

Fig. 2: **Top five nitrogen-consuming countries*, 2021**

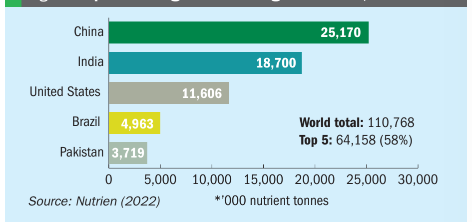

Fig. 3: **Top five phosphate-consuming countries*, 2021**

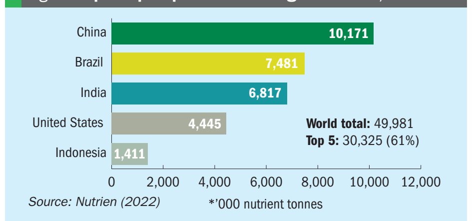

Fig. 4: **Top five potash-consuming countries*, 2021**

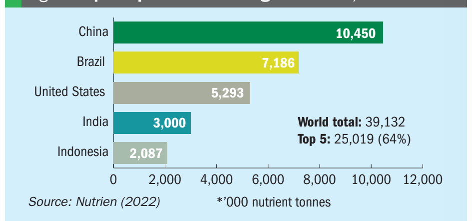

Fig. 5: **Top five nitrogen-producing countries*, by capacity, 2021**

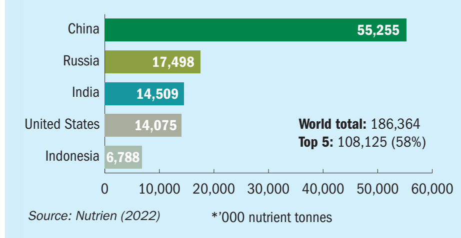

Fig. 6: **Top five phosphate-producing countries*, by capacity, 2021**

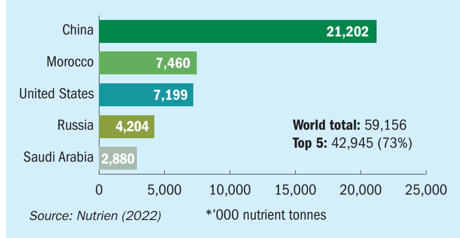

Fig. 7: **Major US urea producers, by capacity*, 2021**

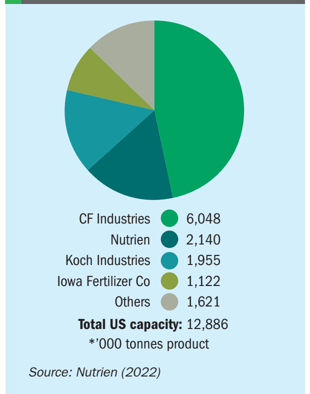

Fig. 8: **Top 10 US urea production plants, by company, location and capacity*, 2021**

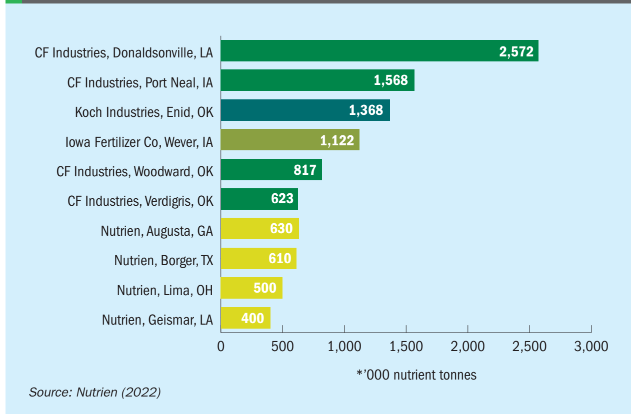

Fig. 9: **US fertilizer production plants**

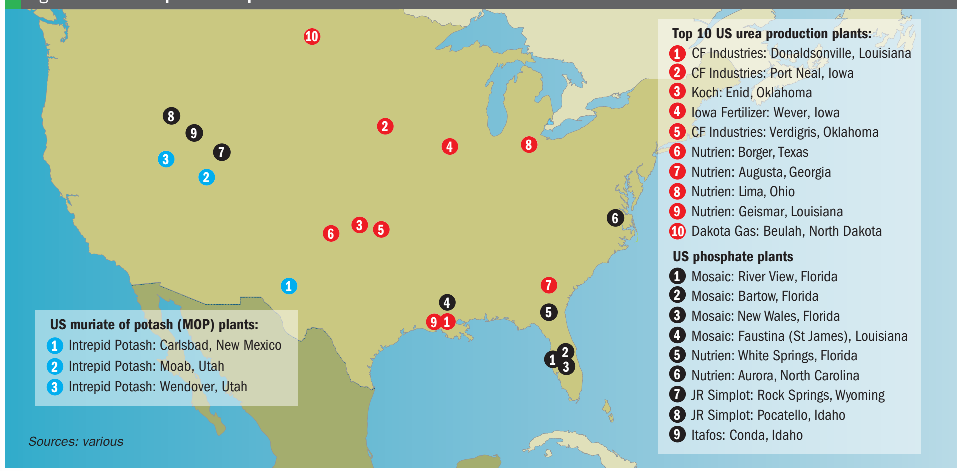

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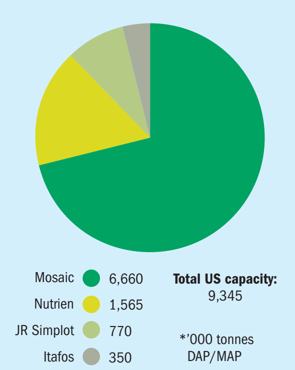
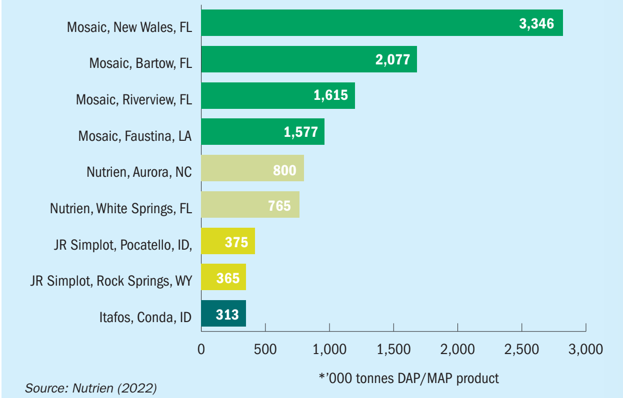
Fig. 10: **US phosphate producers, by capacity*, 2021**



Source: Nutrien (2022)

Fig. 11: **US phosphate production plants, by company, location and capacity*, 2021**



Source: Nutrien (2022)

tonnes), exceeded only by China (83.8 million nutrient tonnes), Russia (33.1 million nutrient tonnes) and its northern neighbour Canada (26.7 million nutrient tonnes).

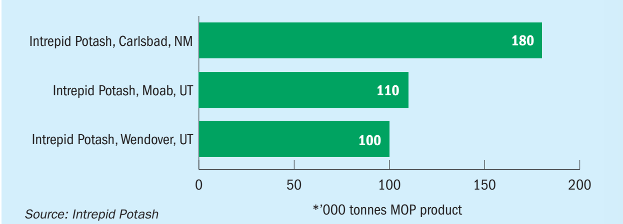
Urea production

The US operates 12.9 million tonnes of urea production capacity. This is mainly in the hands of CF Industries, Nutrien, Koch industries and the Iowa Fertilizer Co, with these four companies combined owning 87 percent of domestic urea capacity (Figure 7). This group of powerhouse companies also operates nine of the 10 largest US urea production plants (Figures 8 & 9). Illinois-headquartered CF industries is the largest US nitrogen fertilizer producer by far, owning almost half (47 percent) of domestic urea capacity, operating at around three times the scale of its nearest rivals Nutrien and Koch.

Phosphates production

The US can draw on 9.3 million tonnes of domestic production capacity for diammonium phosphate and monoammonium phosphate (DAP and MAP). Following several decades of consolidation, phosphate industry ownership is highly concentrated (*Fertilizer International* 496, p40) with just four companies – Mosaic, Nutrien, JR Simplot and Itafos – operating nine DAP/MAP production sites across Florida, Idaho, Louisiana, North Carolina and Wyoming (Figure 9).

Fig. 12: **US muriate of potash (MOP) production plants, by company, location and capacity*, 2023**



Source: Intrepid Potash

Florida-headquartered Mosaic is the dominant US phosphates market player (Figure 10). It operates around 6.7 million tonnes of DAP/MAP capacity from four sites in Florida and Louisiana. This includes New Wales, the country's largest phosphates production complex (Figure 11).

Potash

Intrepid Potash is the sole US supplier of muriate of potash (MOP, KCl). The company has the capacity to produce around 390,000 tonnes of potash annually via solar evaporation from three mining sites (Figures 9 and 12):

- The HB solution mine in Carlsbad, New Mexico
- The Moab solution mine in Utah
- The brine recovery operation in Wendover, Utah.

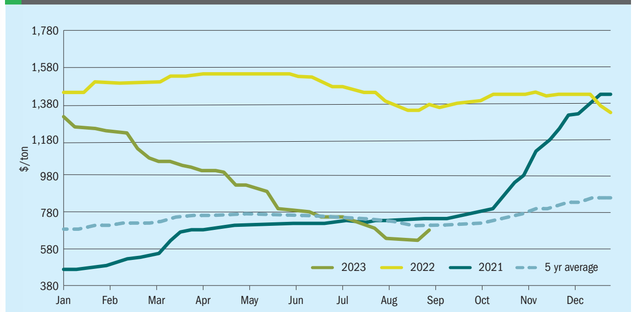
Imports and exports

Due to its limited domestic production capabilities – versus the scale of agricultural demand – the US is the world's second largest potash importing country, after Brazil and China. The country imported 10.3 million tonnes of MOP in 2021 – up from 7.8 million tonnes in 2019 – sourcing much of this from neighbouring Canada as well as Belarus and Russia.

The US falls well outside the global top 10 list of urea exporting countries, exporting just 290,000 tonnes in 2021. That compares to domestic urea production for the year of 9.9 million tonnes, supplemented by imports of 6.1 million tonnes. Indeed, the US is a major urea import market currently, being ranked the third largest globally. The country's top three urea suppliers in 2021 were Qatar, Saudi Arabia and Indonesia.

In recent years, the US has become a net importer of phosphate fertilizers.

Fig. 13: **Average weekly fertilizer prices* in the US, 2021-2023**



Source: DTN

*Based on basket of eight solid products

Although the country produced 6.3 million tonnes of DAP/MAP in 2021 – and was ranked the world's fifth largest DAP/MAP exporter in 2021 (2.2 million tonnes) – annual exports have declined by 1.7 million tonnes since 2019. At the same time, the US has remained the third largest DAP/MAP importing country globally with imports (2.7 million tonnes) exceeding exports in 2021.

Prices track downwards in 2023

Average US weekly retail fertilizer prices have followed a general downward trajectory in 2023, according to the DTN Fertilizer Index, a longstanding price indicator based on a basket of eight solid products. Some fertilizer commodities have lost up to half their value in 2023, as of end-August. The sharp falls seen in 2023 have improved affordability by bringing US fertilizer prices to just below their five-year average – ending a trend of rising prices in 2021 and elevated prices in 2022 (Figure 13).

US ag retailers have typically reported a double-digit percentage decline in both solid and liquid fertilizer prices to DTN in the year-to-date. For example, as of end-August 2023:

- Potash is 41 percent lower
- Urea is 30 percent lower
- Monoammonium phosphate (MAP) is 28 percent lower
- Diammonium phosphate (DAP) is 23 percent lower.

Similarly, liquid fertilizers – such as 10-34-0, urea ammonium nitrate (UAN) and anhydrous ammonia – fell by 30-50 percent between January and September 2023. ■

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Citrus fruits – cash crops of the Americas

Citrus fruit growers are an attractive end-market for fertilizer suppliers due to the high K and N requirement of this widely-cultivated cash crop and the efficacy of fertigation and foliar spraying. We examine the nutrient needs of citrus trees and how balanced application of fertilizers helps maximise citrus fruit quality and yield.

Oranges ripening on a tree.

PHOTO: JANAPH/SHUTTERSTOCK.COM

Large volumes, modest growth

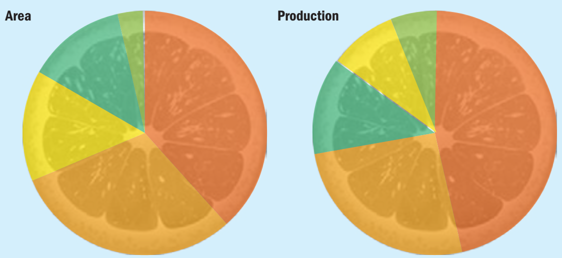
Citrus are the second most widely traded fruits globally, after bananas, and remain lucrative cash crops for the countries of the Americas. With worldwide fresh fruit exports of more than 17 million tonnes annually – valued at around $4.1 billion – they generate significant export earnings for the United States ($903 million), Mexico ($752 million), Chile ($439 million), Peru ($287 million), Argentina ($264 million) and Brazil ($138 million).

World citrus production has undergone a major expansion in recent decades, having more than doubled in the last 30 years to exceed 160 million tonnes per annum currently (Figure 1). Consequently, more than 10 million hectares of land is now devoted to citrus cultivation globally.

Although citrus is a large volume market, accounting for about one-fifth of the global fruit trade, growth rates have stagnated. The 10-year average for citrus is 1.5 percent, for example, versus growth rates of 3.3 percent for banana, 12-13 percent for avocado and blueberries, and 2.1 percent for the fruit market overall.

"Citrus fruits, while remaining a leading fruit and vegetable category, will face significant challenges to maintain their position in an increasingly globalised, complex, and competitive market," comments trade body the World Citrus Organisation. "This will be especially due to strong growth in mango, kiwi, table grape, and avocado, as well as the reduction of fruit consumption due to lifestyle changes and growing competition from other food products."

Fig 1: **Citrus fruits – world production, growing area and average yields, 2021**



	Area, million hectares	Yield, t/h	Production, '000 tonnes
Oranges	3.93	19.2	75,568 (47%)
Tangerines, mandarins, clementines & satsumas	3.11	13.4	41,950 (26%)
Lemon & limes	1.34	15.6	20,829 (13%)
Grapefruit & pomelos	0.36	0.3	9,557 (6%)
Other citrus (n.e.c.*)	1.48	9.4	13,897 (9%)
Total:	**10.22**		**161,801**

Source: FAO (2020) **Not elsewhere classified*

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Fig 2: **World's top 10 citrus fruit producers ('000 tonnes), 2019**

China	37,739
Brazil	19,653
US	15,043
India	13,314
EU	10,538
Mexico	8,414
Egypt	4,634
Turkey	4,299
Argentina	3,469
Iran	3,454
World total	**143,756**

Source: FAO (2020)

Fig 3: **World's top 10 orange producers ('000 tonnes), 2019**

Brazil	17,074
China	10,436
India	9,509
EU	6,099
US	4,833
Mexico	4,736
Egypt	3,197
Iran	2,309
South Africa	1,687
Pakistan	1,615
World total	**76,293**

Source: FAO (2020)

Fig 4: **World's top 10 lemon and lime producers ('000 tonnes), 2019**

India	3,482
Mexico	2,702
China	2,666
Argentina	1,905
Brazil	1,511
EU	1,444
Turkey	950
US	876
South Africa	511
Iran	471
World total	**20,530**

Source: FAO (2020)

Regionally important

Latin America countries, together with California and Florida in the United States, are responsible for around one third of the world's citrus production. Brazil, the US, Mexico and Argentina are all top 10 citrus fruit producers globally (Figure 2) – with the Americas having a particular focus on orange, lemon and lime cultivation. Notably:

- Brazil is the world's largest producer of oranges – harvesting almost as much as China and India, the two next largest producers, combined – while the US and Mexico are the fifth and sixth largest orange producing countries, respectively (Figure 3)
- Brazil is also the world's largest producer and exporter of orange juice, according to the USDA, exporting almost all of the 1.1 million tonnes it produced domestically in 2022/23
- Mexico, Argentina and Brazil, respectively, are also the world's second, fourth and fifth largest producers of lemons and limes (Figure 4)
- Brazil is a top 10 producer of mandarins (Figure 5) while Mexico is a top 10 grapefruit producing nation (Figure 6).

Leading producers

Oranges remain the most popular commercially grown citrus fruit, accounting for almost half of world citrus production. Lemons and limes provide a further one-quarter of global citrus fruit output and are followed by tangerines and grapefruit in order of production volume (Figure 1). Geographically, citrus production is distributed as follows[1]:

- **Oranges**. Growing is concentrated in Brazil, China, the US and Mexico, together with Spain, Italy and Greece in the Mediterranean region (Figure 3)
- **Lemons and limes**. Asia (India, and China), the Americas (Mexico, Argentina, Brazil and the US) and the Mediterranean countries of the EU (Spain and Italy) are the main global growing regions (Figure 4)
- **Tangerines and grapefruit**. China is the leading global grower of grapefruit and easy-to-peel citrus varieties, such as tangerines, mandarins, clementines and satsumas, and has an impressive one-quarter share of the world citrus market (Figures 2, 5 & 6).

According to USDA figures, almost two-thirds of world orange production (47.8 million tonnes) was consumed as fresh fruit (30.2 million tonnes) while just over one-third (17.2 million tonnes) went for processing in 2022/23, yielding 1.5 million tonnes of orange juice. Of these amounts, 4.6 million tonnes of fresh fruit and 1.4 million tonnes of fruit juice were exported from the major producing countries[2].

Citrus production trends

The latest USDA figures show 6.5 million tonne annual declines in global orange production over the last five years, partly offset by four million tonne per annum growth in tangerine/mandarin production over this period (Table 1).

USDA estimates that US orange production will fall by more than 25 percent to 2.3 million tonnes in 2022/23 its lowest level in over 56 years. Production in Florida has fallen precipitously over the last decade, from 8 million tonnes in 2011/12 to the less than one million tonne estimate for 2022/23. Recent production declines are linked to extreme weather and falling yields resulting from 'citrus greening' disease afflicting the state's groves.

"Yields continue to decline in Florida due to fruit drop caused by citrus greening, reduced area harvested and high winds from hurricanes," USDA said[2]. "California is estimated to produce over twice as many oranges as Florida in 2022/23."

Hurricanes have been a particular problem for Florida's citrus farmers in recent years. The high winds and damaging rains from Hurricane Irma that hit key citrus-producing regions in 2017 resulted in the smallest Florida crop yield in over 70 years. More recently, Hurricane Ian's landfall in southwest Florida in September 2022 is estimated to have caused up to $675 million of damage to citrus crops and grower infrastructure in the state.

California's citrus output has been more stable. The state accounted for 79 percent of total US citrus production in 2022/23, while Florida totalled 17 percent, and Texas and Arizona produced the remaining 4 percent, according to USDA. Although the 2022/23 US citrus crop is valued at $2.58 billion (at the packinghouse door), this represents a 13 percent fall on the last season.

Fig 5: **World's top 10 tangerine producers ('000 tonnes), 2019**

China	19,707
EU	2,903
Indonesia	2,000
Turkey	1,400
Morocco	1,375
Egypt	1,096
US	986
Brazil	985
Japan	747
South Korea	645
World total	**37,429**

Source: FAO (2020)

Fig 6: **World's top 10 grapefruit producers ('000 tonnes), 2019**

China	4,930
Vietnam	819
US	512
Mexico	489
South Africa	379
India	323
Thailand	282
Sudan	252
Turkey	249
Israel	149
World total	**9,504**

Source: FAO (2020)

Table 1: **Fresh citrus fruit production ('000 tonnes), 2018/19 to 2022/23**

Year	Total citrus	Oranges	Tangerines/ mandarins	Grapefruit	Lemons & limes
2018/19	103,059	54,302	32,908	9,033	6,816
2019/20	94,416	46,102	32,711	8,806	6,797
2020/21	100,255	48,186	36,026	9,362	6,681
2021/22	105,411	50,410	37,832	10,204	6,965
2022/23*	100,564	47,765	36,923	9,069	6,807

**July 2023* *Source: USDA (2023)*

Varieties, climate and soil

The genus *Citrus* is a type of evergreen tree native to tropical and subtropical Asia. Belonging to the family *Rutaceae*, it numbers around 1,500 species, the main commercial, fruit-producing varieties being:

- Orange (*Citrus sinensis* [L.] Osbeck)
- Mandarin (*Citrus reticulata* Blanco)
- Lemon (*Citrus limon* [L.] Burm.)
- Lime (*Citrus aurantifolia* [Christ.] Swing.)
- Grapefruit (*Citrus paradisi* Macf.)
- Pomelo (*Citrus grandis* [L.] Osbeck)

Due to their intolerance to low temperatures and frost, major citrus growing regions are generally to be found in two bands between 25-35 degrees either side of the equator.

Citrus growing in semi-tropical and Mediterranean climates is most favourable as it results in smooth skinned, bright coloured fruit with an ideal balance of sweetness and acidity. Sweet oranges and mandarins thrive in sub-tropical regions, where the hot humid summers and mild winters yield large, good quality, sweet fruits with a high juice content, making them ideal for either processing or fresh consumption. Navel oranges, blood oranges and lemons, in contrast, are almost exclusively grown in Mediterranean-type climates.

Citrus trees prefer well-drained, low salinity soils with a pH of 5.5-7.0. Although they can be grown on a range of soil types, a well-structured soil ensures root aeration and helps avoid root disease. Acid soil conditions are avoided as citrus yields almost half below pH 4.5.

Citrus trees develop shallow, near-surface root systems in the area underneath their canopy. These require careful water management to avoid root damage. Irrigation is common in many citrus growing areas outside the tropics as higher fruit yields are typically obtained from irrigated groves compared to those in rain-fed areas.

Nutrients and citrus quality

Nutrient and water availability both have a major influence on citrus fruit quality and yield. Fruit size, colour, juice content, sugar content (expressed as total soluble solids, TSS) and acid concentration are some of the most important quality factors for citrus growers, processors and packers.

Distinctly different qualities are required for the fresh fruit and processing markets. Size, shape, colour and maturity date are valued in fresh fruit, whereas high juice and

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soluble solids contents are the main quality factors in fruit processing. Importantly, the external characteristics favoured by fresh citrus produce, such as fruit size and rind coarseness, require lower N and higher K applications than are necessary for fruits grown for processing.

Potassium followed by nitrogen and then calcium are the nutrients removed in greatest quantity by citrus trees (Table 2). The high level of potassium removal is linked to the high K content of citrus juice.

Citrus trees are able to store significant amounts of nutrients in the roots and trunk and later redistribute these to developing leaves and fruits. The nutrient requirements of citrus trees also vary at different growth stage (Table 3).

Leaf analysis is used to monitor the nutrient status of citrus trees, identify deficiencies and tailor fertiliser rates to ensure the correct ratio of plant nutrients. This is supplemented by soil analysis of pH and available N, P, K, Ca and Mg.

Table 2: **Major nutrient and micronutrient removal by citrus fruits**

	Nutrient removal, kilogram per tonne of fresh fruit				
	N (kg/t)	P_2O_5 (kg/t)	K_2O (kg/t)	MgO (kg/t)	CaO (kg/t)
Oranges	1.773	0.506	3.194	0.367	1.009
Tangerines	1.532	0.376	2.465	0.184	0.706
Lemon & Limes	1.638	0.366	2.086	0.209	0.658
Grapefruit	1.058	0.298	2.422	0.183	0.573
	Micronutrient removal, gram per tonne of fresh fruit				
	Fe (g/t)	**Mn (g/t)**	**Zn (g/t)**	**Cu (g/t)**	**B (g/t)**
Oranges	3.0	0.8	1.4	0.6	2.8
Tangerines	2.6	0.4	0.8	0.6	1.3
Lemon & Limes	2.1	0.4	0.7	0.3	0.5
Grapefruit	3.0	0.4	0.7	0.5	1.6

Source: University of Florida Citrus Research and Education Center, Haifa

Nitrogen for juice and colour

Nitrogen is critically important in citrus production as it has more influence on tree growth, appearance, fruit production, and fruit quality than any other nutrient[3]. Fruit yield is largely regulated by N due to its contribution to photosynthesis, carbohydrate production, leaf weight and carbon allocation within trees.

Mature trees require N at around 100-300 kg/ha, depending on environmental factors, the irrigation system and target yield. A fruit yield of 40 t/ha, for example, removes about 50 kg of N from soil. Although fruit yields generally correlate with N application, 200 kg/ha applied annually is thought to be sufficient to sustain good yields and tree development. In fertigation, however, yields continue to increase at N applications of up to 300 kg/ha[4].

'Luxury consumption' from excess N can reduce the commercial value of harvested fruits by affecting fruit quality and shortening storage life. The fruit becomes large and puffy, skin thickens and coarsens, and the percentage and quality of juice also declines[5]. These adverse effects become exacerbated when P is low.

Visible signs of nitrogen deficiency are rare but citrus trees will show symptoms – leaves turning light green to yellow and dropping early is one sign – when leaf N content falls below two percent. However, large falls in N over a prolonged period need to occur before citrus yields are affected.

Table 3: **Nutrient effects at different citrus growth stages**

Nutrient	Flowering	Fruit set	Fruit enlargement and maturation	Post harvest
N	Boost yield and tree productivity	Maintain leaf growth, flowering and strong fruit set	Maintain yields and improve skin thickness and fruit acidity	Encourage active flush of foliage
K	Establish good early growth	Continued strong growth	Maximize fruit fill and fruit size, productivity, skin quality and vitamin C content and reduce granulation and fruit splitting	Maintain long-term fruit productivity
P	Maintain long-term productivity			Maintain long-term tree productivity
Ca	To aid leaf growth, pollination and fruit set	Provide good fruit productivity and quality	Boost leaf growth and tree vigour and reduce skin disorders, including fruit splitting and albedo breakdown	To maintain tree root health and productivity and to encourage leaf flush
Mg		Continued strong growth	Maintain fruit fill, fruit size and condition	
Micro-nutrients		Zinc, manganese and iron to maintain fruit yield and quality; boron to minimise fruit drop, prevent fruit deformities or storage problems from peel breakdown	Zinc to maintain fruit quality; molybdenum to improve juice content, quality and provide a thicker skin; copper to prevent fruit corking; manganese and boron to maintain fruit yield	Iron, manganese and zinc, when needed, for post-harvest foliage flush

Source: Yara

This is because citrus trees have the capacity to adjust to inadequate nitrogen application by recycling stores of N, usually from older leaves into newer ones.

Increasing N application results in the following changes to fruit yield and quality[6]:

- Higher juice content, total soluble solids (TSS) and acid concentration and improved colour
- Increases in TSS per hectare, although excessive N reverses this trend, particularly with inadequate irrigation
- Decreases in fruit size and weight
- Increases in peel thickness and numbers of green fruit at harvest
- Increasing incidence of creasing and scab but decreasing incidence of peel blemishes.

Potassium for size

The large amounts of potassium removed by citrus fruit make the application of K fertilizers essential for maintaining soil productivity. The production of one tonne of oranges, for example, takes up around 2.5 kg of K_2O, corresponding to a soil removal rate of 125-250 kg/ha.

Potassium improves the external characteristics of citrus fruit but can reduce juice yield and quality. In Florida, Brazil and Australia, potassium application has been found to increase fruit production until leaf K content reaches 1.5–1.7 percent.

Insufficient K typically produces small fruit with thin rinds which are prone to creasing or splitting, making them unsuitable for the fresh fruit market and export. Excessive levels of K, in contrast, results in large fruits with coarse, thick rinds and poor colour.

Higher applications of K are associated with:

- Larger fruit size, weight, green fruit and peel thickness
- Reduced incidence of creasing and fruit plugging
- Less stem-end rot in stored fruit
- Higher fruit production and TSS per hectare
- Reduced juice content, TSS and juice colour
- Increased acidity.

The effectiveness of K applications varies widely with soil type. Potassium uptake by citrus trees is highest in acid, sandy soils in humid regions such as Florida.

> “Nutrient availability is a major influence on citrus fruit quality and yield.

Phosphorus for growth

Phosphorus application is particularly important for early tree growth in new groves and maintaining fruit yield and quality in mature groves. However, application rates are relatively low, with the exception of South Africa and parts of Florida, as citrus trees have a limited P requirement compared to N and K[4]. The production of one tonne of citrus fruit requires only 0.2 kg of P, for example, and a fruit yield of 40 t/ha removes just 8 kg of P per hectare.

In P deficient trees, leaves become a dull bronze-green colour and are shed from young shoots, and tree growth and fruiting are also reduced. Low P produces misshapen fruit with coarse, thick rinds and acid juice. Ensuring a balanced supply of nitrogen and phosphorus is important as excess N can exacerbate P deficiency.

The application of P is associated with the following changes to fruit quality:

- No change or a slight decrease in fruit size
- A decrease in rind thickness
- No change or slight increase in TSS
- Reduction in juice acidity
- Lower juice vitamin C content.

Ameliorating soil acidity

Citrus trees contain more calcium than any other metal and Ca plays a vital role in regulating the uptake of other nutrients such as potassium and magnesium. Under normal conditions, however, soil Ca levels and general fertilisztion practice are usually enough to satisfy citrus growing requirements[4]. Irrigation water can also supply Ca in appreciable amounts.

As well as its role as a nutrient, adding calcium can improve the physical properties of heavy soils and reduce soil acidity. Citrus trees are particularly sensitive to acidity and stop growing below pH 5.0 due to root system damage. Dressings of dolomitic or calcareous limestone to correct pH are known to increase yields by up to 200 percent[4].

Magnesium, a constituent of chlorophyll, is found in the leaves and shoots of citrus trees and deficiency is very common on highly acid, low Mg soils. This results in leaf chlorosis and bronzing in older leaves.

Fertilizer recommendations

Fertilizer recommendations for young trees vary with soil type, climate and intensity of cultivation. The N, P and K applications rates for establishing trees on loamy, organic-rich Brazilian soils, for example, are lower than those for sandy, low organic matter Floridian soils. Recommendations in the two countries also vary because Brazilian groves are mostly unirrigated and begin producing in year three, whereas citrus fruits in Florida are more intensively grown and groves are irrigated because of low water retention in soils.

Fertilizer rates during the first three years in citrus groves are calculated on a per tree basis. A minimum of 4-6 annual applications of dry fertilizer is recommended for young trees, whereas 10 or more yearly fertigation applications are usual at this stage.

Citrus trees are commonly harvested for fruit from year four onwards. N and K are key nutrients at this stage whilst P is less critical because of the much smaller quantities removed by fruit. Mature trees are therefore generally fertilized at a N:P_2O_5:K_2O ratio of about 1.0:0.2:1.0. Around 3-6 kg of nitrogen is required to produce a single tonne of fruit and N applications rates are often used as the basis of recommendations for other nutrients.

In Florida, N is applied to oranges at a rate of 135-225 kg/ha (120-200 lbs/acre) in years 4-7 and then at 160-280 g/ha (140-250 lbs/acre) from year eight onwards. These amounts of N are supplied by at least one application for controlled-release fertilizers, by 3-6 separate applications in field dressings and 10 fertigation applications each year. The generally accepted rule for citrus K application is to follow exactly the same application rate as N for both young and mature tree. Identical N and K application rates, for example, are recommended by Haifa in its citrus guide.

Phosphorus application rates are determined on the basis of leaf analysis and soil testing results. Application of P is generally only recommended when soil P is insufficient and leaf P falls below optimum[3].

Magnesium fertilizers are applied, either to soils or as a foliar spray, at 20 percent of the N application rate, If leaf Mg is below optimum and soil tests

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CITRUS – LOOKING FOR BALANCED NUTRITION

Tessenderlo Kerley International share some insights on the nutrients needs of citrus trees and combatting citrus greening – a devastating bacterial disease spread by the Asian citrus psyllid insect.

Blossoming orange tree bearing fruit

PHOTO: ELLEN LEVY FINCH

Fertilization aims and application rates

Citrus fertilization prior to planting is aimed at promoting good rooting and rapid development, whereas the annual fertilization programme for established citrus trees targets balanced nutrition to optimise yield and quality. Fertilization choices will be largely guided by soil analysis complemented by foliar diagnosis.

Citrus cultivation requires an NPK ratio of 1-0.2-1.3. As a rule of thumb, fertilization rates of 130 kg/ha N, 25 kg/ha P_2O_5, 170 kg/ha K_2O and 20 kg/ha S are recommended to balance nutrient removal. This is based on a fresh fruit target yield of 60 t/ha in a fertile soil.

The efficiency of fertilizers, as well as irrigation, greatly depends on root location. The roots of citrus trees are generally shallow and located just beneath the canopy. Fertilizer efficiency is also sharply reduced when the tree canopy lacks space and sun. If branches are too close, a programme of pruning should be implemented as a priority, with severe pruning necessary in some cases.

Chloride sensitivity and sulphur supply

Citrus fruit are very sensitive to chloride. According to the variety, the maximum permissible chloride level in soil water to avoid leaf injury is 20-50 mol/m³ (equivalent to an EC of 2-5 mmhos/cm). Fertilizers with a high chloride content, such as potassium chloride (MOP), should therefore be avoided. Potassium sulphate (SOP) has the lowest salt index of all potash fertilizers – which is why it is recommended for citrus crops instead.

Sulphur is an important nutrient for plants and plays a key role in protein synthesis. For citrus fruit, the normal sulphur content in the leaves is 0.20–0.40 percent of dry matter, with 70 percent of S-proteins contained in the chloroplasts (photosynthesis). The sulphur content of SOP (18 percent) largely covers citrus requirements.

The benefits of SOP are not limited to yield improvements. Potassium sulphate also has a positive effect on the size of fruits, sugar content, juice production, fruit colour and the edible part of the fruit.

Fertigation and foliar application

The method of fertilizer application plays a key role in its efficiency, especially for potassium which is not mobile except in sandy soils.

Since the uptake of nutrients occurs at root level, fertilizers must be applied as close to these as possible, either on the soil surface or 'side dressed' along the line of the trees, ideally at a depth of 15-20 centimetres in clay soils, or at a distance of around 50 centimetres from the trunk when using fertigation drippers.

The application of fertilizers via irrigation water – fertigation – is made according to the age of the trees, their productivity and the individual requirements of each vegetative growth stage. Tessenderlo's **SoluPotasse**® is a completely water-soluble grade of SOP specially prepared for fertigation, while the company's **K-Leaf**® water-soluble SOP product is ideal for foliar application.

Foliar sprays are an efficient way of supplying nutrients to citrus trees. They can complement other nutrient sources or, when severe deficiency is present, supply nutrients while the soil's nutrient content is being replenished.

Foliar applications of SOP have a positive effect on citrus production and quality. In trials on Clementines in Egypt, for example, two sprays of K-Leak (application rate of 21 kg K_2O/ha), applied at the beginning of fruit growth and mid-growth improved fruit yields by nine percent versus the control.

Tackling citrus greening

University of Florida research has shown that fields irrigated with alkaline water raises the pH of soils above the optimum for combatting citrus greening. Ammonium thiosulphate solution (**Thio-Sul**®) has been shown to be more effective than other acidifiers at lowering soil pH more uniformly throughout the top two feet of soil.

For greening-affected citrus trees, **Thio-Sul**® should be applied at a rate of up to 12 gallons per acre (112 l/ha) via micro sprinkler irrigation and repeated every 14 days, as necessary. This fertilizer recommendation has been tested on citrus groves in Florida and found to be valid in situations where alkaline irrigation water is used. ■

Further reading

Marchand, M., 2020. *Sulfate of Potash: More than 100 years of experience.* Tessenderlo Kerley International. Available at: https://mailchi.mp/cropvitality/sopbook [Accessed 6/10/23]

show medium or low Mg levels. Liming the soil to regulate pH at 6.0-6.5 usually supplies sufficient Ca. If soil pH is maintained, there is no need to apply gypsum or soluble calcium fertilizers unless soil test and leaf analysis show levels are insufficient and below optimum.

Micronutrients are applied by foliar spraying or directly to soil on an 'as-needed' basis in response to low leaf analyses or visible signs of leaf deficiency. Foliar applications of Mn, Zn, Cu, B and Mo are generally much more effective and economically practical than soil applications. Foliar spraying usually takes place after the full leaf expansion of new growth. Copper is not applied separately if Cu fungicides are used. Molybdenum deficiency occurs in very acid soils and is a potential indicator of aluminium toxicity. Iron deficiency can be corrected using an Fe chelate.

Cash crop opportunities

The status of citrus fruit as a profitable cash crop makes it a lucrative target market for leading fertilizer suppliers. Numerous bespoke and speciality products are now available for citrus growers, backed by detailed recommendations and extensive agronomic research. Although not exhaustive, a snapshot of currently-available citrus fertilizer products is provided below.

Haifa Chemicals' **Multi-K** potassium nitrate (NOP) and **Solu-Potasse** potassium sulphate (SOP) from Tessenderlo Kerley International provide citrus growers with chloride-free, water-soluble sources of major nutrients and are suitable for fertigation. Tessenderlo's **K-Leaf** SOP product is also suitable for foliar application to citrus. SQM offers formulations that are well-suited to the nutrient needs of citrus trees in its field-applied (**QDrop**), fertigation (**Ultrasol**) and foliar (**Speedfol**) NOP product ranges.

Monoammonium phosphate (MAP) products for citrus fertigation include SQM's **UltrasolMAP**, Haifa's **Multi-MAP** and ICL's NovaMAP. Citrus micronutrient deficiencies can be addressed using Yara International's **YaraVita** range, for Mn, Zn and B deficiency, for example, and SQM's **Ultrasolmicro** iron chelate products for Fe deficiency. Both Yara (**YaraLiva Tropicote**) and SQM (**QDrop Calcium**) also market calcium ammonium nitrate (CAN) fertilizers for citrus groves. ■

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The road to high yielding and sustainable citrus production

A proper fertilization programme is necessary to sustain both citrus productivity and soil fertility over the longer term. ICL agronomists **Fabio Vale**, **William Wang**, **Patricia Imas** and **Francisco Morell** outline the nutrient needs of citrus fruit – a regionally important crop in the Americas, Europe and China.

Overlapping fruit maturation and flowering in orange trees (variety Valencia Late).

PHOTO: ICL REPOSITORY

Citrus nutrient requirements

The citrus fruit family comprises of several tree species, most notably oranges (*Citrus sinesis*), lemons (*C. limonum*), grapefruits (*C. paradisi*) and mandarins (*C. reticulata*), with each type of citrus fruit having several dozen varieties. Although the nutrient needs of citrus trees are broadly similar, their exact requirements will vary according to the species cultivated and/or plantation growing conditions.

In general, high yielding citrus trees will take up large quantities of the major mineral nutrients – nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca). These macronutrients need to be supplemented by minor quantities of magnesium (Mg), sulphur (S) and micronutrients.

Most of the nutrients removed by citrus trees during the growing season are subsequently exported with the fruit at harvest. N, P and K, for example, are generally exported at a ratio of 3:1:5. More precisely, one tonne of harvested oranges removes[1]:

- 1.18-1.90 kg of N
- 0.17-0.27 kg of P
- 1.48-2.61 kg of K
- 0.36-1.04 kg of Ca
- 0.16-0.19 kg of Mg

PHOTO: ICL REPOSITORY

Clementines (variety Nadorcott) ready for harvest, Valencia, Spain.

As with most crops and farming systems, fertilization management is essential to properly regulate the uptake of nutrients by citrus plants and maintain nutrient availability during the growing season in response to demand. A proper fertilization programme is also necessary to maintain soil fertility and citrus productivity over the longer term.

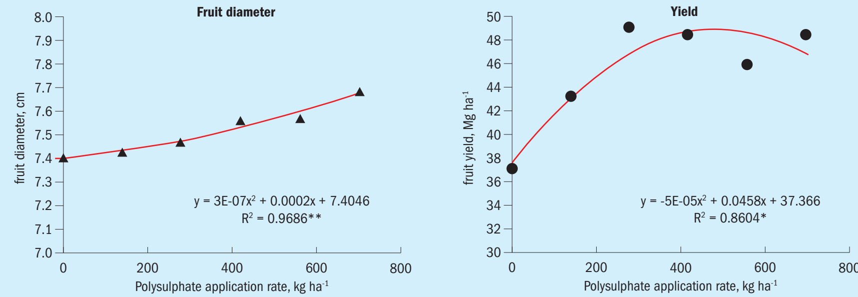
ICL's fertilization programmes for citrus

The fertilization programme recommended for citrus varies according to the climatic conditions and production system (irrigated or rainfed). In general, **irrigated production systems** are found in the Mediterranean climates of both the northern and southern hemispheres – including California, Chile, parts of Australia, South Africa, and the growing areas that fringe the Mediterranean basin in Israel, north Africa, and southern Europe. **Rainfed production systems**, meanwhile, predominate in tropical and wet subtropical climates that are typical of the main citrus producing regions of China, India, and South America.

For **citrus plantations in full production**, the fertilization programme needs to consider the nutrients status of soils and crops, the yield target, and the end-market for the produce.

Orange and mandarin plantations growing fruit for fresh consumption, for example, need around 160, 100 and 180 kg/ha of N, P_2O_5 and K_2O, respectively, for a yield of 40-50 t/ha, assuming a fertile soil and a well-nourished plantation. These application rates will, however, need to be adjusted according to the nutrient status of the plantation, the end-market and the yield target.

Fig. 1: **Polysulphate trial results for Natal orange trees in Brazil.**
Left: increase in fruit diameter vs application rate. Right: fruit yield improvements vs application rate.



Source: ICL/Silva & Vale (2021)

For oranges destined for the juice industry, the fertilization plan requires a higher nitrogen application rate together with a slightly lower application rate for potassium – although, again, these rates need to be adjusted for the yield target and nutrient status of the plantation.

In **rainfed systems**, fertilizers are applied to the soil surface with two-thirds applied under the canopy and one-third outside. The total fertilizer supply is usually split between five or six applications across the growing season. The use of controlled-release fertilizers (CRFs), such as ICL's **Agromaster** product, is advantageous, as this allows the number of applications to be reduced while, by avoiding 'plant hunger', improving yields as well as nutrient use efficiency (NUE) in most cases.

Citrus fertilization programmes can also include ICL's **Polysulphate** fertilizer, either applied together in combination with Agromaster or as a separate application. This multi-nutrient (K, Mg, Ca, and S) polyhalite product continues to fertilize citrus plants following rainfall events, as its special solubility pattern prolongs nutrient availability.

In **irrigated systems**, crop fertilization is performed via fertigation. ICL's **Agrolution** family of water-soluble fertilizers (WSFs) are ideal for the fertigation of citrus trees These products, as well as components such as **PeKacid**, provide a range of formulations with different nutrient balances for each development stage of the crop.

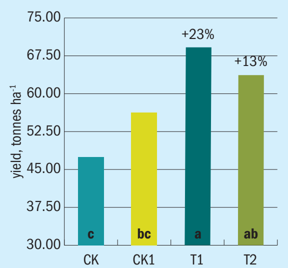
A fertilization programme that combines fertigation (e.g., Agrolution) with soil application (e.g., Agromaster and Polysulphate) can be suitable for citrus growing in areas with meaningful spring rainfall (>200-300 mm). Fertigation can avoid periods of plant nutrient hunger, while the application of Polysulphate ensures the supply of secondary macronutrients to the crop during wet periods.

Fertilization management for organic citrus farming

Organic farming practice involves maintaining citrus productivity levels by building up soil fertility over the medium- and long-term. In both irrigated and rainfed systems, organic citrus growers rely on base fertilization of the soil to provide an increased proportion of the total nutrient supply. Soil fertilization can include both recycled nutrient sources, such as compost and organic fertilizers, and natural mineral fertilizers, such as **Polysulphate**. Comprising of the naturally-occurring mineral polyhalite, Polysulphate is certified as a suitable organic input for farming systems in the main citrus producing countries.

It is also now possible for organic citrus growers to complete their nutrient supply through fertigation – using this to activate soil nutrient mineralisation and improve nutrient uptake by the plant. In countries such as Spain, for example, ICL offers the **Flecotec** range, a whole family of organic and mineral fertigation products, for organic farming. These can be used in combination with Polysulphate, which is also organic and, uniquely, the world's only polyhalite fertilizer.

Fig. 2: **Agromaster trial results for mandarin in China**



CK = control with no fertilization
CK1 = control, conventional fertilization, 4 kg/plant/year
T1 = Agromaster (18-10-18), 4 kg/plant/year
T2 = Agromaster (18-10-18), 3 kg/plant/year

Source: ICL

Evidence from global trials

Polyhalite (Polysulphate) has been shown to improve the productivity and nutrients status of citrus trees across trial results from different regions.

For example, improvements to the yield of **sweet oranges** (fruit counts and size) and plant nutrient status were observed in Polysulphate trials in Brazil[2]. Combining the use of Polysulphate, at an application rate of 400 kg/ha, with potassium chloride increased orange yields by 30 percent, versus the control in which potassium chloride was applied alone as the sole potassium source (Figure 1).

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Visual signs of nutrient deficiencies in the leaves of orange trees grown on a calcareous soil in Valencia, Spain. Left: iron deficiency in the leaves of an orange tree (variety Ortanique). Right: manganese deficiency in the leaves of an orange tree (variety Naveline).

ICL experiments with Polysulphate in China have also shown increased **grapefruit** yield and quality. The application of Polysulphate also reduced N, P and K inputs by 44 percent, 38 percent and 17 percent, respectively, versus standard NPK practice. This lowered fertilizer costs by 11 percent while raising the income of growers by seven percent, compared to conventional NPK fertilization.

Citrus trials with the CRF product **Agromaster** have also demonstrated proven benefits. When applied in **mandarin** plantations at a rate of 4 kg/tree, Agromaster (18-10-18) delivered a yield increase of 23 percent and – by improving fruit size – raised the percentage of commercial fruit, versus growers practice that applied conventional fertilizers at similar rates (Figure 2).

Deficiencies and foliar analyses

It is usually possible to visually recognise severe deficiency symptoms in citrus plants – as these are clearly visible in either old or young leaves, depending on the nutrient. In general, severe deficiencies of N, P, K, Mg show in old leaves, while severe Ca, S, Fe, Mn, and Zn deficiencies show in young leaves.

Calcium deficiency notably occurs in fruits and young leaves. Unlike certain other nutrients, Ca cannot be mobilized from older tissues and redistributed via phloem. Instead, developing plant tissues rely on the immediate supply of Ca in the xylem – which is dependent on transpiration – and, consequently, Ca deficiency always shows up in young leaves and fruits first.

Leaf analyses enable more precise measurement of nutrient deficiencies and can therefore be used to guide the fertilization strategy at citrus plantations. These analyses are particularly useful when assessing crop nutrient uptake and then adjusting crop management accordingly.

Leaf sampling for nutrient analysis is typically performed on the 4–7 months old leaves of non-fruiting twigs or fruiting terminals[1,3]. On fruiting terminals, samples are collected on the third and fourth leaves away from the fruit towards the plant, with sampling carried out when fruit reaches the size of a table tennis ball. Leaf nutrient contents are then checked against reference values[1,4], as well as locally developed technical guidelines.

Left: when establishing citrus plantations, controlled-release fertilizers (CRFs) such as Agroblen can be incorporated within the soil and used to cover the planting hole at the transplanting stage. Right: a well-established one-year-old plant at a clementine plantation, Oliva, Valencia, Spain

Foliar nutrition and biostimulants

Foliar nutrition programmes can be widely applied in all kinds of citrus production systems, being suitable for both irrigated and rainfed systems and cultivation in all kind of climates.

During the **establishment of new plantations,** citrus plants usually require intensive crop protection programmes during their first 2–3 years. This is necessary to enable plant growth and control leaf miners (*Phyllocnistis citrella*) and other pests. The pressure from pests, as well as the growth and nutrient needs of citrus plants, is higher during warm periods. Crop protection is therefore practiced during these periods, typically by applying foliar sprays. Spraying also offers the opportunity for an intensive foliar nutrition programme. Citrus varieties with extended vegetation periods, for example, are sprayed as frequently as once every 10 days.

A full foliar nutrition programme for citrus plantations can be designed using ICL's **Agroleaf** and **Nutrivant** product ranges, as these offer a wide range of formulations for each development stage. **Agroleaf Power** improves the assimilation of nutrients by the plant – thanks to its DPI and M-77 growth enhancer technologies. **Nutrivant Booster**, meanwhile, comes in macro- and micro-nutrient formulations designed for citrus crops. Nutrient products also incorporate Ferti-Vant technology to improve the spread of nutrients over the leaf surface. This can
boost the uptake of applied nut… r
a period of more than three wee… -
ing to deliver better fruit yield… r
quality fruit, and improve grower
Additionally, in certain citr… -
ing regions, such as Brazil, I… s
a complete biostimulant progr… o
improve productivity and resil… o
biotic and abiotic stresses. The… -
ucts can be applied within foli… s
alongside nutrient and crop p… n
components.

An organic orange (variety Navelina) plantation, Valencia, Spain, before (right) and after (left) harvest.

New citrus plantations

When starting a new plantation, the CRF **Agroblen** can be added to the planting hole (50-100 grams per tree) during transplanting operations – in either rainfed or irrigated production systems. Agroblen, by fulfilling nutrients needs throughout the first year, helps young plants to become well-established, thereby reducing the numbers that will require replanting.

During the establishment of new plantations, the soil fertilization programme can be complemented with an intensive foliar fertilization programme, as described previously. When additional nutrient supply is required, these can provided by applying fertilizers to the soil surface, in circular strips around the tree canopy, or via irrigation systems using WSFs. ■

About the ICL authors

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Europe battling a dual production and demand challenge

PHOTO: EUROCHEM

Low demand, high gas prices and cheaper Russian imports of urea and ammonia are keeping a lid on European fertiliser production, prompting fears of permanent plant closures. ICIS's **Deepika Thapliyal**, **Sylvia Tranganida**, and **Aura Sabadus** examine the challenges faced by the sector and the potential long-term impacts on the European fertilizer industry.

The region's largest ammonia plant, Northwest 1, is located in Kingisepp, Russia.

Introduction

Thin consumption, rising gas prices and cheaper Russian imports of urea and ammonia are keeping a lid on European fertilizer production, prompting fears of permanent plant closures.

More positively, operating rates at European nitrogen plants may soon touch around 80 percent, unconfirmed data suggest, a ten percentage point increase on reported rates over the summer, with units at Poland's Grupa Azoty and Romania's Azomures scheduled to restart in October.

Nevertheless, Europe's gas-intensive industries – which were severely affected last year by the record energy costs after Russia cut gas supplies to Europe –still face headwinds. The region's fertilizer production continues to be affected by a combination of elevated gas costs and depressed demand (Figure 1).

The lower output from fertilizer and other chemical plants is reflected in lower aggregated gas demand in the higher-consuming north-west European countries, which remains at least 20 percent lower than the five-year average, ICIS tracking data reveal.

European gas prices

Gas prices, having dropped nearly tenfold since the record highs seen at the end of August 2022 (Figure 2), are still above the long-term average. Extensive unplanned outages at upstream facilities in Norway, which restricted daily supplies by almost a third in the latter part of summer, have contributed to elevated price levels.

Looking ahead, a combination of sluggish industrial demand and ample stocks (Figure 3) is likely to exert a downward pressure on gas prices, although overall price direction will largely depend on the weather this winter.

More generally, bullish and volatile gas prices combined with maintenance at fertilizer production plants globally have been squeezing margins. In some cases, producers have increased their sale prices to reflect higher feedstock costs. The October ammonia price agreed between Norway's Yara and US producer Mosaic, for example, was set at $575/t cfr (cost & freight), an increase of $185/t on the $390/t September price.

An ammonia trader told ICIS that this new monthly price was enough to allow the seller to eke out a margin. European ammonia production costs are currently running just below $500/t (Figure 4).

Ammonia plants do not, however, pay spot market prices for their gas. Instead, Europe's producers, because their price formulas are based on averages, will still be paying for gas in the €30-40 per MWh price range currently, in our view. Therefore, with no signs of further declines ahead, the longer-term impact of gas prices on European fertilizer sector profitability is another concern.

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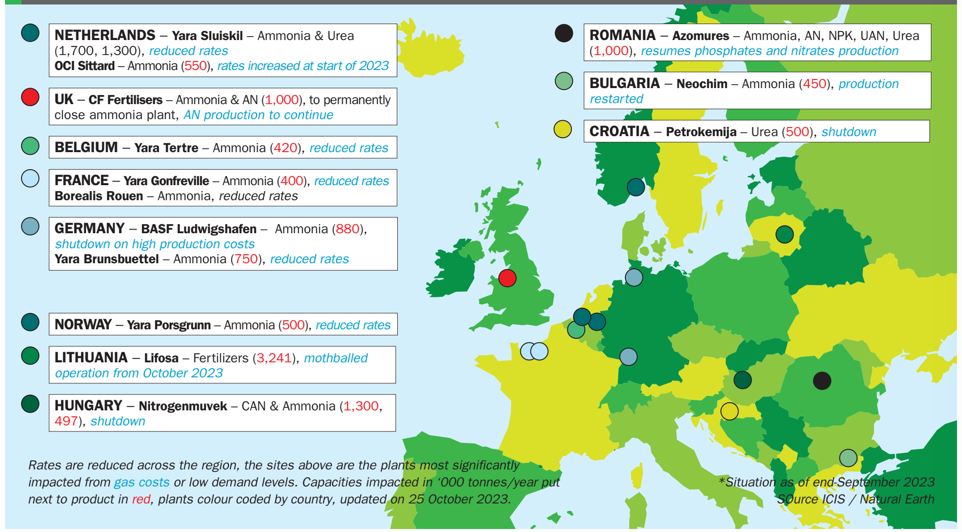
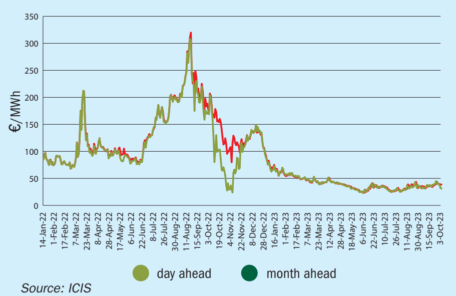
Fig 1: The impact of high gas costs and low demand on European fertilizer production*



Rates are reduced across the region, the sites above are the plants most significantly impacted from gas costs or low demand levels. Capacities impacted in '000 tonnes/year put next to product in red, plants colour coded by country, updated on 25 October 2023.

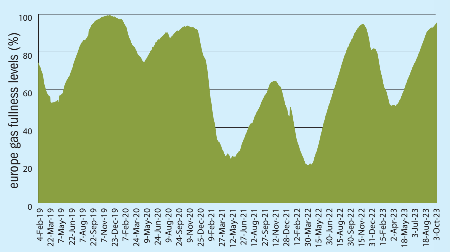
**Situation as of end-September 2023*
Source ICIS / Natural Earth

Fig 2: European TTF day-ahead and month-ahead gas prices



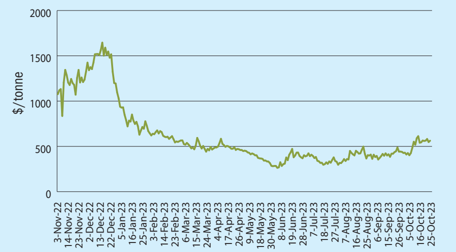
Source: ICIS

Fig 3: European gas stocks



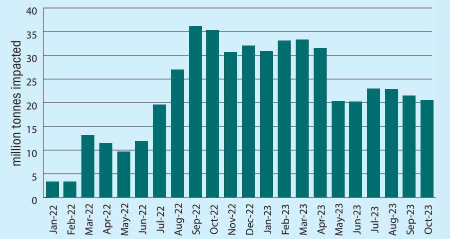
Source: ICIS

Fig 4: European ammonia production costs



Source: ICIS

Fig 5: Europe's chemicals and fertilizer industry: volume of production affected by gas prices and poor demand since 2022*



Source: ICIS

**Annual production capacity (million tonnes per year) offline or running at reduced operating rates at the end of each month*

While high production costs have not forced any new permanent European plant closures – since BASF revealed plans in February to shut its Ludwigshafen caprolactam and ammonia units in Germany by the end of 2026 – we believe the threat of further closures by several producers in the region is very real.

Competition from cheaper Russian imports

The revival of European fertilizer production is also being hampered by the influx of much cheaper Russian products. These can cost seven times less to produce than corresponding European fertilizers.

While the EU has sanctioned a number of Russian oligarchs associated with the fertilizer sector, following the invasion of Ukraine, these are limited in scope. Consequently, Russian fertilizers such as urea are accepted into Europe and imports continue to be ample. Fertilizer products supplied by major Russian producers are no longer sanctioned in France, for example, and are also moving into other European countries.

On the demand side, the picture is equally challenging.

Poor European demand

European demand for most nitrogen products is still lacking. This is despite the recent unexpected tightening of fertilizer exports from China and the support this has given to global urea and phosphate prices.

Europe's chemicals and fertilizer industry still has around 20 million t/a of capacity either offline or operating at reduced rates – due to the pincer effect of low demand and high gas costs (Figure 5).

The slump in European consumption may be related to macroeconomic factors, such as the weakness of sterling in the UK, suggests Adam Joslin, customer manager at ProAgrica, a sister organisation of ICIS. He thinks a combination of seasonality, inflationary pressures and higher costs is making Europe's farmers more cautious in their buying and application of fertilizer products.

"I think the state of the economy has the potential to affect [fertilizer] demand – rising inflation globally, together with rising interest rates, is perhaps leading the market to expect recessional behaviour and demand not being as strong," Joslin said.

The well-supplied grain market could be another factor, especially if Russia is still selling grain from last year's bumper harvest. Wheat prices, while lower than in recent years, do however remain above their 2013/2014 peak, points out Joslin.

"Actually, you can see the pattern of the wheat prices spike in 2013/14 mirrored by what has happened in 2021/2022 and the decline in the following year – we do seem to be seeing a little of history repeating itself," he said.

About the authors

Deepika Thapliyal is Deputy Managing Editor, Fertilizers, Sylvia Tranganida is Senior Ammonia Editor and Aura Sabadus is a Senior Journalist at ICIS. Visual data by Yashas Mudumbai, ICIS Data Editor.

Please note that the analysis and commentary in this article reflects the market situation as of the end of September 2023.

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Casale granulation – revolutionising finishing technology

PHOTO: CASALE

Operational Green Granulation urea plant.

With the addition of Green Granulation technology (GGT), Casale is the only industry licensor able to provide customers with an entire nitrogen fertilizer complex. **Ken Monstrey** and **Matteo Fumagalli** of Casale outline the benefits of this technology and its revolutionary new elements.

IMAGES: CASALE

Top: Casale GGT granulator. Bottom: Casale GGT plant.

Casale's technologies cover the entire value chain for nitrogen fertilizers – from syngas through to NPKs – including ammonia, urea, nitric acid and ammonium nitrate production. The range of services provided by the company include the revamping of existing fertilizer plants as well as the design and construction of new fertilizer complexes.

Casale successfully acquired Green Granulation Ltd in 2022 to strengthen and broaden its nitrogen technology portfolio. The newly purchased company, now part of Casale Ltd, is the licensor of granulation technology for urea, ammonium nitrate (AN), calcium ammonium nitrate (CAN) and urea ammonium sulfate (UAS) production. Historically, it has been more active in the Chinese market.

With the addition of GGT technology, Casale is the only industry licensor able to provide customers with an entire nitrogen fertilizer complex – covering every process step from gas treatment all the way through to solid finishing.

The recent award of a front-end engineering design (FEED) contract for a new 1,800 t/d capacity urea granulation complex in Uzbekistan provided the opportunity to combine the technologies of Casale's holding and subsidiary companies for the first time. This project is scheduled to be completed in the first half of 2025.

Casale Green Granulation process

Since its establishment, Casale has developed and incorporated revolutionary new elements within the overall fluidised bed process used to produce nitrogen-based fertilizer granules. The company has embedded proprietary innovations such as Optimised Fluid Bed Dynamics and Double Temperature Scrubbing within Cold Recycle Urea Granulation (CRG) technology. These developments have provided the business with a technological edge over its competitors.

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Casale offers the most advanced fluidised bed technology currently available and, thanks to its unique plant design with a horizontal layout, offers both lower construction costs and higher efficiency. Additionally, the inclusion of CRG technology provides customers with tangible operational, economic and environmental benefits, such as:

- Lower total investment costs
- Lower power consumption
- Simplified operations
- Greater operational flexibility.

The Casale Green Granulation process (Figure 1) proceeds as follows:

- The fluid bed urea granulation plant receives concentrated solution from the evaporation section of the upstream synthesis plant.
- This solution is sprayed inside the granulator where it is transformed from liquid into solid granules of the desired size and quality.
- The fluid bed process produces granules by spraying this solution onto seed particles which are kept in a fluidised state.
- The seeds grow by continuous evaporation, crystallisation and solidification.
- The spraying system, by producing a large number of very fine droplets, guarantees a highly homogeneous granule structure.
- After cooling, the end product is sent to a bulk storage and/or bagging section.

In urea production, the Casale Green Granulation plant uses a feed of melt urea solution with a concentration of 96-97 percent (urea + biuret). The ammonium nitrate (AN) process, in contrast, introduces the AN melt to the granulation section at a concentration of 97.5-98 percent.

Optimised Fluid Bed Dynamics

A crucial factor in producing superior quality granules – whether these are urea, AN, calcium ammonium nitrate (CAN) or any other fertilizer or non-fertilizer granules – is achieving adequate particle movement within the fluidised bed layer. This is needed to create a continuous stream of fresh particles and direct these towards the different spray zones within the granulator, as well as ensuring water in the melt feed is evenly distributed and can evaporate.

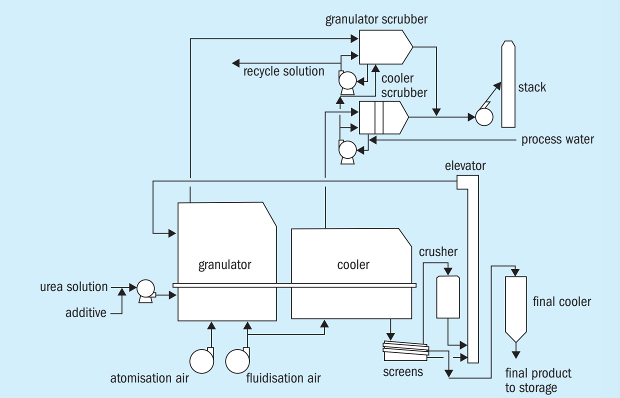
The Green Granulation process incorporates Optimised Fluid Bed Dynamics (OFBD) technology. By combining a low operating fluidised bed level with a rolling movement inside the bed, OFBD ensures a constant and predictable feed of seed particles to the different spray zones. This has major technical advantages.

The low bed level, for example, reduces power consumption because it allows the fluidised bed to operate with a low pressure drop across the entire system. The rolling movement in between the consecutive sprayer banks also ensures a more predictable particle movement compared to a traditional 'bubbling bed' system.

Casale Green Granulation plants therefore benefit from the operational advantages of OFBD. These ensure sufficient particle movement occurs within the bed while avoiding the large pressure drop found in traditional high level bubbling beds. This enhanced performance contrasts with the high power consumption of traditional fluidised bed systems caused by the large pressure drop created by their high bed level.

Another crucial aspect of OFBD technology is the liquid sprayers used. These hydraulic sprayers were developed in-house and produce a homogenous spray of fine, uniform droplets in the spray zones. This spray penetrates deeply into the fluidised bed layer, assisted by a stream of atomised air, without generating too much dust.

Fig. 1: Schematic of Casale's Green Granulation process



Source: Casale

> Casale offers the most advanced fluidised bed technology currently available and offers both lower construction costs and higher efficiency

Within fluidised beds, for every granule that leaves the system, a replacement 'seed' granule is required to restart the granulation process. Traditionally, these seeds are generated by crushing oversize granules (or on-size product) to feed the granulator. Crushers need to supply a constant stream of seed material – the exact amount determined by the recycle ratio – to maintain the reliability of the process and ensure that product granules have a stable size distribution.

Advantageously, the hydraulic sprayers used in the Green Granulation process can be set to generate seeds. This, in turn, makes the OFBD process much more stable and less dependent on feed from the crusher(s). This allows the granulator to function at a very low recycle ratio, while still maintaining a very stable granulation process without size distribution fluctuations.

Cold Recycle Granulation

Casale Green Granulation plants incorporate Cold Recycle Granulation. This cools granules to optimise process conditions and guarantee stable operations. In particular, the crushers and vibrating screens are kept clean thanks to the low temperature of the solid recycle.

In other processes, in contrast, the presence of warm granules, being softer than cooled granules, leads to fouling of the screen decks and roll crusher. This is deleterious as the blocking of screen decks has a huge influence on the size distribution of the end-product. Fouled crusher rolls also create excessive dust which can build up inside the granulator and overload the process.

Casale Green Granulation plants avoid these problems as they are designed to handle the solid recycle at the lowest economically feasible temperature. Their deep cooling action also helps to generate granular products with a desirable highly polished surface.

The overall reliability of the Green Granulation process is also ensured by optimising the airflow. Proper airflow through the system is beneficial as it:

- Creates movement
- Evacuates heat from the fluidised bed layer
- Removes dust particles from the spray zones
- Maximises the interval between wash stops by keeping the walls and roof sides inside the granulator and cooler(s) clean.

Double Temperature Scrubbing

The tail gases from Casale Green Granulation units are treated using Double Temperature Scrubbing. Installed scrubbers are designed to meet the strictest emissions limits and usually comprise of 2-4 consecutive wet scrubbing stages, depending on regulatory requirements and the type of end product.

The combination of horizontal wet scrubbers and irrigated vertical demister stages in this type of granulator scrubber provides a highly efficient scrubbing action at very low pressure drop. The mist formed in the double temperature stage(s) makes it possible to catch even sub-micron dust particles. As well as this, the high concentration (50-55 weight-percent) of the recovered solution – which is recycled to the synthesis unit – also keeps steam consumption in the evaporation section low.

Comprehensive capabilities

Casale Green Granulation technology can produce a wide range of granular products for agricultural and industrial markets, including:

- Urea
- 'Urea+' products that incorporate, for example, ammonium sulphate (U+AS), elemental sulphur (U+ES) and small quantities of plant nutrients (U+micronutrients)
- Ammonium nitrate (AN)
- Calcium ammonium nitrate (CAN)
- Compound fertilizers
- Urea for diesel exhaust fluid (DEF)
- Urea for cattle feed
- Technical grade urea.

These comprehensive capabilities are valuable, especially as the nitrogen fertilizer market is continuously looking for enhanced fertilizers, higher nitrogen efficiency, and more effective, tailor-made products for specific crops.

As outlined in this article, the state-of-the art finishing technologies in the Green Granulation portfolio open up various new market opportunities, at a time when requirements from fertilizer producers are becoming ever more challenging. Casale is consequently well positioned to meet the demands of its customers, today and tomorrow, by offering front-to-end solutions and complete key-turn projects, as well as revamping options for outdated units. ■

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Liquid fertilizers – compatibility and safety

Liquid fertilizers are prized because of their flexibility – especially the freedom to blend nutrients together to create customised products for growers. **Dr Karl Wyant**, Nutrien's Director of Agronomy, offers guidance on compatibility and safety, two key concerns when blending and handling liquid fertilizers.

PHOTO: NUTRIEN

Nutrien's production plant at Gesimar, Louisiana, manufactures large volumes of liquid fertilizers (UAN, 32-0-0).

The fertilizer industry has responded to demands from growers for innovation in crop nutrition by continuing to develop new fertilizer products and improved nutrient formulations. In recent years, one notable and landmark shift in product development has been the introduction of liquid fertilizers.

Introduction

Liquid fertilizers, also known as fluid fertilizers, have become increasing popular in the agriculture, horticulture and turf markets (*Fertilizer International* 508, p18). This is largely due to their flexibility. They are well suited to both fertigation and foliar application, for example, and can be applied as starter fertilizers alongside seeds or as a side dressing. Formulations also offer myriad possibilities for combining N, P and K with other crop inputs.

The global liquid fertilizer market is valued at around $2 billion currently and is growing at more than three percent per annum, according to market research. Liquid fertilizers represent the frontier of nutrient management for many ag retailers and their customers, having been pioneered by growers across a diverse range of row and field crops, oilseeds and legumes, and fruit and vegetables.

Nutrient suspensions versus nutrient solutions

Liquid fertilizers divide into two broad categories: firstly, **suspensions** of very fine solids and, secondly, **solutions** of dissolved nutrients.

Suspension fertilizers are commonly used in direct soil application. They consist of finely-ground solids suspended within a small volume of water or thixotropic gel. Suspending agents are used to help keep the fertilizer in a dispersed state and prevent settling. Advantageously, suspension formulations can offer a higher nutrient analysis relative to solutions.

Solution fertilizers, on the other hand, are obtained by completely dissolving solid nutrients in water. Common formulations include urea ammonium nitrate (UAN, 32-0-0), ammonium polyphosphate (10-34-0), and potash-derived fertilizers (0-0-17). Fluid fertilizers can also supply secondary nutrients and micronutrients, depending on the fertilizer source and the formulation.

Due to their flexibility, these nutrient solutions have a wide range of uses including starter applications, fertigation and foliar sprays. The introduction of liquid fertilizers, and their growing popularity in certain markets, has heralded a marked shift away from standard, granular commodity fertilizers like urea (46-0-0), monoammonium phosphate (MAP, 11-52-0), and muriate of potash (MOP, 0-0-60), etc. This specific category of liquid fertilizers – nutrient solutions – is where we will turn our focus next.

Benefits and limitations

Crops cannot tell the difference between nutrients delivered by a solid, granular fertilizer or those delivered by a liquid product. Instead, these two distinct forms of fertilizer offer different nutrient delivery mechanisms and, as a nutrient management choice, have both advantages and disadvantages. Therefore, to ensure crop performance is not compromised, the relative merits and demerits of liquid fertilizers – as set out below – must be considered when incorporating these products into an existing nutrient programme.

Liquid fertilizers are prized because of their blending behaviour – especially the freedom to combine nutrients together to create new products with customised analyses. Unique blends can be formulated, for example, by partnering nitrogen, phosphorus and potassium with micronutrients, adjuvants, biostimulants, and crop protection products. Furthermore, these novel nutrient solutions can be offered to growers at different scales, depending on logistics and convenience, ranging from large volumes delivered direct by suppliers to smaller batches provided by the local ag retail store. Either way, liquid fertilizers can be provided as custom blends tailored to match specific crop and geographical needs.

Another advantage is flexibility in both application timing and placement. Liquid fertilizers are typically administered in-season when crop nutrient demand is highest. They can be applied through an irrigation system (fertigation), as a starter or side dress blend, or to the crop itself as a foliar treatment.

Granular fertilizer applications, in contrast, come with limitations. Their bulky handling equipment and attendant height limitations can prevent spreaders from getting into the field. This often limits applications to when the field is fallow or during early crop growth stages.

The ability to make nutrients rapidly available to plants is another key advantage. Crops can quickly take up nutrients from applied liquid products, since the nutrients are already dissolved in water, a characteristic which also drives up nutrient use efficiency. Moreover, nutrients can be applied more safely as the risk of plant burn is less with liquid fertilizers – relative to granular fertilizers – as they tend to have a lower salt content.

Liquid fertilizers do, however, have several shortcomings. As a result, there are undoubtedly circumstances where the use of granular fertilizers or manures/compost might be a better choice instead.

First, liquid fertilizers tend to have a lower nutrient density relative to their dry counterparts. The available nitrogen in one tonne of urea (46-0-0) granules versus one tonne of liquid UAN-32 (32-0-0), for example, is heavily weighted in urea's favour. Consequently, liquid fertilizers are not as well suited to supplying nutrients in larger doses, versus dry fertilizers, as their unit nutrient cost makes them much less affordable. Granular fertilizers are therefore the most economical choice if large nutrient doses are needed, say at the end of harvest or at the pre-plant stage.

Second, liquid fertilizers generally require more specialised storage and application equipment, relative to dry fertilizers. Growers need to store liquid fertilizers in large tanks (e.g., tank farm), for example, or in small batch totes, whereas dry fertilizers only need simple pile-and-bin storage. Liquid fertilizers also require special equipment for field application including:

- Fertigation systems (centre pivot, drip and mini sprinkler, flood, linear, etc.)
- Liquid starter kits on planters
- Side dress rigs
- Spray bars for foliar application.

Upfront equipment costs can therefore prohibit the use of liquid fertilizers unless the grower already has the necessary items.

Finally, liquid fertilizers also have long-term storage challenges with the settling out of ingredients from solution ('salt out') when cooler weather arrives. Getting ingredients back into solution, once a blend 'salts out', can cause headaches, on farm and for ag retailers, due to the considerable remixing effort involved.

Overall, careful consideration of the strengths and limitations of liquid fertilizers is required when incorporating these formulations into a crop nutrient programme. As liquid fertilizers continue to gain in popularity, honest accounting of nutrient needs and logistics requirements, plus realistic crop performance expectations, should set up the supply chain for success.

Storage guidelines and tank maintenance

As mentioned previously, liquid fertilizers have distinct storage requirements versus dry fertilizers. Guidance on storage tank maintenance and advice on how to manage 'salt out' is set out below. (Further information on regulatory policy for large-scale storage of liquid fertilizers and site preparation, if needed, is provided in the bibliography.)

Growers increasingly prize the on-farm storage of liquid fertilizers. This enables them to take advantage of pre-pay programmes and accept delivery of liquid fertilizers during the off-season when prices are typically lower. Ag input suppliers are also storing liquid fertilizers in bulk to ensure availability to growers. As a result, seasonal tank maintenance now regularly features on annual 'to do' lists. The following tank maintenance tips should help keep liquid fertilizers inside tanks where they belong – and out of the environment where they can behave as a pollutant and/or become a safety risk:

- Inspect the interior and exterior of liquid fertilizer tanks annually – look for issues with corrosion, cracking, pitting, and blistering of the tank floor and walls.
- Keep annual records and photos available for comparison.
- Interior walls and floors should be gently cleaned annually.
- Repairs should be left to specialists as welding repairs on metal tanks is not a standard procedure. Epoxy coated tanks also require paint that can be lethal if managed incorrectly.
- Valves and plugs should be inspected annually and replaced with corrosion resistant materials such as stainless steel, if necessary.
- Growers should contact their fertilizer dealer as and when tank issues arise or if they are unsure of how to proceed with repairs.

The following storage guidance is specific to weather-related challenges:

- In cold climates, avoid storing liquid fertilizers during the winter, if possible.
- Alternatively, move liquid fertilizer tanks into warm storage, if available.
- Do not store liquid fertilizers for more than one winter season.
- If liquid fertilizers do salt out, allow time to recirculate and resuspend any settled-out materials during spring warm up.
- Circulate product in the tank for at least 48 hours post-storage and use agitation or introduce turbulent flow, if possible.
- The time required for recirculating salted out materials depends on the tank volume. The larger the tank volume, and the higher degree of salting out, the longer the re-circulation. A 25,000 gallon (94,635 litre) tanks may need two days of circulation, while a 47,000 gallon (177,914 litre) tank may need at least five days.
- Contact the dealer for fresh product if salt out cannot be reversed after re-circulation of the liquid fertilizer.

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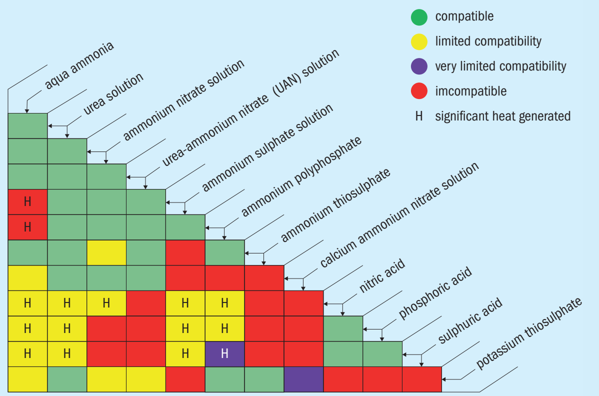
Compatibility and safety

Individual liquid fertilizers can be combined to produce final blends with unique analyses. This high degree of customisation is valuable as it allows for innovation, product differentiation, and unique formulations. However, two important concepts – compatibility and safety – require close examination before starting to combine liquid fertilizers.

Two liquid fertilizers are generally considered incompatible if they interact to produce solid particles (precipitation), separate out, or produce a hazardous by-product. The blending compatibilities of common liquid fertilizers are shown in Figure 1. This scheme uses a 'traffic light' classification system. Green confirms that the two liquid fertilizers are compatible, yellow shows limited compatibility, while red indicates incompatibility. An additional colour (purple) is included for those combinations with very limited compatibility.

While a yellow or purple classification does not rule out the formulation of stable blends, special attention should be paid to the solubility of the mixture with efforts made to keep the ingredients together. For combinations marked 'H', care must also be taken to avoid injury due to the heat generated by exothermic reactions during mixing.

Fig 1: **Compatibility chart for liquid fertilizer mixtures**



Source: Nutrien (eKnomics.com) and the Fluid Fertilizer Foundation.

Liquid fertilizers are easy enough to blend. This characteristic is generally an advantage. But it also means one can get into trouble if the safety of the blend is not considered beforehand. Examples of unsafe blends and practices (with potential hazards) are shown in Table 1.

Safety is a particular priority for mixtures with very limited compatibility and incompatible mixtures (shown as purple and red, respectively, in Figure 1). With incompatible mixtures, there is a high certainty of salt-out issues and the likelihood that precipitates or potentially hazardous by-products will form.

The general rules when blending liquid fertilizers are:

- When in doubt, pick the green boxes!
- Always follow label instructions for tank mixing to avoid blend sequence issues.

Table 1: **Examples of unsafe blends and practices with potential hazards**

Practice/blend	Hazard	Risk
Cleaning tanks with aqua ammonia and bleach	Chlorine dioxide gas	Lung irritant; can cause buildup of fluid in lungs; highly flammable and explosion risk
	Chloramine gas	Lung irritant; can cause buildup of fluid in lungs; lung irritant; potential for moderate residual injury & if sulphur mustard (presence of sulfonylureas or sulphate-containing compounds) is present, it could react with chloramine to produce mustard gas – severe eye burns and permanent eye damage; severe skin burns and blisters; irritation of the lungs causing coughing and/or shortness of breath; convulsions
	Mustard gas	
Mixing nitrates with acids	Nitrogen dioxide gas	Lung irritant; eye and skin burns; nose and throat irritation
Mixing potassium thiosulfate with urea and sulphuric acid mixtures before diluting tank	Sulphur dioxide gas	Irritating odour; skin, eye, and lung irritant
Mixing urea and sulphuric acid mixtures with phosphites	Phosphine gas	Extremely flammable and explosive; can cause eye damage and burn the skin; fatal if inhaled
Mixing acids with caustics	Heat	Burn risk
Mixing acids with humic substances	Carbon dioxide gas	Can reduce or displace oxygen in the air and cause respiratory issues

Source: Nutrien

Compatibility testing and assessment

It is always advisable to perform a bench-top jar test on a new blend before making a large batch. Jar tests help predict how blends will behave (in the tank farm and in grower equipment) and if a formulation will clog application equipment with unwanted precipitates (Figure 2).

Jat test mixtures, even when they appear to be stable after initial blending, should be observed for several days – and even weeks or months, if destined for storage – to see if solids form or components separate in the solution (Figure 3). If storage in colder conditions is anticipated, the blended mix should be exposed to the lowest expected temperature to determine if salt out will occur.

The adoption of an innovative, new liquid fertilizer blend requires pre-planning to answer two crucial questions:

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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

PHOTO: ALLEN HAYNES AND EDGARD JAUREGUI.

Fig. 2. When mixed, incompatible liquid fertilizers can form solid precipitates (left photo) that can damage and clog equipment. In another example, a jar test revealed that liquid calcium fertilizer (calcium ammonium nitrate) is severely incompatible with a phosphate-based fertilizer (ammonium polyphosphate) as they form an immobile green sludge when combined (centre and right photo). This blend would have caused considerable headaches if formulated on a large scale.

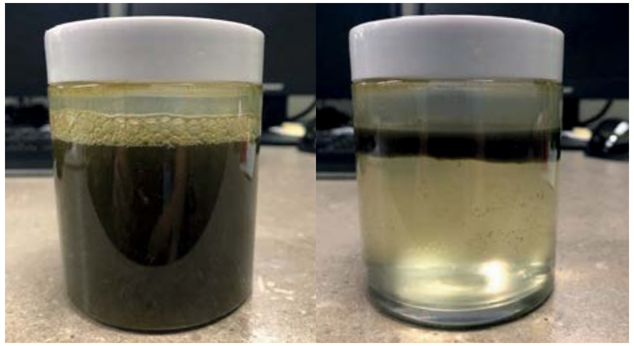


PHOTO: KARL WYANT

Fig. 3. Jar testing is crucial for revealing how blends will behave over the long-term in the field. In this example, the blended ingredients were compatible at initial mixing (left) but showed strong separation after sitting for 48 hours (right). This shows a clear failure that should be avoided.

- First, can the ingredients be blended without compatibility issues?
- Second, can the ingredients be blended safely without risk of injury?

When assessing a new blend, the use of a logical workflow (Figure 4), with its 'pass/fail' and 'yes/no' steps, can help answer both questions by anticipating hazards and revealing compatibility challenges. This workflow uses a series of check points – when scaling-up from the initial bench top (jar test), to a small batch, and then to full scale production – to help achieve a compatible and safe blend.

Concluding thoughts

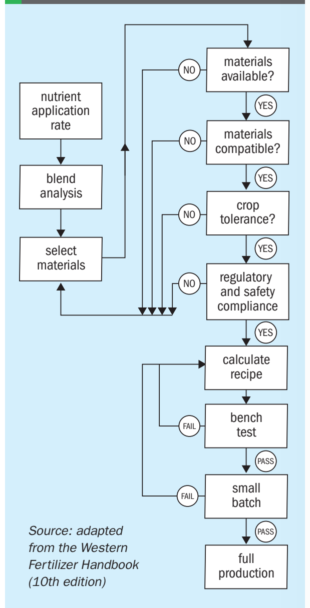
Liquid fertilizer blends are a fast-growing market category, as more agricultural suppliers and growers incorporate them into their crop nutrient management portfolios and plans.

Liquid fertilizers have a wide and unequalled range of uses – these including fertigation, starter and side dress applications, and foliar sprays. Valuably, different liquid products can be combined to create unique, customised nutrient formulations.

Compatibility and safety are the two key concerns when blending and handling liquid fertilizers. For new formulations, pre-planning and jar testing are especially useful, as they can help predict compatibility and mixing issues.

It is always advisable to consult the Material Safety Data Sheets (MSDS), product labels and mixing directions to reduce the risk of injury. Potential hazards can also be assessed (and therefore avoided) prior to blending by checking compatibility charts (Figure 1).

Fig 4: **A viable liquid fertilizer blend needs to be both compatible and safe to produce. A logical workflow helps achieve both goals.**



Source: adapted from the Western Fertilizer Handbook (10th edition)

If all of the above steps are clear, then move onto a jar test before proceeding to a final batch at scale.

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phosphates & potash INSIGHT

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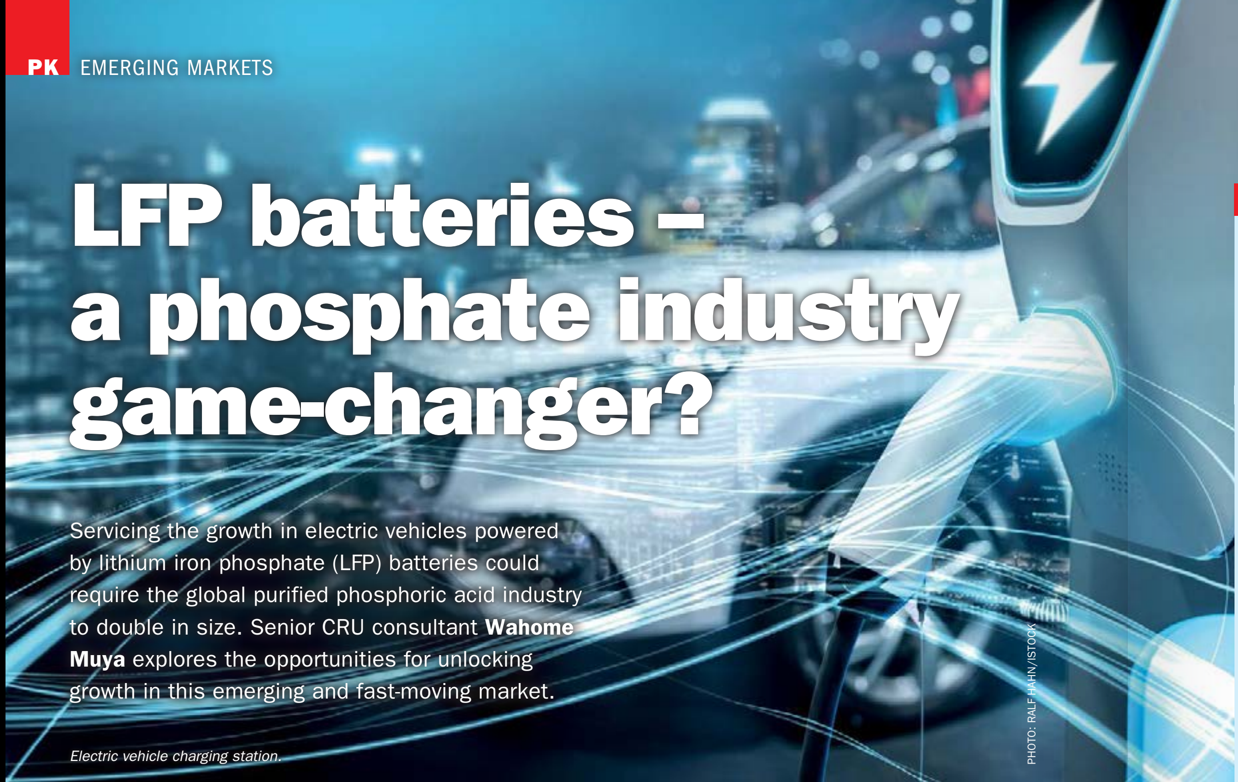


LFP batteries – a phosphate industry game-changer?

Servicing the growth in electric vehicles powered by lithium iron phosphate (LFP) batteries could require the global purified phosphoric acid industry to double in size. Senior CRU consultant **Wahome Muya** explores the opportunities for unlocking growth in this emerging and fast-moving market.

Electric vehicle charging station.

PHOTO: RALF HAHN/ISTOCK

Introduction

Globally, lithium iron phosphate (LFP) batteries are an increasingly important part of the fast-growing electric vehicle industry. As a result, global LFP demand is forecast to increase more than ten-fold over the next 20 years – spreading well beyond China into the rest of the Asia-Pacific and other regions such as Europe and North America.

The ability of phosphate producers outside of China to tap into this expanding market depends on one crucial factor – whether the LFP industry and its supply chain moves out of East Asia and develops internationally in future. This is by no means certain at present.

The emergence of LFP production outside of China could result in game-changing market growth for purified phosphoric acid (PPA) suppliers globally. Yet such growth is unlikely to materialise if LFP supply chains remain within China, as this would lock out the world's major phosphate producers from this growing market.

Despite the uncertainty, forecast growth in LFP usage will still require PPA production to double in size globally over the next 20 years, in CRU's view.

The global shift towards battery electric vehicles

The world is embarking on a major transition away from the internal combustion engine towards battery electric vehicles (BEVs) – driven by rapid technological progress, supportive policy regimes, and shifting consumer attitudes.

Advances in technology have increased the energy density of batteries, extending the travel range of BEVs, while also lowering their purchase and ownership costs to levels comparable with traditional petrol or diesel vehicles. Government subsidies and tax credits to consumers and automakers, alongside legislation, are also encouraging the long-term phase-out of vehicles powered by traditional internal combustion engines. Meanwhile, range anxiety – the fear of BEV owners that their power will run out before they reach the next charging location – continues to slowly decline as battery capacities increase and public charging infrastructure improves.

Combined, these positive factors are driving significant growth in BEV sales globally. These are forecast to reach 18 million units in 2025, up from 2.3 million in 2020 – an eight-fold increase over five years. By 2045, BEV annual sales of 65 million are expected, accounting for more than two-thirds of total light-duty vehicle sales globally.

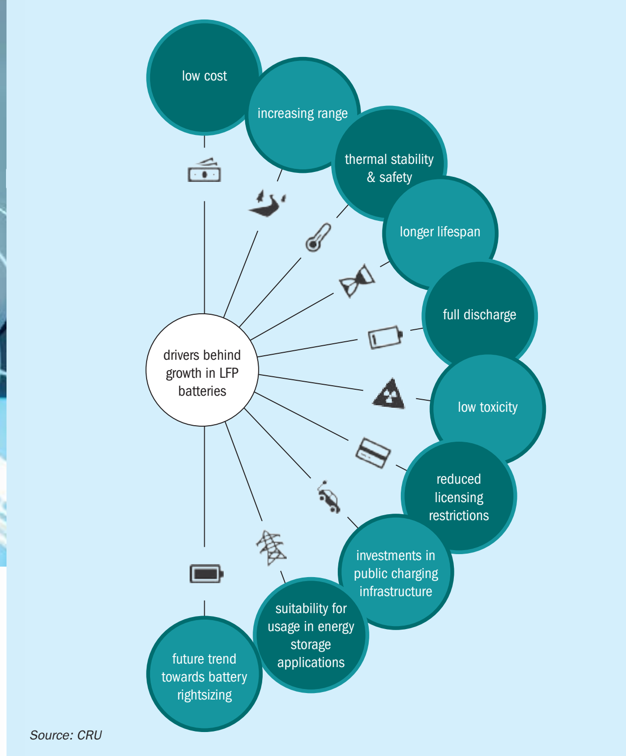
The enormous growth in global BEV sales anticipated over the next 20 years will be coupled to the rising popularity of both LFP and – in the longer term – lithium manganese iron phosphate (LMFP) batteries. Indeed, for BEVs, the global market share of LFP/LMFP batteries is expected to increase from 15 percent in 2020 to 33 percent in 2025 and then to 37 percent in 2035.

The growing use of LFP/LMFP batteries in BEVs is due to a wide range of factors (Figure 1). These include their:

- Lower cost relative to nickel-rich batteries
- Greater longevity
- Superior level of safety.

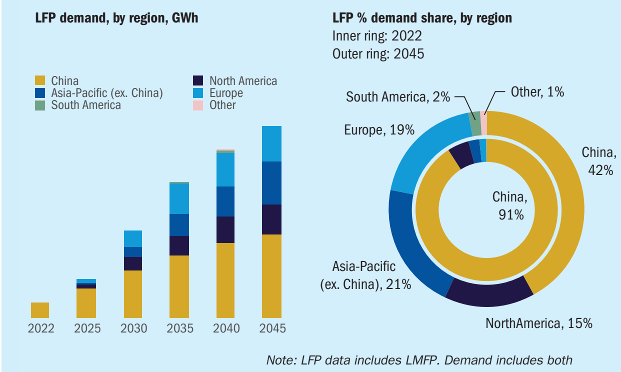
In addition, the main downside to LFP batteries historically – their lower energy density relative to nickel manganese cobalt oxide (NMC) batteries – has been largely offset by technological improvements. Nonetheless, nickel-rich NMC batteries do still retain a slight energy density advantage, as well as offering superior performance at low temperatures. The higher

Fig. 1: Ten major drivers spurring the adoption of LFP batteries



Source: CRU

Fig. 2: Future growth in LFP demand will be driven by regions outside China



Source: CRU

Note: LFP data includes LMFP. Demand includes both EV and energy storage applications. EV-related LFP/LMFP demand is derived from forecast sales per region.

value of their raw material constituents also makes the recycling of NMC batteries more economically viable.

Outside the BEV market, the greater usage of LFP batteries in energy storage systems is also on the rise. Valuable characteristics such as low-cost, durability, and thermal stability make LFP batteries particularly well-suited for this end-use.

Rocketing global demand

The LFP market is forecast to grow more than ten-fold over the next 20 years – with demand accelerating and spreading well beyond China's borders. At present, though, China completely dominates the LFP market, being responsible for more than 90 percent of world demand (200 GWh in 2022).

The current popularity of LFP batteries with Chinese auto manufacturers can be explained by two factors:

- Firstly, their lower cost relative to NMC batteries.
- Secondly, the preferences and travel habits of Chinese EV owners. These are geared towards shorter urban journeys in small/medium-sized vehicles – in contrast to the popularity of larger SUVs in the US and other markets.

Technical improvements in battery design, electric motors, power electronics, and vehicle lightweighting are helping to overcome the traditional range disadvantage associated with LFP batteries and help broaden their appeal outside of China.

Recent innovations in battery packs pioneered by Chinese manufacturers – such as 'cell-to-pack' battery configurations with large-format cells – have also delivered further cost savings and energy density improvements. This has added to LFP battery uptake in China, while also adding to their attractiveness to automakers in other regions.

All of these improvements, coming on top of traditional advantages such as low-cost, safety, and durability, are expected to drive greater LFP battery adoption in Europe, North America, and other parts of the Asia-Pacific.

Indeed, CRU is forecasting a more than ten-fold increase in global LFP demand over the next 20 years or so, with around 60 percent of this demand expected to be based outside of China at the end of this period (Figure 2). In CRU's, China will cease to be the sole dominant player over the medium- and long-term, as the

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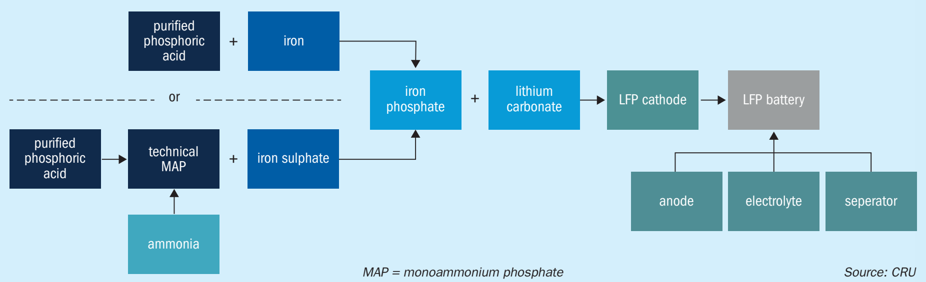
Fig. 3: **Simplified LFP battery production process**



MAP = monoammonium phosphate *Source: CRU*

LFP market expands internationally and becomes more relevant to automakers, battery producers, and raw material suppliers – including the phosphate industry – in the rest of the world.

International expansion prospects

In the LFP battery production process (Figure 3), purified phosphoric acid (PPA) is used as a starting material to generate iron phosphate, either directly or via a monoammonium phosphate (MAP) intermediate, which is then combined with lithium carbonate to manufacture LFP cathodes. These are incorporated within LFP batteries alongside other key components, namely the anode, electrolyte and separator.

Currently, virtually all the world's manufacturing capacity for LFP cathodes is based in China. The iron phosphate used to produce these cathodes is also sourced domestically – China being self-sufficient in phosphate and accessing iron ore imports for its steel industry.

China will continue to domestically supply the raw materials and precursors used in LFP production, such as PPA and iron phosphate, as long as its in-country manufacture of LFP cathodes dominates the global market. This situation, if it were to continue, would essentially lock-out phosphate producers located outside of China from the LFP industry and prevent them from enjoying the sales growth and premiums associated with this emerging market.

Therefore, the key question for international phosphate producers is whether LFP cathode manufacture – and the PPA and iron phosphate supply underpinning this – will expand outside of China and proliferate in other regions over the long-term to reflect the pattern of LFP demand.

Recent LFP battery project announcements are now helping to answer this question. Many of these new LFP battery cell plants are due to be built in North America and Europe over the next 5-10 years, with the total planned manufacturing capacity in these regions surpassing 150 GWh and 200 GWh, respectively.

However, it is rare for these battery projects to include captive/integrated upstream production capacity for LFP cathodes. Non-integrated, standalone LFP cathode capacity in these regions also falls far short of the necessary supply requirements of these battery cell projects. The upshot is that planned regional LFP cathode capacity is only sufficient for 13 percent and 7 percent, respectively, of announced battery cell capacity in North America and Europe, according to CRU estimates, resulting in respective LFP cathode manufacturing deficits of 87 percent and 93 percent.

This suggests that, unless we start to see many more LFP cathode projects announced in regions outside of China over the coming months and years, the cathode requirements of North America and Europe will be largely met through imports, even if both regions succeed in building up domestic LFP battery cell capacity. In this scenario, the phosphate raw materials required for LFP battery cathodes would still be sourced and consumed within China.

The extent to which new legislation can incentivise local production of LFP cathodes in North America and Europe remains to be seen. The 2022 US Inflation Reduction Act (IRA) does promote the domestic production of electric vehicle batteries and battery components. Yet, while this has played some role in incentivising new LFP battery cell projects, we have yet to see the same effect for cathode projects.

A similar EU policy – the Critical Raw Materials Act – is also being planned. But this proposed legislation is at an earlier stage than its US equivalent, making its effectiveness in encouraging domestic LFP cathode projects even less well-understood.

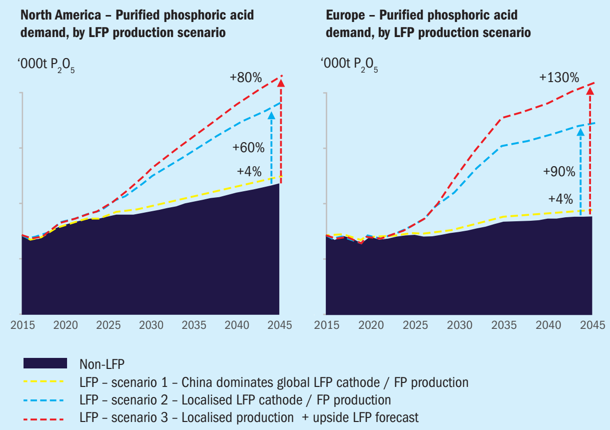
Purified phosphoric acid capacity to double?

Nonetheless, while the effects of LFP demand growth on regional demand for purified phosphoric acid (PPA) remain uncertain, it is likely that the global industry will need to double in size over the next 20 years, in CRU's view.

Our long-term forecasts for PPA demand in North America and Europe are based on three scenarios (Figure 4), these varying according to where LFP cathode and iron phosphate production is located:

- In **Scenario 1**, China continues to dominate both global LFP cathode and iron phosphate production, despite growing LFP demand in the rest of the world. This outcome would result in minimal uplift to PPA demand in North America and Europe – totalling just +4 percent in 2045. In this scenario, these two regions would largely import LFP cathodes from China to supply their battery cell plants.
- In **Scenario 2**, both regions establish enough domestic production capacity for LFP cathodes and iron phosphate to fully eliminate their import reliance on China. This outcome would deliver a considerable upside to the PPA industries in North America and Europe. PPA demand would be 60 percent higher in North America in 2045, for example, while the European PPA market would nearly double (+90 percent).
- In **Scenario 3**, in-region production of LFP cathode and iron phosphate is combined with an upside LFP demand forecast. This outcome would deliver incremental increases in PPA demand of +80 percent in North America and +130 percent in Europe – resulting in game-changing market growth for domestic PPA suppliers and exporters to both these markets.

Fig. 4: **North American (left) and European (right) purified phosphoric acid (PPA) demand out to 2045 for three different scenarios**



Note:
FP = iron phosphate
PPA demand includes acid consumed in FP production – either directly in the process or for generating the technical MAP intermediate used instead *Source: CRU*

CRU has also estimated Chinese PPA demand out to 2045 under three different scenarios. In Scenario 1, the country, by continuing to be the world's exclusive supplier of LFP cathodes, would see its domestic PPA market size more than double (+110 percent). Furthermore, when coupled to an upside LFP forecast (Scenario 3), China's PPA demand levels grow hugely (+150 percent) above its non-LFP requirements. However, the expected rise in PPA demand falls back to +50 percent in our base case forecast. In this situation, China is no longer the world's exclusive LFP cathode supplier and instead only produces enough to supply its domestic market needs (Scenario 2).

Summing up

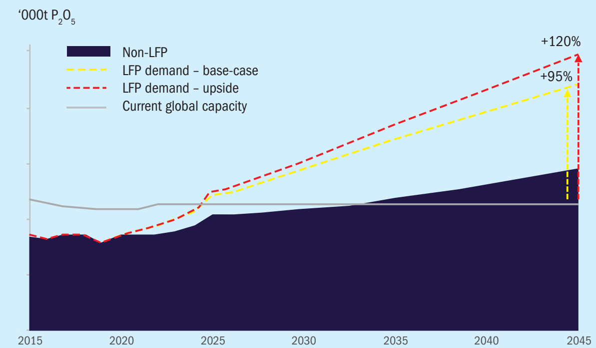
At the global level – regardless of whether China continues to dominate LFP cathode and iron phosphate production – CRU's forecasts show overall PPA demand far outstripping current world capacity in the long term, driven primarily by LFP market growth. In our base case, global PPA capacity would need to nearly double in size by 2045 (+95 percent) to meet LFP demand growth, while our upside forecast requires PPA capacity to grow by as much as 120 percent (Figure 5).

The magnitude of global LFP demand growth, combined with uncertainty about where this will be distributed geographically, presents phosphate industry players with a number of strategic questions – these being of interest to incumbent and prospective phosphate producers, raw material suppliers, cathode and battery manufacturers, investors, and policymakers.

Fortunately, the team at CRU Consulting is well placed to answer these wide-ranging questions, including:

- The likely effectiveness of legislation in the West to encourage localised battery supply chains
- The potential price premiums that phosphate producers supplying the LFP sector might enjoy
- The potential for first-mover advantage for phosphate producers entering the LFP industry outside of China.

Fig. 5: **Global production capacity for purified phosphoric acid may need to double by 2045 to satisfy LFP market demand**



Source: CRU *Note: global capacity shown at 80 percent operating rate*

CRU Phosphates 2024

The LFP battery market will be a hot button topic at the forthcoming 16th CRU Phosphates Conference being held in Warsaw, Poland, 26-28 February 2024 (p43). Register at: events.crugroup.com/phosphates/register ■

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Potash project listing 2023

Fertilizer International presents a global round-up of current potash projects.

Plant/ project	Type	Company	EPC/EPCM contractor(s)	Equipment/technology	Location	Product	Capacity '000 t	Status	Start-up date
AUSTRALIA									
Beyondie	G, LBE	Kalium Lakes	DRA Global	Ebner/K-UTEC/Köppern	Western Australia	SOP	90	C	In administration
Lake Mackay	G, LBE	Agrimin			Western Australia	SOP	450	FS	N/A
Lake Way	G, LBE	Sev.en Global Investments			Western Australia	SOP	245	C	N/A
Lake Wells	G, LBE	Australian Potash			Western Australia	SOP	170	FS, P	On hold
BRAZIL									
Autazes	G, CM	Brazil Potash	CITIC Construction			MOP	2,400	FS	N/A
CANADA									
Bethune	G*, SM	K+S Canada			Saskatchewan	MOP	500	UC	2022/26
Esterhazy K3	B, CM	Mosaic	Hatch/AMC	DCM Group	Saskatchewan	MOP	1,800	UC	2024
Jansen	G, CM	BHP	DMC Mining	Herrenknecht SBR system	Saskatchewan	MOP	7,300	UC	2027
Milestone	G, SM	Western Potash	Artisan Consulting/AKITA Drilling		Saskatchewan	MOP	146	UC	2023
Russel McAuley	G, SM	PADCOM		Beechy Potash Products Corp	Manitoba	MOP	100	UC	2023
Tugaske	G, SM	Gensource/Helm			Saskatchewan	MOP	250	FS, P	N/A
Wynyard	G, SM	Karnalyte Resources/GSFC	Amec FW (Wood)		Saskatchewan	MOP	625	FS, P	N/A
CHINA									
Ge'ermu	G, LBE	Zangge Potash			Golmud, Qinghai Province	MOP	200	UC	2022
eritrea									
Colluli	G, CM	Sichuan Road and Bridge Group Co Ltd	DRA Global		Danakil Depression	SOP	472	FS, P	N/A
ETHIOPIA									
Dallol	G, SM	Liberty Metals and Mining/ XLR Capital	SNC-Lavalin		Afar	SOP	600	FS, P	On hold
Danakil Potash	G, SM	Circum Minerals			Danakil	MOP/SOP	2,000/750	FS, P	On hold
ISRAEL									
Dead Sea Works	B, LBE	ICL			Dead Sea	MOP	200	UC	2022
JORDAN									
Safi	B, LBE	Arab Potash Co			Dead Sea	MOP	300	UC	2025
LAOS									
Ganmeng	G, CM	Lao Kaiyaun			Ganmeng	MOP	500	UC	2023
Ganmeng	G, CM	Lao Kaiyaun			Ganmeng	MOP	1,000	UC	2026
Ganmeng	G, CM	Asia-Potash			Ganmeng	MOP	1,000	UC	2023
Ganmeng	G, CM	Asia-Potash			Ganmeng	MOP	2,000	UC	2025
MOROCCO									
Khemisset	G, CM	Emmerson			Khemisset	MOP	810	FS	N/A
PERU									
SalSud	G, LBE	Salmuras Sudamericanas			Sechura desert	SOP	100	P	On hold
RUSSIA									
Solikamsk II	B, CM	Uralkali			Perm	MOP	900	UC	2024
Solikamsk III	B, CM	Uralkali			Perm	MOP	500	UC	2023
Talitsky	G, CM	Acron (Verkhnekamsk Potash Company)			Perm	MOP	2,000	UC	2026
Usolskiy II	G*, CM	Eurochem			Perm	MOP	1,500	UC	2026
Ust Yayvinsky	G, CM	Uralkali			Perm	MOP	2,000	UC	2024
SPAIN									
Muga	G, CM	Highfield Resources			Navarra & Aragón	MOP	800	FS, P	2027
UK									
Woodmsith Mine	G, CM	Anglo American	DMC Mining/STRABAG AG/Worley	Herrenknecht SBR system	North Yorkshire	Polyhalite	13,000	UC	2027
USA									
Sevier Playa	G, LBE	Peak Minerals (EMR Capital)			Utah	SOP	215	FS, P	2027

NOTES:
Greenfield projects (G): generally, these must have reached the detailed/bankable feasibility study (FS) stage for inclusion. Brownfield expansions (B): capacity indicates incremental additions, not total capacity.

PROJECT TYPE:
G Greenfield
G* Greenfield ramp-up/expansion
B Brownfield expansion
CM Conventional mine
SM Solution mine
LBE Lake brine extraction

PRODUCT:
MOP Muriate of potash, KCl
SOP Sulphate of potash, K_2SO_4

START-UP DATE:
N/A Not available or provided

PROJECT STAGE:
FS Feasibility study
P Permitted
UC Under construction
C Completed/commissioned

BRAZIL POTASH

The Autazes potash project

Potash ore core sample, Autazes potash project, Amazonas, Brazil

Brazil Potash is developing the Autazes potash project in Brazil's Amazonas state near the town of Autazes, 120 kilometres from the city of Manaus. The 2.2 million t/a capacity project, although located deep in the country's interior, is advantageously, situated just eight kilometres from the Madeira River, the Amazon's biggest tributary.

If it gets the go ahead, Autazes' output could eventually supply 20 percent of Brazil annual potash consumption of around 12.6 million tonnes. Importantly, the project's 'in-market' position, close to Brazil's major farming regions, and the potential for river barge transportation, provides Brazil Potash with a cost and transit time advantage over international suppliers.

The company is forecasting a delivered MOP cost of $166/t (cfr Mato Grosso) for the project with product transit times to domestic farming regions of just 2-3 days. That compares to delivered costs in the $270-398/t range for its overseas competitors who can face transit times of 100 days or more, including port demurrage days.

> **"If it gets the go ahead, Autazes' output could eventually supply 20 percent of Brazil annual potash consumption of around 12.6 million tonnes.**

Brazil is currently import dependent for 98 percent of its potash demand. Mosaic Fertilizantes is the country's only major potash producer currently, operating the 500,000 t/a capacity Taquari mine in Sergipe.

The Autazes project involves the construction of an underground mine, an ore processing plant, a loading port, and the expansion of the road linking the mine site to the port.

The project is well advanced, having completed both a bankable feasibility study (BFS) and environmental and social impact assessments, with $240 million having been raised for its development to date. Most of the necessary permits are said to be in-hand and the required land mostly purchased.

Autazes will require a further capital investment of $2.5 billion (after tax) and a 4-5 year installation and construction phase before it can enter production. The project has sufficient reserves for a 23-year operational life at a nameplate production capacity of 2.2 million t/a.

Autazes has the potential to generate annual earnings (EBITDA) of $1 billion and offers a post-tax internal rate of return (IRR) of more than 20 percent, according to the project's feasibility study. The project's capital intensity is less than $1,021/t with an estimated operating cost (opex, f.o.b. port) of $87/t at its full run rate.

Brazil Potash plans to have 80 percent of Autazes production output covered by offtake agreements. The company already has several agreements in place with Amaggi Group, one of the world's largest private soybean producers. These include:

- A binding 'take of pay' offtake agreement for around 500,000 t/a of potash
- A marketing agreement to sell the project's remaining potash tonnages annually
- A river Barge transportation agreement to ship the initial potash output from Autazes to inland ports close to major farming regions in Brazil.

Brazil Potash is also committed to potash industry leadership on sustainability and innovation, and highlights the following aspects of the project:

- Substituting local potash supply for overseas sources could potentially avoid 1.2 million tonnes of CO_2 equivalent emissions
- The plan is to sell a portion of the project's potash production at subsidised rates in exchange for commitments by farmers not to burn the Amazon rainforest
- Providing a domestic source of potash helps ensure food security
- Construction on cattle land at Autazes minimises its rainforest impacts.

Having already been granted a Preliminary License (LP), Brazil Potash is currently in the process of securing an installation license (LI). This will provide the necessary authorisation to begin construction and is contingent on the approval of the project's mine development plan (PAE) and basic environmental plan (PBA).

Although not located on indigenous land, Autazes is sited within 10 kilometres of two indigenous reserves which therefore have a legal right to be consulted. In September, the local Indigenous people, the Mura, signalled their support for the Autazes potash project by voting in support of its construction as part of a consultation process.

As a final hurdle, Autazes will also require an operational license (LO) from Brazil's Mining and Energy Ministry before it can start production. This is to ensure the mine and plant are compliant with domestic industry codes.

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ASIA-POTASH

Laos emerges as a major potash player

PHOTO: HUAWEI

An Asia-Potash technician uses an innovative industrial smartphone to make a video call from a cavern 300 metres underground at its potash mine in Laos.

In a milestone for Southeast Asia, Chinese developer Asia-Potash (Sino-Agri International Potash Co Ltd) successfully completed and commissioned the first one million t/a capacity phase of its potash mining project in Khammoung province, Laos, in 2021. The project's potash capacity was subsequently expanded to two million t/a in March 2023.

Asia Potash has mining rights in Khammoung province covering 215 km² (Dongtai and Phonexay-Nong Bok mines) and exploration rights for a further 49 km² (Nonglome mine). This area encloses more than six billion tonnes of ore reserves. After processing, these have the potential to generate more than one billion tonnes of saleable, high-quality muriate of potash (MOP).

Asia-Potash has plans to incrementally raise the project's potash production capacity in two further phases – to three million t/a by 2024 and then to 5-7 million t/a output during 2025-26. The company believes that its potash production in Laos could ultimately expand to 7-10 million tonnes, depending on market demand.

Khammoung is in central Laos. Asia-Potash's mine site in the province is located 380 kilometres south of the capital Vientiane, 180 kilometres from the Laos-Vietnam border to the east, and 40 kilometres from the Third Thai-Laos Friendship Bridge to the west.

The mine has good access to the 1,409 kilometre long Asian Highway 13 (AH13) that runs from Thailand through Laos to Vietnam. This transnational road heads north to Vientiane, offering links to the China-Laos railway. The mine has other eastwards road connections with the Vietnamese ports of Vung Ang, Glo and Hai Phong, some of which have wharves supporting potash shipments. Mine-to-port transport should also improve in future as the route of the planned Vientiane-Vung Ang railway will pass near the mine site.

Asia-Potash has developed and installed innovative proprietary ore mining and processing technologies at its Laos potash operations. These include innovative dissolution and crystallisation systems and solid-liquid separation equipment. The company says it is committed to 'smart mining' and the introduction of digital and fully automated potash mining operations in Laos in future. ■

Complete Broadfield process unit, Aswan, Egypt.

PHOTO: BRADLEY PULVERIZER

Minimising heavy metals in superphosphate manufacturing

The cadmium and heavy metal content of sedimentary phosphates are of great concern. This has seen industry raw material consumption shift towards igneous phosphates or the blending of phosphate rocks from different sources. While rock blending can successfully reduce the heavy metal content of superphosphates, it needs to be accompanied by careful process adjustments, as **Ian Hancock**, Bradley Pulverizer's vice president sales & operations, explains.

Introduction

The manufacture of single superphosphate (SSP) and triple superphosphate (TSP) fertilizers, through acidulation of fluorapatite rock, continues to evolve. Process adaptations have been necessary, for example, in response to the consumption and depletion of known phosphate rock resources worldwide.

In addition to the more obvious economic consequences, the environmental impacts of declining phosphate rock quality also demand attention and must be compensated for by the production process. Avoiding the presence of unacceptable levels of cadmium and other heavy metals in phosphate fertilizers is a particular concern and priority – as this can eventually lead to soil contamination.

Farmers first began applying phosphorus-rich materials to soils over 200 years ago by adding ground animal bones to provide crops with beneficial nutrients. The subsequent development of NPK fertilizers eventually paved the way for the large-scale fertilization of crops that is commonplace today.

The development of the Broadfield® process by the Bradley Pulverizer Company in 1936 boosted the worldwide production of commercial fertilizers to new levels. This made the mass production of superphosphate fertilizers possible for the first time. The process produces single superphosphate (SSP) by acidulation of phosphate rock with sulphuric acid, while the addition of phosphoric acid produces triple superphosphate (TSP) and other enriched superphosphates.

Single superphosphate production

SSP production (see *Fertilizer International* 510, p61 for full process description) begins with the grinding of crushed phosphate rock (mainly fluorapatite, $Ca_3(PO_4)_2CaF_2$) in an airswept Bradley mill (Figure 1) to generate particles of the specified size (commonly 53–150µm). The resulting powder is then continuously fed into a Broadfield mixer along with sulphuric acid produced on-site. The mixer agitates the rock/acid mixture and, by coating the rock particles with the acid, kicks off the following chemical reaction:

$$2Ca_5(PO_4)_3F + 6H_2SO_4 + 3H_2O \rightarrow 6CaSO_4 + 3Ca(H_2PO_4)_2 \bullet H_2O + CaF_2$$

After an average reaction time of 3-4 minutes (Figure 2), the mixture is discharged as a cake into a rugged, sealed den (Figure 1). Exothermic reactions continue within the den for approximately 20-40 minutes as the material is slowly conveyed towards the exit. On leaving the Broadfield den, the material is extruded through a cutter to break the cake into granules. It is then stored for an average of 7-10 days to allow the complete conversion of insoluble phosphate rock into water-soluble SSP fertilizer.

The acidulation process is something of a balancing act. While the number of mechanical process variables is kept to a minimum, the few that are available are designed for production flexibility, regularly allowing machines to operate at between 60-110 percent of their rated capacity.

The sulphuric acid required by the process is often generated on-site and is relatively inexpensive in comparison to overall operating costs. This means that the economics of continuous superphosphate production, at consistent yields, is primarily determined by the quality/chemistry of the phosphate rock feed. In fact, it is fair to say that

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superphosphate production economics are totally dependent on the phosphate rock source.

The relatively long operating life of Broadfield equipment – and the need to accommodate increasingly frequent changes to the price, quality and specifications of raw materials – means superphosphate plants have to be installed with both foresight and flexibility. To minimise costs, new installations need to combine sensible process design and operational flexibility with the latest process controls and materials technology.

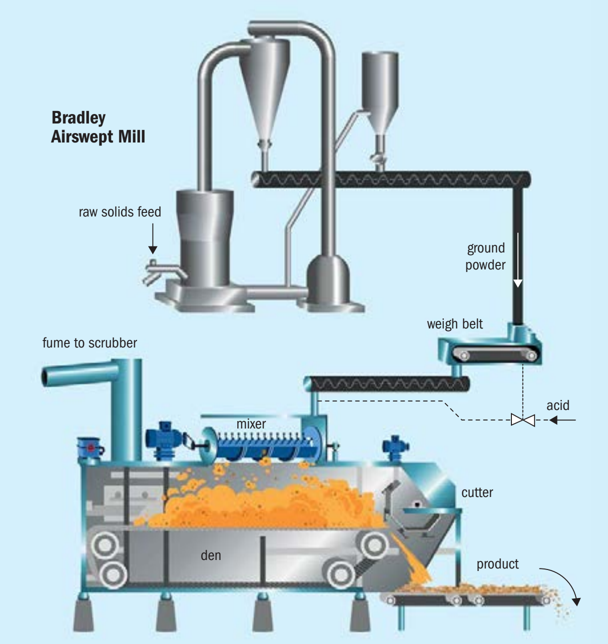
Equipment upgrades generally remain an economic option even for long-lived plant operations. In fact, some Broadfield dens have continuously operated for more than 50 years. Over this period, they have experienced a marked decline in the average phosphate feedstock grade (P_2O_5), down from 36 percent originally to a level of 27 percent or less currently.

Environmental considerations

Most phosphate rock sources used in superphosphate production worldwide contain concentrations of heavy metals (cadmium, uranium, radium, lead, mercury, etc.). Such elements are known to be toxic to both livestock and humans and injurious to health if ingested at high levels.

High cadmium (Cd) levels tend to be most prevalent, making this element the heavy metal of most concern. Care is therefore taken to minimise its concentration in superphosphate fertilizers. Cd levels are typically kept to below a threshold of 280 ppm, although regulations do vary from country to country.

Fig. 1: Schematic of the Bradley Broadfield Den

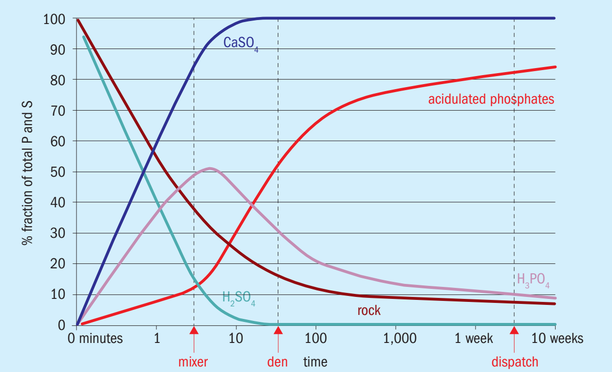


Source: Bradley Pulverizer

In superphosphate production, there is no simple or economically feasible way to remove heavy metals from the phosphate rock feed prior to the acidulation process, as these potentially toxic elements are locked within the crystalline structure of minerals. Fortunately, blending feed rock from multiple sources, as described in this article, can ensure that maximum Cd levels are not exceeded. Blending is a successful approach that can help prevent cadmium from accumulating in soils, crops, livestock and ultimately humans – this being the desirable long-term goal.

As well as potentially toxic elements, careful attention is also paid to the iron (Fe_2O_3) and aluminium (Al_2O_3) content of the phosphate rock feed. These two minor elements – collectively known as 'R_2O_3 compounds' – directly affect overall reactivity during the acidulation process and together are responsible for relatively high sulphuric acid consumption.

Fig. 2: Acidulation reaction timeline for the Broadfield process



Source: Bradley Pulverizer

Table 1: The contrasting characteristics of igneous and sedimentary phosphate rock sources used in superphosphate production

Variable	Igneous	Sedementary
Phosphate grade (P_2O_5 content)	typically lower	higher
R_2O_3 content	lower	higher
Cadmium content	lower	higher
Carbon content	lower	higher
F and Si content	higher	lower
Reactivity	slower	faster

Source: Bradley Pulverizer

Table 2: The process variables in the production of high grade superphosphates

Variable	High	Low
Phosphate grade (P_2O_5 content)	optimal (S)	low grade product
R_2O_3 content	sticky product	optimal (Ig)
Cadmium content	toxic product	optimal (Ig)
Carbon content	optimal (S)	"dead" product
F and Si content	high scrubber load	optimal (S)
Reactivity	optimal (S)	lower grade product/low production rate
Strength of acid	sticky product	wet product
Retention time in den	dry/dusty product	sticky product
Retention time in mixer	blockages	low grade product
Acid temperature	extra corrosion	slow reaction
Rock particle size	fine	coarse

Source: Bradley Pulverizer (S) - Sedementary rock source, (Ig) - Igneous rock source

Iron and aluminium also have a strong influence on 'retrogradation', a phenomenon that occurs when unreacted acid is present due to a lowering of the reaction rate. This increases the liquid content of the mix and, together with iron and aluminium dissolution, causes processing difficulties and production headaches at superphosphate plants.

A phosphate rock feed with an iron and aluminium content of 1.5-2.5 percent is generally considered ideal, as it produces the best granules when processing with sulphuric and phosphoric acids. Levels above three percent, in contrast, will result in a sticky and difficult to granulate product, while, conversely, granules will degrade during storage if levels are below one percent. Running operations outside of this range is suboptimal and undesirable as, to offset inefficiencies in the acidulation process, it requires higher acid demand and energy consumption at the production plant. This result in both higher environmental impacts and lower production profitability.

Regulating heavy metals through blending

As already stated, the typical target limit for cadmium in superphosphate fertilizers is <280 ppm. It might be concluded, therefore, that the answer is to simply source phosphate rock with cadmium levels (in fluorapatite) below this limit as a production feedstock. However, this apparently simple answer is not generally practical due to the different processing characteristics of low cadmium (igneous) and high cadmium (sedimentary) phosphate sources (Table 1).

In practice, igneous phosphate ores, typically sourced from South Africa, Brazil, and Russia, while providing safe cadmium levels (typically 30 mg/kg P), come with operational downsides. Hard, crystalline igneous phosphates, because they are less reactive during the acidulation process, can unfortunately deliver suboptimal end-products. Softer sedimentary rocks, meanwhile, from major suppliers such as Morocco are unsatisfactory for different reasons. Although their reactivity rate during the acidulation process is more optimal, they can contain prohibitive levels of cadmium (200-600 mg/kg P average).

The most practical and effective solution, therefore, is to blend together phosphate rock from multiple sources to achieve the desired cadmium target limit (<280ppm) while also ensuring the acidulation process and overall operation of the superphosphate plant remains optimal.

New Zealand leads the way

New Zealand has led the way and successfully reduced Cd levels in soils that have been treated with superphosphate for decades. The country sources both igneous and sedimentary phosphate rock from worldwide suppliers – chemically analysing each shipment to establish its composition. Individual phosphate rock sources and shipments imported by New Zealand have distinctly different physical and chemical characteristics (Table 2). These include:

- Total phosphorus content
- Reactivity rate
- Amounts of impurities (i.e. Cd, Fe, Al)
- Fluorine content and volatilisation levels
- Quantities of odorous compounds.

All of the above properties need to be evaluated before the feedstock can enter the Broadfield process. The optimal rock blend is calculated, based on these operational considerations and the results of chemistry analyses.

The amount of cadmium present in the end-product is directly controlled by the levels introduced into the process. This can therefore be regulated by precise blending of different feedstock sources to provide the required rate of dilution. Typically, this is achieved by storing each phosphate rock shipment in its own feed hopper. This allows the independent control of feed volumes from different sources, to match the established blend proportion, while also allowing for adjustments during continuous operation and in-between shipments.

Blending rocks from different sources is necessary to keep superphosphate production within an 'optimal window'. Operating within this window is desirable as, by maintaining optimal process conditions, it ensures that the end-product generated will meet all of the required specifications.

To help achieve these production objectives, Broadfield superphosphate units are designed and engineered to

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Table 3. **Key phosphate source rock considerations in superphosphate manufacturing**

Source rock (Phosphate-rich apatite)	Key considerations	Target/Optimal specifications
Chemical specifications	Are phosphate levels high enough for economic feasability?	27%-36% phosphate-rich rock
Cadmium levels	Can the 280ppm limit be met?	Rock blend <280ppm Cd
Physical specifications	Can levels of iron and aluminium be regulated?	<3% (can be reduced by flotation if needed)
Rock hardness	Expected rate of production?	"Optimal window" rock blend
Fluoride levels	Environmental consents?	Typical consent is <5mg F/M^3
Odour levels	Environmental consents?	Particularly a concern in populated areas
Competition	Profitability?	Low production cost to increase profitability

Source: Bradley Pulverizer

provide operators with the ability to make necessary process adjustments – for milling fineness, acid concentrations, mixer speeds, den time, etc. This allows the unit to operate efficiently, at between 60-110 percent of rated capacity, while consuming most low- and high-grade phosphate rock types.

Notably, the ability to make in-line adjustments (see below) is critical to the success of superphosphate manufacturing – given that the chemistry of the blend can change at any time due to the arrival of a new phosphate rock source, or even a new shipment from the same source. Some key manufacturing considerations are summarised in Table 3.

> **"Once the optimal blend is established, the production process tends to be straightforward and can run unimpeded with only relatively minor mechanical adjustments"**

Determining the ideal rock blend

A stepwise approach for determining the optimal rock blend in superphosphate manufacturing is outlined below. Once the optimal blend is established, the production process tends to be straightforward and can run unimpeded with only relatively minor mechanical adjustments. However, any significant change in chemistry – due to a new phosphate rock source and/or sourcing from a new face in an existing quarry, for example – will potentially require a change to the blend.

1. **Chemical analysis**. This is used to determine elemental concentrations in each phosphate rock source. At a minimum, chemical analyses should be performed by the manufacturer every time a new rock source is introduced into the process, including potential source changes at existing mines and quarries.

   In continuous processing, analysis of the source rock(s) at regular intervals is also recommended to determine what process or mechanical adjustments might be required to maintain the highest end-product yields. Particular attention is placed on phosphorus, iron, aluminium, calcium, and fluoride concentrations, as these elements have the greatest influence on the reaction process and the specifications of end-products. Levels of heavy metals such as cadmium are also verified at this point as, although having a minimal effect on the acidulation process, these are of primary importance to the commercial viability of the end-product.

2. **Determine ideal acid:rock (A:R) ratio.** The information collected in step 1 is run through stoichiometric calculations to establish a theoretically ideal rock blend that will meet end-product specifications. This assumes 'perfect-world' conditions such as constant process conditions and uniform rock chemistry. A further quantitative analysis is then applied to establish the volume of acid required for optimal process conditions. This is known as the A:R ratio and, for the purposes of calculation, assumes 100 percent acid strength.

3. **Pilot-scale testing to confirm actual A:R ratio**. Laboratory testing of phosphate rock sources only requires around 100 grams of material. The nearly instantaneous results obtained make this the ideal step for establishing the 'real world' rock blend necessary for commercial-scale superphosphate production. The data gathered is used to determine the optimal phosphate rock blend and A:R ratio at production-scale needed to meet the target end-product specifications.

4. **Production testing**. During production, the actual acidulation reaction conditions (e.g., time and volume) taking place in the exothermic conversion of rock to fertilizer cannot be replicated in laboratory batch tests. Production testing is therefore necessary. Conveniently, there is an opportunity to test both the physical and chemical properties of partially reacted superphosphate when this exits the den and enters the storage silos. Target values – for optimal maturation time and high-quality superphosphate – typically include 7-8 percent free acid and 11-12 percent water content. The target cadmium levels (<280 ppm) in the end-product are also confirmed at this stage. Further blending and testing, to keep within cadmium limits and achieve commercial acceptance, will be necessary if product Cd levels exceed this target value.

In-line process optimisation

Actual process conditions within the Broadfield superphosphate unit are only fully measurable during full scale production. In-line process sampling and testing is non-disruptive and the ideal way to maximise plant profitability by ensuring continuous production with minimal shutdowns.

As this article makes clear, superphosphate fertilizer production is always subject to unexpected changes in process conditions (temperature, rock chemistry, reaction times, etc.). Increases in iron, aluminium and magnesium levels, for example, introduce undesirable effects by:

- Preventing the A:R ratio being reached
- Consuming more acid
- Making the ex-den product sticky.

Fortunately, the Broadfield unit can be mechanically adjusted to compensate for these changes by increasing:

- The fineness of the rock
- The residence time in the mixer or den
- The reaction temperature within process restraints.

In fact, the Broadfield mixer, with its horizontal trough design, is specifically engineered to compensate for many of the variations frequently encountered during the acidulation process, as described in this article, such as changes in phosphate rock composition. In particular, the mixer's low speed means it can hold materials for longer and therefore slow down processing times if necessary. Indeed, the ability of the Broadfield mixer to alter residence time, and the operational flexibility this provides, is a valuable characteristic that enables superphosphate producers to make process improvements that increase product quality worldwide. ■


Broadfield mixer unit, Ballance Agri-Nutrients, New Zealand.

PHOTOS: BRADLEY PULVERIZER

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