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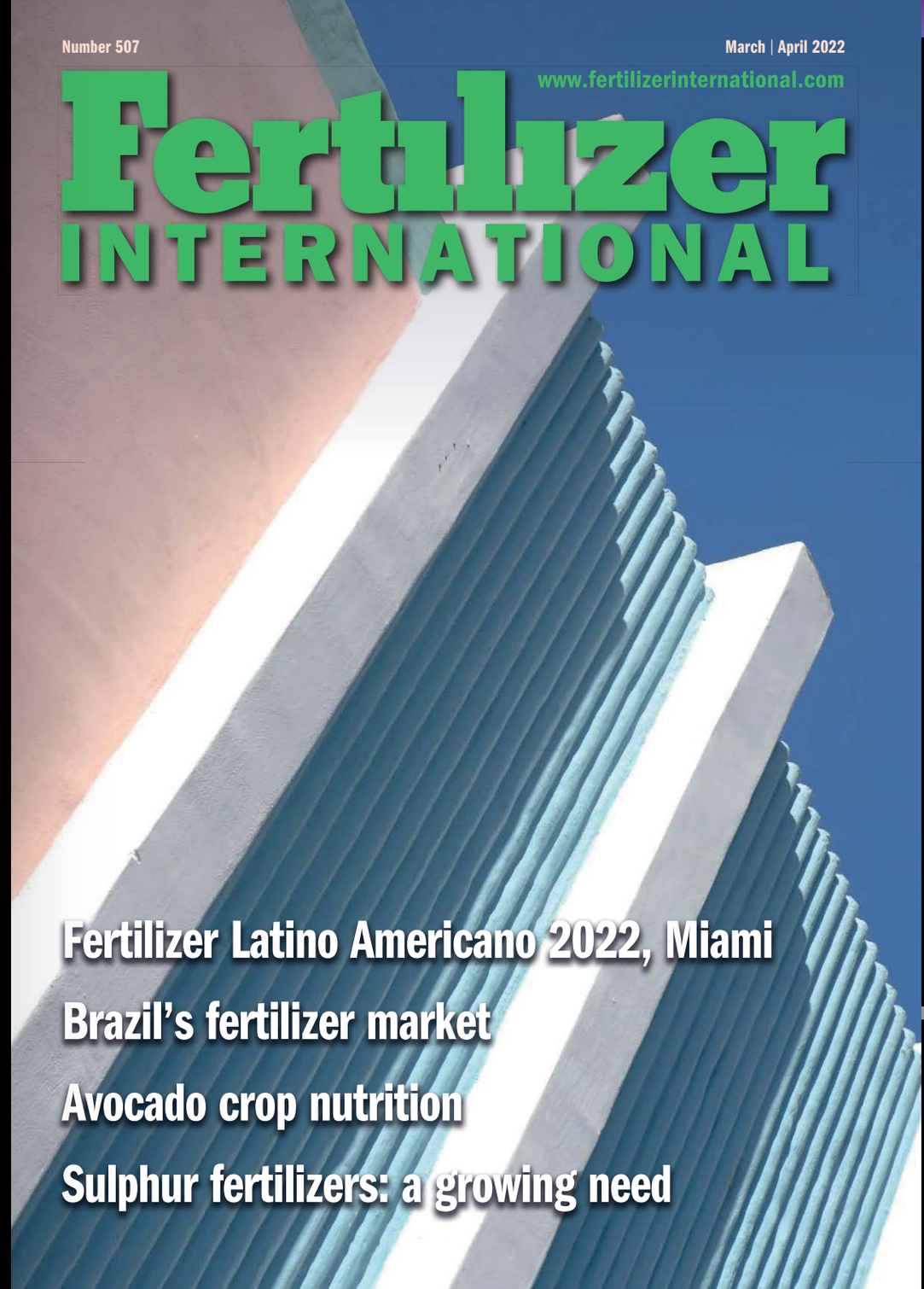

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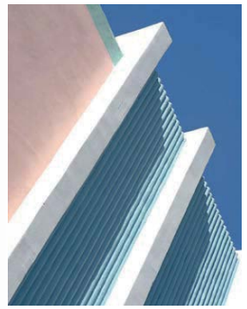

Cover: Art Deco architecture, Miami. Flyguy1980/iStockPhoto.com

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PHOTO: ARGUS

Exposure to the Russia-Ukraine conflict

Argus Media's **Alistair Wallace** assesses how exposed fertilizer and fertilizer raw material markets are to the conflict in Ukraine.

Russia possesses substantial potash and phosphate reserves, as well as one of the largest natural gas resources in the world, providing the country with a large N, P and K production base. Consequently, Russian supply is vitally important to the global fertilizer market – and difficult to replace too, as ratcheting western sanctions begin to restrict the country's access to world markets.

Exposure and disruption

We have assessed the potential impact of the military conflict between Russia and Ukraine on the eight major fertilizers, using six measures to quantify each commodity's exposure to sanctions:

- Russian share of global capacity
- Russian share of global production
- Russian share of global trade
- OECD share of Russian export business
- Share of Russian trade via Ukrainian or EU f.o.b. ports
- Russian share of forecast growth in capacity.

Sanctions, the story so far...

Based on this analysis, the ammonia industry is going to be the most exposed, followed by the potash and urea industries, while the sulphuric acid industry looks like it will be the least affected. The other major fertilizers fall along a spectrum between those two extremes.

The initial impact has been limited in terms of physical supply disruptions but huge in terms of psychological shock, greatly increasing the risk profile of fertilizer trading. Booking freight from Russian ports is looking to be an early and growing problem.

Ammonia most affected

Ammonia has been the most affected in the early days of the conflict. Around 2.4 million tonnes of ammonia shipped from Pivdenny port (Odessa) in 2021, of which only 150,000 tonnes were Ukrainian. The balance is Russian ammonia shipped through the pipeline from TogliattiAzot and Rossosh. Typically, these Russian exporters move 1.8 million t/a and 0.5 million t/a, respectively, through Pivdenny.

The conflict in Ukraine has forced the closure of the Togliatti-Pivdenny ammonia pipeline and all ammonia has ceased shipping from Ukraine. This will have huge implications for supply and prices west of Suez. The largest offtakers from Pivdenny last year were Morocco (800,000 tonnes), Turkey (600,000 tonnes), India (360,000 tonnes) and Tunisia (190,000 tonnes). This means that non-integrated (with ammonia) DAP and MAP producers in north Africa will be the most disrupted in the near term.

Potash is also in a uniquely difficult position given the disruption to trade already being experienced from the sanctions against Belarus' potash sector. Direct sanctions on Russian potash would cause a combined 40 percent of global exports to become unviable for Europe and the US.

The impact of the removal of Russia from the Swift financial transaction system and the sanctioning of Russian banks on Russian fertilizer sales is uncertain. Many Russian producers process fertilizer transactions through Swiss trading subsidiaries and we are unsure how these will be affected in the short run.

Despite no direct sanctioning of Russian fertilizer trade, and EU ports remaining open to Russian cargoes, we are already seeing impacts on fertilizer shipping. While nominated vessels are loading as normal, the fixing of future fertilizer cargoes appears increasingly problematic for Russia. We are also hearing reports of 'self-sanctioning' with some western companies that would normally import Russian fertilizers pre-empting tighter sanctions.

Gas markets price-in risk

So far, we have only considered the impacts of direct sanctions on Russian fertilizer trade and indirect effects from the sanctioning of Russian financial institutions. Yet gas markets are also pricing in risk premiums – with implications for nitrogen producers.

The European gas market has pre-emptively priced in a risk premium of around $10/mn Btu, moving from the mid-$20/mn Btu range to the mid-$30/mn Btu level. This will disproportionally affect EU nitrogen producers given the industry's gas-based cost structure.

Initial conclusions

As US and EU sanctions on Russia ratchet up, all fertilizer products will face upwards price pressure – should sanctions directly target fertilizer HS codes, fertilizer producers, or their owners.

Any limits on Russian exports will make global fertilizer markets less efficient. This means that buyers within affected jurisdictions – primarily the EU, US, UK and Japan – will lose bargaining power as the pool of available sellers decreases with the enforced absence of Russia and Belarus.

In addition to any trade disruption, ammonia and other nitrogen fertilizer prices will undergo a substantial cost-push as the risk premiums on gas increase the industry's marginal cost of supply. Actual disruption to Russian gas flows has the potential to push gas prices and nitrogen costs higher still.

Ammonia is already facing both outcomes, with the loss of almost 2.4 million tonnes of supply from Ukraine – and Russia through Ukraine – and the substantial increase in EU gas prices as European markets attempt to price in Russian risk.

Potash buyers in the west, having started to adapt to the sanctioning of Belarusian exports, now face the prospect of losing access to Russian supply as well, should the conflict continue and western sanctions begin targeting the Russian potash trade as well. ■

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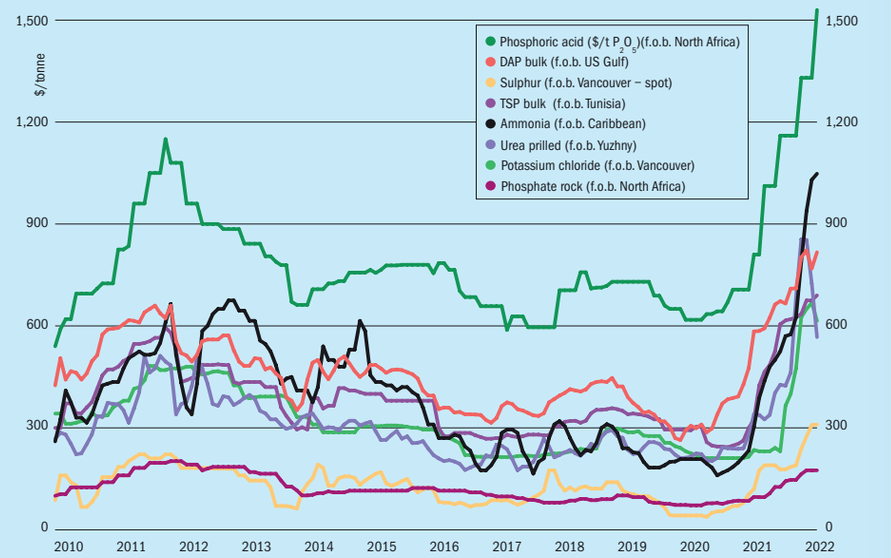
Market Insight

Historical price trends $/tonne



Source: BCInsight

Market Insight courtesy of Argus Media

PRICE TRENDS

Urea: Nitrogen prices spiralled rapidly upwards in early March, as Western sanctions on Russia severely curtailed the supply available to most buyers. European and Latin America importers stepped into the market *en masse* at the beginning of March looking for urea. Traders also competed for tonnages from producers. In response, f.o.b. and cfr prices escalated in tandem.

The Egyptian granular urea price was a particular standout. In a flurry of trades in early March, it added another $145/t to finish at $905/t f.o.b. Asian markets were quieter – as Russian supply is less significant – but still saw double-digit price increases in many locations.

Key market drivers: Russian cargoes are hard to find and expensive. Financing trade in Russian fertilizers is also proving challenging. Many buyers in Europe and the Americas will not buy Russian fertilizer. EU natural gas prices have also soared to record highs. This is likely to drive nitrate prices up and/or prompt EU producers to shut down.

Ammonia: The loss of 200,000 tonnes per month of Black Sea supply has exposed the ammonia market to even further volatility. In Ukraine, Pivdenny suppliers are unable to cover shipments, while Russian producer ToAz, which exports through Yuzhny, declared force majeure on contracts. This is likely to leave several key buying regions short of ammonia in April.

Moroccan, Turkish, Tunisian and Indian buyers all face shortage risks. Some are looking to Middle East producers to fill the gap, with f.o.b. prices in the region likely to spike higher once negotiations have been finalised. Soaring gas prices are yet another factor. These are making it difficult for traders to firm up a position, with the European cost of production fluctuating from below $1,000/t at the end of February to over $1,700/t on 2nd March.

Key market drivers: Baltic contract rising $40/t with Yara settling with Russian producers EuroChem and Uralchem at $1,155/t f.o.b. for March shipments. Natural gas prices soared with the outbreak of the Russia-Ukraine conflict, settling at a new high of around $57/mn Btu on 2nd March. Yara and Mosaic failed to reach an agreement for contract shipments to Tampa in March, with both sides remaining too far apart on price.

Phosphates: DAP and MAP prices in several western markets surged in early March. In Brazil, importers returned to the market, with Moroccan MAP trading at $1,010-1,015/t cfr. Indications at the start of the month were lower, ranging $950-1,000/t cfr. The price had been at $900-925/t cfr at the end of February. In northwest Europe, a small lot of Russian DAP traded at $1,000/t fca, with offers reaching $1,030/t fca. Previously, European DAP trading had been lacklustre, with prices at Ghent in the $930-940/t fca range. In the US, DAP barges hit $850-900/st f.o.b. Nola, up by over $100/st.

Market price summary $/tonne – End February 2022

Nitrogen	Ammonia	Urea	Ammonium Sulphate	Phosphates	DAP	TSP	Phos Acid
f.o.b. Caribbean	1,020-1,075	-	f.o.b. E. Europe 300-410	f.o.b. US Gulf	935-985	-	-
f.o.b. Yuzhny	1,115-1,140	610-720	-	f.o.b. N. Africa	880-930	670-710	1,490-1,600
f.o.b. Middle East	869-985	750-825**	-	cfr India	915-950	-	1,530*
Potash	KCl Standard	K_2SO_4	**Sulphuric Acid**		**Sulphur**		
f.o.b. Vancouver	530-700	-	cfr US Gulf	200-275	f.o.b. Vancouver	325-350	-
f.o.b. Middle East	540-700	-	-	-	f.o.b. Arab Gulf	330-345	-
f.o.b. Western Europe	-	820-875	-	-	cfr N. Africa	320-355	-
f.o.b. Baltic	530-670	-	-	-	cfr India	360-370+	-

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.*

Key market drivers: Soaring commodity prices – with crude oil, natural gas and grains all surging in early March following the outbreak of the Russia-Ukraine conflict. Freight costs also jumped, putting further pressure on global supply chains. Governments sanctioning the Russian economy – at least one major European distributor has distanced itself from future Russian fertilizer purchases. The closure of Ukraine's Pivdenny port has prompted concerns for the supply of ammonia to some north African phosphates producers.

Potash: Asia, Brazil and northwest Europe MOP prices all rose in early March. This reflected buyer concerns about the potential supply shortages that could emerge if Russian producers were unable to deliver potash to importers because of the Russia-Ukraine conflict. Despite the seasonal lull, enquiries shot up at the beginning of March, and producers are in the process of offering new prices in different markets.

Key market drivers: The EU ban on Belarus potash – further economic sanctions against Belarus now ban all potassium chloride products. Fallout from the Russia-Ukraine conflict – potash distributor Uralkali Trading and producer EuroChem were able to sell as normal, as of the beginning of March. But Russian potash customers may already be looking for alternative sources.

NPKs: Key buyers in west and central Europe stepped into the market for NPKs at the beginning of March amid fears of a supply shortage for the upcoming spring application season and rising prices. Buyers in Germany and Central Europe readily accepted prices which they deemed to be too high in late February. Prices have been rising throughout early March. Offers for 15-15-15 in Germany now stand at €680/t fca Hamburg.

Outside Europe, the market is still largely in wait-and-see mode following the start of the Russia-Ukraine conflict, and the ever-expanding list of western sanctions.

Key market drivers: The likelihood of more sanctions on Russia – western nations are under pressure to impose further sanctions on Russia, while a growing list of companies are refusing to conduct business with Russian producers. Shipping companies suspending cargoes moving out of Russia – future fixtures for loading Russian NPKs are difficult to conclude as many shipping companies, including Msc and Maersk, are refusing to move Russian product.

Sulphur: Global market prices have climbed rapidly following the outbreak of the Russia-Ukraine conflict. The market remains in wait-and-see mode due to the fluid situation around tightening sanctions.

F.o.b. pricing has seen substantial lift, due to supply concerns, while cfr offers also continue to climb. Rapid bunker price increases have lifted freight costs globally, a factor which has also raised cfr offers. The gap between current offer levels and previously concluded business has become sizeable. Offer levels at the beginning of March were broadly quoted at $400-420/t cfr China and India, versus the Qatar March price of $333/t f.o.b. which equates to mid-$390s/t cfr south China or higher.

Key market drivers: Sanctions against Russia have created uncertainty on fertilizer and sulphur export availability from the region. The Russia-Ukraine conflict has also cut off significant ammonia and wheat export availability.

OUTLOOK

Urea: The outlook is understandably volatile. Trade flows will eventually adjust across products, as market participants adapt to the new difficulties in trading Russian fertilizer. But that is still likely to take a considerable time and, in the interim, supply is tight.

Ammonia: The market is braced for higher pricing. An increase in east to west shipments or demand destruction could bring some relief to the supply balance.

Phosphates: The outlook is volatile. Phosphate prices are set to continue rising, pressured by both raw material costs and tight availability. EU markets are likely be hit hardest by the constricted supply, if buyers avoid Russian manufactured products.

Potash: Higher potash prices around the world are expected. Producers will increase offers while Russian supply remains a concern for market participants. Ever tighter supply will mean buyers are forced to pay more. However, demand destruction created by inflated prices is already starting to occur, suggesting that price ceilings may emerge over the coming weeks.

NPKs: While there is still much uncertainty, NPK prices are almost certain to rise on the back of surging feedstock costs. Fears of a supply shortage in the west will also support higher pricing. In the east, meanwhile, prices are coming under pressure, as buyers are reluctant to pay at current levels and consequently demand destruction is taking place.

Sulphur: Pricing is set to firm in the coming weeks. The logistical bottlenecks caused by sanctions are expected to maintain a tight market globally. Redirected trade flows may also result, potentially leading to price discrepancies between regions. ■

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EUROPE

EuroChem makes offer for Borealis' nitrogen business

EuroChem has made a binding offer for Borealis Group's fertilizer, melamine and technical nitrogen business.

The sale to EuroChem includes production sites across Europe and an accompanying sales and distribution network. These are valued at €455 million.

Austrian-headquartered Borealis is a key European producer and supplier of straight nitrogen and complex NPK fertilizers. The company manufactures ammonium nitrate (AN) in France and calcium ammonium nitrate (CAN) in Germany. It also operates around 60 warehouses across the continent with a holding capacity of 70,000 tonnes.

Borealis is jointly owned by Austrian petrochemicals company OMV (75%) and Abu-Dhabi based Mubadala (25%). It has been seeking a buyer for its European nitrogen business since February 2021.

The company owns and operates five European fertilizer production plants. Three of these plants are located in France, one in Germany and another in Austria. Sales volumes from these sites totalled 3.9 million tonnes in 2020, generating revenues of €908 million. This sales volume includes approximately 0.8 million tonnes of technical nitrogen solutions and around 150,000 tonnes of melamine. The five nitrogen production sites supply the market through an established distribution network in France and Central and Eastern Europe, partly located along the Danube River.

Borealis' largest fertilizer production site is in Linz, Austria. This produces ammonia, nitric acid, urea, NPKs and CAN.

Despite the planned divestment, Borealis is retaining its large ownership stake (77.4%) in Rosier and its two production sites in Moustier, Belgium, and Sas van Gent, the Netherlands. Rosier is a major manufacturer of speciality NPKs and liquid and water-soluble fertilizers.

"The addition of the Borealis nitrogen business to our portfolio, once approved, will strengthen our foothold considerably in such a key market as Europe," said Vladimir Rashevskiy. EuroChem Group's CEO. "We are delighted with the results of our negotiations, and look forward to creating opportunities for further growth in the European market together with Borealis' impressive management team."

If approved, the acquisition will significantly expand EuroChem's European production assets. These include the Lifosa DAP/NPS plant in Lithuania, plus NPK and nitrates units in Antwerp, Belgium. The company also owns and operates its Russian fertilizer production assets at Belorechensk, Kingisepp, Novomoskovsky and Nevinnomysskiy. EuroChem is also a relatively recent new potash market entrant, having developed the large-scale Usolskiy and VolgaKaliy mines in Russia and brought these into production in recent years.

As *Fertilizer International* was going to press, however, news emerged that Borealis was likely to reject EuroChem's bid, as a consequence of the war in the Ukraine and tightening western sanctions. ■

Yara halts ammonia production in France and Italy

Yara has stopped production at its Ferrara (Italy) and Le Havre (France) ammonia plants.

The two plants have a combined annual capacity of one million tonnes for ammonia and 0.9 million tonnes for urea.

The decision to temporarily cease production was made on 9th March in response to record European natural gas prices. These have skyrocketed following Russia's invasion of Ukraine on 24th February.

Yara said its European ammonia and urea production assets were likely to be operating at approximately 45 percent of capacity, taking into account optimisation and maintenance work at other sites.

"Yara will continue to monitor the situation and to the extent possible use its global production system to keep supplying customers and secure continuity in food supply chains, but curtailing production where necessary due to challenging market conditions," the company said in a statement.

Yara, like many European producers, was forced to cut ammonia production in response to record high natural gas prices in early October last year. Ammonia production costs became unsustainable for most market players and, consequently, units across the region ceased production and were idled indefinitely (*Fertilizer International* 505, p8).

As a consequence, the company's European ammonia production had been operating at approximately 30 percent (circa 370,000 tonnes) below capacity from September to November 2021. Most of this production did, however, eventually come back on stream by mid-December as gas prices eased (*Fertilizer International* 506, p9).

RUSSIA

TOAZ shutters four ammonia plants

Russia's Togliattiazot (TOAZ), the world's largest ammonia exporter, has shut down four ammonia units and reduced operating capacity at a further three units.

The company announced the major production curtailment on 25th February. Simultaneously, it also suspended pipeline movements of ammonia to the Black Sea because of the "safety of people living in the area of the ammonia pipeline".

TOAZ usually produces three million tonnes of ammonia and nearly one million tonnes of urea annually. Limited ammonia production would continue to maintain urea production and fulfil contracted tonnages that are moved by rail, the company said.

TOAZ exports ammonia to Morocco and Turkey via pipeline through the Black Sea port of Yuzhny. However, both the port and its pipeline closed on 24th February following Russia's invasion of Ukraine.

Russia exported $2.14 billion in ammonia and fertilizers to Europe in 2020, according to UN Comtrade data. This total includes $250 million in trade to Turkey and $240 million in trade to Morocco.

Yuzhny itself is responsible for distributing around one-fifth of seaborne ammonia west of the Suez Canal.

Sources told S&P Global Platts that Moroccan phosphates producer OCP could lose access to 40 percent of its ammonia sourcing due to the ammonia shutdown.

In the immediate aftermath of the TOAZ plant and pipeline closures, the cfr Northwest Europe price for ammonia reached $1,150/t and the Black Sea f.o.b. price reached $1,125/t, S&P Global Platts said.

NORWAY

Linde wins electrolyser contract for Porsgrunn plant

Linde Engineering has secured a contract from Yara International to build a 24-MW electrolyser as part of a green ammonia demonstration project at the company's Porsgrunn production complex in Norway.

This large-scale electrolyser will produce around 10 t/d of green hydrogen. This in turn will be used to generate around 20,500 tonnes of green ammonia annually. Green ammonia production at this scale will cut Porsgrunn's CO_2 emissions by around 41,000 t/a by avoiding hydrocarbon-based production at the site. Norwegian government investment agency Enova has awarded Yara NOK 283 million to help bankroll the project (*Fertilizer International* 506, p8)

"The project aims to supply the first green ammonia products to the market as early as mid-2023, both as fossil-free fertilisers, as well as emissions-free shipping fuel," said Magnus Ankarstrand, president Yara Clean Ammonia.

The green hydrogen system will use proton exchange membrane (PEM) technology from UK company ITM Power. Casale is designing the accompanying ammonia converter for Yara.

CANADA

Nutrien signals potash production boost

Nutrien, the world's biggest potash miner, could boost production by up to 29 percent in future, its CEO has told *Reuters*.

The potential move would depend on the extent and longevity of any sanctions placed on rival Belarusian and Russian potash producers.

Interim chief executive Ken Seitz, in his first interview since his appointment in January, said Saskatchewan-based Nutrien could restart up to four million tonnes of idled annual potash capacity, depending on whether economic sanctions were likely to be lengthy or not.

"If these are short-lived events, we don't want to spend all kinds of money staffing and opening up ground," Seitz told *Reuters*. "If this is going to be a longer-term problem for the market, we will absolutely do that, we will absolutely step into that void."

As a first step, Nutrien could raise output by between 700,000 tonnes and one million tonnes in the second half of 2022, Seitz confirmed, as this output increase would not incur any major expense. However, he did not confirm how soon the company might restart its other idled capacity.

Seiz's comments were made on 1st February, several weeks before Russian troops crossed the border into Ukraine on 24th February. Since then, Russia's invasion of its European neighbour has deepened global potash availability concerns.

Currently, Nutrien produces almost 14 million tonnes of potash annually, equivalent to around 19 percent of global sales. Demand for Canadian potash is strong at present. Canpotex, the Canadian export consortium jointly owned by Nutrien and Mosaic, is fully committed on sales until the end of March.

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Despite strong market demand, global operational capacity still exceeds this by more than 10 million tonnes, according to BMO Capital Markets.

"In a normal situation, the potash market is oversupplied," BMO analyst Joel Jackson told *Reuters*. "If I was Nutrien, I would probably hold back on my decision to expand too much too fast."

Potash prices moved upwards in early March edging closer to their previous 2008 peak value – driven higher by commodity market fears over the impact of Russia's invasion of Ukraine. Prices had already climbed fast this year following the imposition of Western sanctions against Belarus.

Russia's Uralkali and the Belarus Potash Company (BPC) together account for more than one-third of global potash sales. Additional Canadian production would therefore only replace a fraction BPC's output, which is typically around 12.5 million annually.

UNITED KINGDOM

Anglo set to invest £440m in Woodsmith project in 2022

Anglo American expects to invest £440 million in its UK Woodsmith mine project this year.

The under-construction polyhalite mine is located in North Yorkshire near England's North Sea coast.

The investment was announced by chief executive Mark Cutifani during the company's annual results at the end of February. He also provided investors with an update on the project's progress.

Cutifani said that Anglo had invested nearly £390 million in the polyhalite mine project in 2021. Excavation of the mineral transport tunnel from Teesside had exceeded 18 kilometres by the end of the year, beyond the intermediate access shaft site at Lockwood Beck.

The Lockwood Beck shaft is also complete, having reached its target depth of 383 metres, and shaft lining is currently under way. At the mine head itself, shaft boring has started in the services shaft, while progress is also being made on the production shaft infrastructure.

The company is currently working on a number of improvements to the project's design. These will ensure the project meets Anglo American's safety and operating standards, as well as its commercial objectives, given the very long life of the mine.

"This is a world class fertiliser project and a business segment that we are even more positive about than when we acquired the project," Cutifani said. "This is a very long-life asset and a product for which we see increasing market interest as the commercial trials demonstrate its crop yield and numerous environmental qualities, so we are going to take the necessary time to get every aspect of the design right to match our long-term vision and value aspirations."

The latest tranche of investment coincides with the appointment in January of Tom McCulley as the new CEO of Anglo American's Crop Nutrients business. Under his leadership, the company will continue to develop the project's detailed design engineering this year, with expected changes to the phasing of work, particularly at the Woodsmith mine site.

PHOTO: ANGLO AMERICAN

The under-construction Woodsmith polyhalite mine in the UK.

INDIA

Nuberg secures NPK expansion project from FACT

Nuberg has won an engineering, construction and procurement (EPC) contract from Fertilisers and Chemicals Travancore Limited (FACT) for a 1,650 t/d NPK fertilizer project in India.

The brownfield expansion will be delivered for the company's FACT-Cochin division and built at the Ambalam Edu production site in the Ernakulam district of Kerala state. This will increase the site's total NPK fertilizer production capacity to 3,650 t/d

Indian-based Nuberg is a leading global EPC and turnkey project management company.

The expansion will incorporate pre-neutralizer with pipe reactor (PN+PR) technology licensed from INCRO. It is scheduled to be completed by mid-2023.

The extra capacity will be mainly dedicated to two products: NPK 20:20:0:13 production at a rated capacity of 75 t/h using pre-neutralizer (PN) technology and DAP 18:46:0 using the PN+PR technology. The process will consume ammonia, phosphoric acid, sulphuric acid and urea as feedstocks.

Nuberg has also been contracted to carry out the design and detailed engineering work to enable the owner to manufacture different NPK grades in future (e.g., 10:26:26, 16:20:0, 28:28:0, 12:32:16 and 14:35:14).

"We are thankful to the Government of India and FACT for entrusting another turnkey project to our engineering capabilities and EPC services and solutions," said A K Tyagi, CMD, Nuberg Engineering Ltd. "This project serves as a prime example of the successful combination of Nuberg EPC's global expertise and local knowledge to offer a complete turnkey solution."

FRANCE

Tessenderlo plans new organic fertilizer plant

Tessenderlo Group is planning to construct a new production line for organic fertilizers at its Akiolis manufacturing plant in Vénérolles, Aisne, France.

The new line will produce organic pellets for Tessenderlo's Violleau business unit. It is being built in response to rising demand for organic fertilizers. The new plant should become operational in the first-quarter of next year.

By incorporating valorised meat and bone meal and animal proteins, the organic fertilizers from the new manufacturing line will offer nutrients (nitrogen and phosphorus) at high concentrations, a characteristic that is particularly valued by the organic farming sector.

Tessenderlo Group created Violleau in 2021 as a new high-growth business unit to support its expansion into organic agriculture in Europe. Violleau specialises in the production of organic products from animal and vegetable matter, and the commercialisation of biocontrol products.

Violleau's French-manufactured organic and organo-mineral formulations, offered as compost or pellets, can be used in both organic and conventional agriculture. Applications include field crops, vineyards, arboriculture and market gardening.

"With the new production line in Vénérolles, we are further expanding our local presence in the organic fertilizer market. Our new production line responds to the growing demand for organic fertilizers from the European market, which is in line with the European Union's Farm to Fork Strategy," said Didier Coppieters, GU Director of Violleau.

"At the same time, we will also ensure a better service to the agricultural market in Northern France and Belgium thanks to the strategic location in Vénérolles," added Dominique Billard, general manager, Violleau France.

Violleau already operates a production plant at La Ronde en Deux-Sèvres inn France.

MOROCCO

Koch to acquire half share in JFC III

Koch Ag & Energy Solutions (Koch) has signed an agreement with OCP to acquire a 50 percent share in the Jorf Fertilizers Company III (JFC III) production unit.

JFC III owns and operates a 1.1 million t/a capacity integrated phosphate fertilizer production unit at the Jorf Lasfar fertilizer production complex, Morocco. JFC III will operate as a OCP/Koch joint venture on closure of the deal.

The massive Jorf Lasfar fertilizer complex is the world largest phosphate fertilizer production site.

Products manufactured at JFC III will be jointly marketed by OCP and Koch Fertilizer, LLC. Both companies will also collaborate on OCP's ammonia and sulphur supply and take advantage of their combined logistical capabilities to ship fertilizers from Morocco.

"The venture builds on Koch's long-standing relationship with OCP and a shared vision to expand phosphate offerings globally," said Scott McGinn, Koch Fertilizer executive vice president. "We are excited to grow Koch Fertilizer from a predominately nitrogen producer and distributor by offering a larger suite of phosphate products to our customers. We look forward to collaborating with OCP and leveraging the unique capabilities of both companies."

"Our collaboration with Koch is now entering a new phase after more than a decade of commercial relationship," said Soufiyane El Kassi, OCP's chief growth officer. "Koch is a key strategic partner with a shared vision on how to best serve farmers and agriculture. Through this transaction, we are happy to welcome another leading industrial player such as Koch to Morocco."

Go-ahead for the new Koch/OCP venture will require the clearance of customary closing conditions. ■

FERTILIZER INDUSTRY NEWS

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People

The inclusion of several high-profile Russian business leaders on an EU sanctions list in March has led to round of high-level resignations from leading Russian fertilizer producers.

EuroChem Group announced that its owner **Andrey Melnichenko** had resigned from its board of directors and had also withdrawn as the company's "main beneficiary" with effect from 9th March.

"The move follows Mr Melnichenko's inclusion in an EU sanctions list, and was taken to ensure EuroChem is able to continue providing millions of people around the world with nutrients for agriculture, helping to underpin global food security," EuroChem said in a statement.

Uralchem JSC also announced changes to its ownership structure on 10th March. **Dmitry Mazepin**, who previously held a 100 percent stake in parent company Uralchem Fundamentals LLC, has reduced his ownership to a non-controlling 48 percent holding. He also resigned as CEO of Uralchem to be replaced by **Dmitry Konyaev**, previously the chair of Uralchem's board of directors. Former deputy chair **Dimitry Tatyanin** was named as Uralchem's new chair.

PJSC PhosAgro's board of directors accepted the resignation of **Andrey A Guryev** as CEO on 10th March and announced the appointment of **Mikhail Rybnikov** as his replacement. At the same time, three individuals, Xavier Rolet, Andrey A Guryev and Andrey G Guryev, also stepped down as directors of the company.

Thorsten Boeckers left his role as Chief Financial Officer (CFO) of German-headquartered potash and salt producer K+S at the end of February. **Christian Meyer** will become the company's new CFO in spring 2023. Until then, the chairman of K+S Burkhard Lohr is taking on the role on a transitional basis.

PHOTO: K+S

The chairman of K+S, Burkhard Lohr, has temporarily taken on the role of company CFO.

"We would like to thank Mr Boeckers for his work over the past years. During his service on the board of executive directors, he successfully contributed to the reduction of debt and the restructuring of the company. We wish Mr Boeckers all the best for the future, both in his professional and private life," said Andreas Kreimeyer, chairman of K+S's supervisory board.

Dr Kreimeyer added: "We are looking forward to working with Dr Meyer. He is a renowned financial expert with many years of experience as an auditor and tax advisor. We welcome him as a future member of the board of executive directors in the K+S team."

In a change of leadership at Anglo American's Woodsmith project, **Tom McCulley** is the new CEO of Crop Nutrients. He replaces **Chris Fraser** who, after 12 years of leading the UK-based polyhalite project, stepped aside in January to take on a strategic projects role at Anglo American.

The change was made following Woodsmith's integration into Anglo American and ahead of the full project execution phase. McCulley previously led the development of Anglo's Quellaveco copper project in Peru.

Mark Cutifani, Anglo American's CEO, said: "We are enormously grateful to Chris Fraser for his founding vision over some 12 years in bringing Woodsmith to reality – a project with sustainability principles at the core of its design and in the product itself. His dedicated leadership in progressing the project this far and integrating it into our organisation, and doing so while making considerable construction progress during the upheavals of the pandemic, also deserves enormous credit. As we move towards full project execution, it is a natural time for Chris to step into a new role and I'm pleased that we will benefit from his experience as he works with us on a number of strategic projects."

Cutifani added: "I am delighted that Tom McCulley, currently CEO of Anglo American in Peru, who has so skilfully steered our Quellaveco copper project to a point of pre-commissioning, on time and on budget, will now lead the development of Woodsmith as CEO of our Crop Nutrients business. I am confident that Tom and his team will finalise our plans and then deliver the project we all envisage safely and with great precision."

Calendar 2022

! **The following events may be subject to postponement or cancellation due to the global coronavirus pandemic. Please check the status of individual events with organisers.**

MARCH

21-23

Argus/CRU Fertilizer Latino Americano 2022, MIAMI, Florida, USA
Contact: Argus Media
Tel: +44 (0)20 7780 4340
Email: conferences@argusmedia.com

23-24

European Mineral Fertilizer Summit, London, UK
Contact: Hayden De Menezes
Tel: +44 (0)203 141 0607
Email: h.demenezes@acieu.net

28-30

Nitrogen+Syngas Conference 2022, BERLIN, Germany
Contact: CRU Events
Chancery House, 53-64 Chancery Lane, London WC2A 1QS, UK
Tel: +44 (0)20 7903 2444
Email: conferences@crugroup.com

28-31

IFA, Global Sustainability Conference, Virtual event
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

MAY

12-13

IFS Technical Conference, AMSTERDAM, The Netherlands
Contact: Steve Hallam
Tel: +44 (0)1206 851819
Email: secretary@fertiliser-society.org

30 MAY - 1 JUNE

IFA 2022 Annual Conference, VIENNA, Austria
Contact: IFA Conference Service
Tel: +33 1 53 93 05 00
Email: ifa@fertilizer.org

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Fertilizer Latino Americano welcomes you to Miami!

Argus in collaboration with CRU will convene the 2022 Fertilizer Latino Americano conference in Miami, Florida, 21-23 March.

After more than two years of uncertainty and a pause on live events, Argus in conjunction with CRU are excited to bring FLA to the vibrant and exciting US city of Miami at the Hilton Miami Downtown. The conference will bring the industry together in person once more at Latin America's largest fertilizer networking event with 600-700 delegates expected to attend.

The return of this premier Latin American fertilizer event should not be missed. Especially with a new location for 2022 and a renewed focus on the agenda for technology, innovation and sustainability. This year's conference includes an 'Added Value Fertilizers Americas Forum' together with plenty of networking opportunities at our renowned evening receptions.

Below, three leading industry experts who will be presenting at FLA this year share their thoughts on the market outlook, emerging trends and the latest innovations. They also explain what they hope to gain from attending this year's conference – particularly the importance of the event to themselves and the whole fertilizer industry.

Alzbeta Klein, director general, International Fertilizer Association (IFA)

Which current and emerging trends do you predict will promote growth within the Latin American fertilizer market?
The Latin American market is a vital contributor to feeding the world. Several countries in the region have grown to become world-leading exporters of several major crops in recent years, and the agricultural sector accounts for a significant portion of GDP.

To support and further grow this contribution, fertilizers are needed to maximise yields in a sustainable way. The region is forecast to see some of the fastest rates of fertilizer consumption in the coming years and this has attracted several international fertilizer companies to the region, investing in distribution and retail networks.

There is pressure for the fertilizer industry to become more sustainable due to global climate targets. How do you see this creating opportunities within the market?
Sustainability is the most important business opportunity that we have ahead of us, and leaders in our industry are harnessing technology to make it happen.

In fertilizer production, companies are already working hard on energy efficiency in their plants, carbon capture and reuse, and investing in green and blue ammonia and hydrogen. Beyond 2030, it is likely that regions with abundant solar or wind power energy could emerge as cost-efficient locations for green hydrogen production.

In fertilizer use, there are great opportunities to increase nutrient use efficiency, including through innovations in precision agriculture and the development of novel plant nutrition products and application methods, as well as carbon storage in soils.

How to pay for this? The 2015 Paris Climate Agreement created an impetus to finance a wide range of initiatives to limit global warming. Total issuance of sustainability-linked debt has surpassed $1 trillion and is rising.

Which solutions do you see helping the fertilizer industry meet climate targets and increase sustainability?
The adoption of best available technologies and use of renewable power to generate ammonia will help to decarbonise fertilizer production. In October last year, the International Energy Agency, together with EBRD and IFA, released the *Ammonia Technology Roadmap* – a guide to how nitrogen fertilizer producers can reduce up to 90 percent of carbon dioxide emissions from ammonia production between now and 2050.

Nutrient capture and recycling innovations, meanwhile, can make fertilizer production more circular and help ensure that more nutrients are returned to the field.

The more efficient and effective use of plant nutrients can be achieved through specialty slow and controlled-release fertilizers, digital precision agriculture tools and biological solutions such as biostimulants. These can all help farmers and the fertilizer industry to become more sustainable.

Green financing, an enabling policy for environmental partnerships with governments and players across the agricultural value chain, are needed to support and accelerate all of the above.

How do you see global policies helping to set the direction for Latin American fertilizer markets in the energy transition?
Some governments have implemented carbon pricing and are subsidising innovation aimed at supporting the sector's transition, while producers have established emission reduction targets and are pursuing research and development initiatives around the world.

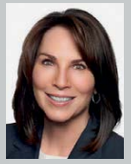
Latin American-based producers have the know-how and resolve to develop their own transition strategies, including how to implement low emission technologies. But any successful transition will have to involve close co-operation and partnerships between the private and public sector, and adequate financing.

What do you hope to gain from attending FLA 2022 in Miami? Why do you think this event is important for the industry?
I am here to listen, learn and see how we can develop relationships that support what drives us – helping to feed the world sustainably.

We are keen to grow our membership in Latin America and can offer companies in the region the leading source of fertilizer and raw materials statistics in the world with IFASTAT, as well as access to our networks and expertise on sustainability, in public affairs and in the latest plant nutrition science through IFA events and initiatives for the sharing of information and best practices.

Just as importantly, Latin American companies have a lot of knowledge to give to others and I look forward to learning more about the latest developments and connecting with companies in the region.

Corrine Ricard, president, Mosaic Fertilizantes



What current and emerging trends do you see giving fertilizer markets an upside in 2022?
Currently trade-related impacts such as sanctions, countervailing duties and export limitations are interrupting supply chains and causing concerns in the Brazilian markets today. Additionally, I believe that environmental, social and governance pressures will continue to be a rising trend in our discussions of agriculture in Brazil.

What are the biggest challenges and opportunities currently facing the Brazilian fertilizer market?
Rapid expansion of demand for crop inputs in Brazil has exceeded the infrastructure capability for importing in an efficient manner. We will see further investments in ports, rail lines, transshipment facilities and other infrastructure to improve consistency and reliability of supply of fertilizers.

How will the drive for more sustainability and reducing environmental impacts affect the market and global food value chains?
We believe there will be an increased focus on soil health and sustainable agricultural practices, and this aligns with our industry's 4R stewardship programmes. Balanced crop nutrition, practices which respect environmentally sensitive areas, commitment to improving degraded pasture lands and a focus on rebuilding the long-term health of our soils – all while ensuring we produce adequate food, fuel and fibre for the world's needs.

What market innovations will have the biggest impact on the fertilizer market over the next few years?
Digital solutions for improved agricultural practices, improved trade and supply chain transparency and efficiency.

What do you hope to gain from attending FLA in Miami? Why do you think this event is important for the industry?
A personal connection with customers and suppliers is so important, and something we have all missed these last couple of years. I look forward to meeting in person and listening to the views of others.

Ana Dutton, head of technical services & application, Omya International

What do you think is the biggest area of growth in the added-value fertilizer market?
The biggest area for growth will come from a combination of increased precision farming practices and providing more precise, easier to use value-added products. The greater a farmer's ability to recognise the needs for these products, then the easier they are to work with and the greater the growth opportunity.

What current and emerging trends do you see giving the specialty market an upside in 2022?
Fertilizer pricing will be a main driver of specialty market growth in 2022. Products that help farmers fully realise their basic NPK investment, whether that revolves around fertilizer use efficiency or complementary nutrients to ensure yields are maximised.

How will the drive for more sustainability and creating less impacts on the environment affect the market?
We have to keep in mind that the world population is growing, and the amount of land used for agriculture is declining. More efficient productivity, where fertilizers are used when and where they are required, will be imperative if we are to meet the demands of food production. Over-fertilization and the creation of acid soils will need to be minimised or corrected to enable more efficient crop production, and be environmentally compliant with reduced greenhouse gas emissions.

What do you hope to gain from attending FLA in Miami?
It will be my first time at FLA and for me will be a great opportunity to understand how our Omya advanced soil amendment technology products fit within growers' needs for improving fertilizer efficiency and plant nutrition in order to contribute to the demand for food production.

Why do you think this event is important for the industry?
For me, and I think other participants, it will be the first opportunity to meet at a conference in person after almost two years due to Covid-19. The exchange of information and ideas is vital for the agricultural segment. It is an excellent opportunity to meet people from the fertilizer industry, learn from new research and connect with costumers. It is also an opportunity to understand what can be improved in our products, or ideas for new products.

Visit the website to download the e-book featuring the rest of the pre-conference interviews with other key industry speakers.
For more information visit: www.argusmedia.com/fla

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Brazil's fertilizer market

Debora Simoes, **Bruno Fardim**, and **Cleber Vieira** of Agroconsult report on what's driving the Brazilian fertilizer market currently and look at prospects for the coming year.

2021 – a remarkable year

2021 proved to be a remarkable year for fertilizer consumption in Brazil. Fertilizer product deliveries reached 45.96 million tonnes, Agroconsult estimates, setting a new record high. To put this in context, this total is 5.4 million tonnes up on 2020 – the previous high – an increase that is equivalent to the entire fertilizer consumption of Argentina, Latin America's second largest fertilizer market after Brazil.

This was the second year in a row that Brazil's agricultural sector registered a double-digit growth in fertilizer consumption (Figure 1). This growth was largely driven and sustained by the rapid improvements in farm profitability during the 2020/21 and 2021/22 crop seasons. This, in turn, was due to a combination of the price upsurge for leading agricultural commodities during the Covid-19 pandemic and the falling exchange rate of Brazil's currency (Brazilian Real, BRL) versus US Dollar.

The extremely high soybean profits in Mato Grosso state, one of the Brazil's main agricultural regions, in 2020/21 and 2021/22 provide a good example (Figure 2). Average profits in the latest 2021/22 crop year have tripled from their 2019/20 pre-pandemic level.

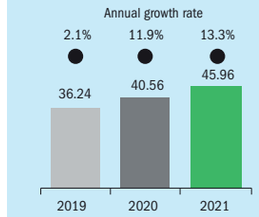
Higher earnings in 2020/21, together with positive prospects for the coming season, enabled Brazil's farmers to pre-buy their 2021/22 crop season fertilizers in late 2020 and at the start of 2021, using additional cash to take advantage of the more favourable barter ratio, i.e. the amount of harvested crop necessary to buy one tonne of fertilizer (Figure 3).

By December 2020, about 40 percent of the fertilizers for delivery and use in 2021 had already been purchased in advance, according to Agroconsult's periodic survey with sales representatives. This advance purchase rate by farmers would typically be below 10 percent in normal years.

Imports at a record high

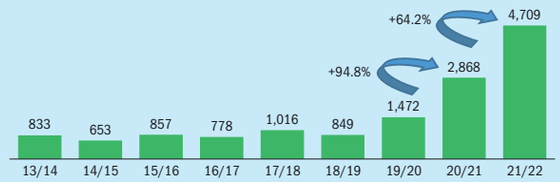
On the supply side, the Brazilian fertilizer market remains highly import-dependent. This makes logistics a critical factor in ensuring fertilizers are delivered to farmers on time and at a competitive cost. Overall fertilizer imports reached a record high of 39.15 million tonnes in 2021, equivalent to some 83 percent of fertilizer supply. Fertilizer imports through Brazilian ports rose by 6.3 million tonnes year-on-year in 2021 – creating operational challenges across the whole value-chain. Consequently, Brazil faced issues in distributing these imports to meet the exceptional demand levels seen in

Fig. 1: **Brazil's fertilizer product deliveries, 2019-2012, million t**



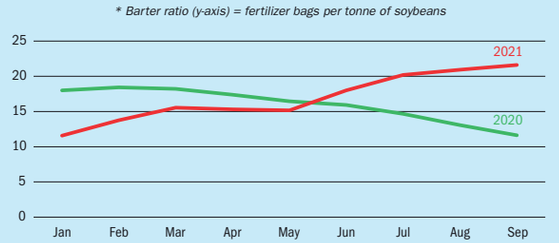
Source: Agroconsult

Fig. 2: **Average soybean operational profits (BRL/ha) in Mato Grosso state, 2013/14-2021/22**



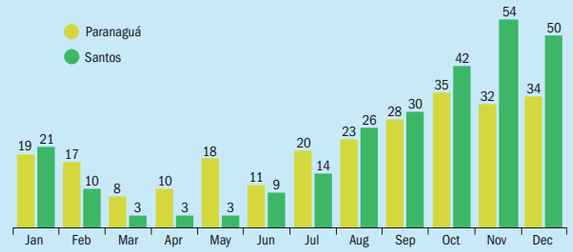
Source: Agroconsult

Fig. 3: **Average monthly soybean barter ratio* in Sorriso, Mato Grosso state: 2021 vs 2020**



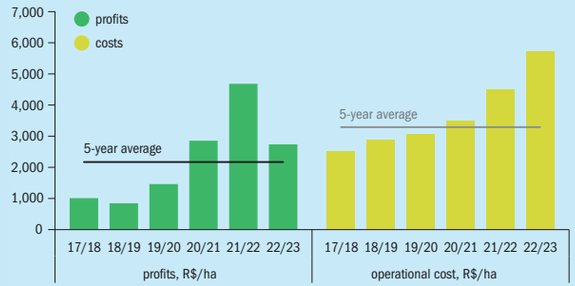
Source: Agroconsult

Fig. 4: **Waiting time in days at two major fertilizer unloading ports, Paranagua and Santos, during 2021**



Source: Agroconsult

Fig. 5: **Expected farm profits and operational costs for the 2022/23 crop season (BRL/hectare). Example for soybean farming in Mato Grosso state**



Source: Agroconsult

2021. Unloading delays in ports (Figure 4), late deliveries to farms, and even shortages of specific types of NPK, were some of the common complaints reported to us last year.

Prospects for 2022

In the current geopolitical situation, forecasting is a tough task for even the most experienced analyst. At the time of writing (end of February 2022), in the immediate aftermath of Russia's invasion of Ukraine, prospects for 2022 fertilizer deliveries to Brazil remain positive.

Agroconsult is forecasting that Brazilian demand may reach 46.53 million tonnes in 2022 – up 1.2 percent on 2021 and a year-on-year increase of 574,000 tonnes. With average fertilizer application rates expected to remain flat, this growth in fertilizer use is expected to be largely driven by a 1.7 million hectare expansion in the crop planting area (Table 1).

While farm incomes for 2022/23 still look positive – and above the five-year average – they are expected to fall by about 40 percent on the previous crop season. One reason for this is the across-the-board increases in agricultural input prices, particularly for fertilizers, now facing Brazil's farmers as they plan for the 2022/23 crop season. For example, the planting costs for a hectare of soybean in 2022 look set to be 27 percent higher than last year (Figure 5).

The severe drought in the south of Brazil has also been affecting farmers and the agricultural market. This region accounts for about one-third of the planted area for soybean and summer corn. Agroconsult estimates that so far this year more than 18.5 million tonnes

Table 1: **Brazil's fertilizer consumption, land area and fertilizer application rates by crop: 2021 vs 2022 forecast**

Crop	Consumption ('000 t)			Area ('000 ha)			Fertilizer use (kg/ha)		
	2021	2022	-	2021	2022	-	2021	2022	-
Soybean	18.991	19.348	357	40.802	41.727	925	465	464	-2
Summer Corn	2.333	2.274	-59	5.198	5.081	-117	449	448	-1
Winter Corn	7.243	7.346	103	15.684	16.102	418	462	456	-6
Sugarcane	4.946	5.014	69	11.557	11.594	37	428	432	5
Cotton	2.157	2.218	61	1.652	1.698	47	1.306	1.306	0
Coffee	2.495	2.496	0	2.218	2.209	-10	1.125	1.130	5
Forest	2.408	2.440	32	8.763	8.883	120	275	275	0
Others	5.388	5.399	11	16.824	17.063	239	320	316	-4
Total	45.960	46.535	574	102.698	104.357	1.659	448	446	-2

Source: Agroconsult

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of grains have been lost due to dry weather conditions. Total losses exceed 40 percent of expected production in some regions. As a result, famers in the most affected regions have registered financial losses after more than 10 years of good profits.

The drought could also hit fertilizer demand. Most summer crops in the worst affected regions, for example, were incapable of extracting much of the applied potassium. It is therefore expected that the remaining residual K still available in the soil will be sufficient to meet the February-June demand of this year's winter corn crop.

Looking ahead, it is the 2022/23 crop season and the start of planting in September that will determine the size of the fertilizer market this year. At the time of writing, farmers in the south of Brazil have not yet decided if they will reduce their average fertilization rates for 2022/23, as they usually wait until the end of the current harvest season in May-June before making this decision. Currently, Agroconsult still believes that average fertilizer rates in the region – noted for the strong presence of agricultural cooperatives – will be maintained due to credit availability. This is due to the money received from insurance companies as well as the positive financial results obtained in previous years.

Logistics is another important factor to highlight. Delivering 46.5 million tonnes of fertilizer to Brazil's farmers in 2022 will require a concerted effort by all participants in the fertilizer supply chain. With imports expected to reach 40.0 million tonnes this year, famers, blenders, fertilizer producers, port terminals and logistic companies will all need to work together and plan in advance. This will be necessary to avoid the port unloading delays seen in 2021 and minimise the risk of product shortages.

In fact, it would be an important and great achievement if the share of imported volumes needed to cover demand until September was already domestically available mid-year to build up inventories. This is especially true in 2022, given the challenges of the international market, and the risks surrounding Russian and Belarusian fertilizer supply to the Brazilian market (see box). ■

Authors' note

The information in this article was correct at the time of writing (end-February). However, future Brazilian fertilizer supply could be influenced by the deepening conflict in the Ukraine, which has created a fast-moving and volatile market situation.

Russian fertilizer supply to Brazil

At the time of writing, although Russia's fertilizer sector has not been specifically targeted by the economic sanctions imposed by western countries, the war in Ukraine itself could put Brazilian fertilizer supply at risk by creating logistical obstacles and affecting Belarus and Russia's ability to export.

Current situation

Russia plays an important role in global fertilizer trade, having a significant market share of international nitrogen, phosphorus and potash exports. Brazil, in particular, is highly dependent on Russian fertilizer supply. Russia and Belarus are strategic fertilizer trading partners with Brazil. Together, they supply about one-third of the country's total fertilizer imports (Figure 6) – 28 percent for nitrogen, 45 percent for potash and 15 percent for phosphate fertilizers.

While other countries could step in to replace current Russian supply to Brazil, fertilizer producing companies would have to mobilise quickly. As there would be an urgent need to rapidly settle contracts with new partners and reorganise logistics to avoid any subsequent supply problems. Any delays could raise the risks to Brazilian market supply in 2022.

What is the invasion of Ukraine likely to change?

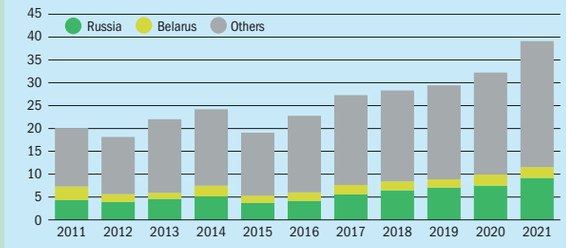
International fertilizer prices are likely to rise again. The risk of a supply crisis is also likely, especially if the conflict affects shipments by creating logistical bottlenecks, or if barriers to Russian fertilizer exports are introduced as part of tougher economic sanctions.

If western countries impose further trade sanctions, Russia could also retaliate by cutting the natural gas exports the west needs for nitrogen fertilizer production, resulting in shutdowns and output cuts in the European Union.

Spring demand in the northern hemisphere (typically 80 percent of global fertilizer consumption) will have been largely met by the end of the year's first quarter – enabling the 2022/23 crop season there to start with few impediments. Whereas countries in the southern hemisphere, including Brazil, are likely to have to deal with the consequences of the conflict such as higher prices and possible supply shortages.

There is a possibility that barter transactions between fertilizers and grains – which have been improving on the back of higher soybean and corn prices – may become unfavourable to Brazilian farmers. If that were to happen, the likelihood of a drop in Brazil's fertilization rates for the 2022/23 crop season, and a corresponding downgrade to current market projections for 2022, is a risk that cannot be ignored. ■

Fig. 6: **Brazil's fertilizer imports (million t), 2011-21**



Source: Secex/Brazil

Avocado fertilization

Mexico supplies more than half of the international avocado market. This oil-rich, nutritious fruit is also widely grown in Colombia, the Dominican Republic and Peru. We look at the nutrient needs of this regionally-important cash crop.

Central American native

The avocado (*Persea americana*) is a native of Central America and the West Indies. Written accounts date back to the early 1500s when the Spanish conquistadors encountered extensive avocado growing by the Aztec and Incas. The fruit was later introduced into Florida, California and Hawaii in the early 1800s and is now cultivated widely globally where growing conditions are suitable[1].

World production of avocados exceeded eight million tonnes in 2020, having more than doubled in a decade (Figure 1). Four Latin American and Caribbean countries – Mexico, Colombia, the Dominican Republic and Peru – dominate production being collectively responsible for almost 60 percent of global output (Figure 2). Mexico is both the world's lead avocado producer (2.4 million tonnes) and exporter (1.3 million tonnes).

Global exports of avocado reached 2.3 million tonnes in 2020. Peru, Colombia and Kenya are the three emerging exporters with a combined global trade share of 25 percent The US is the largest import market. The EU also accounts for a substantial share of world consumption.

Looking ahead, world avocado production is likely to expand to 12 million tonnes by 2030, according to OECD-FAO projections, triple its 2010 level.

Heavy fruiting evergreen

Avocado is evergreen tree whose growth habit varies from tall and upright to well-shaped and spreading. The fruit has one large central seed and can vary greatly in size, shape, colour, texture and flavour. The edible part – the flesh between the seed and the skin – is cream to yellowish-green in colour with the consistency of soft butter when ripe. The fruit is unusual in that it does not ripen until harvested and can be left on the tree for some time on reaching maturity[1].

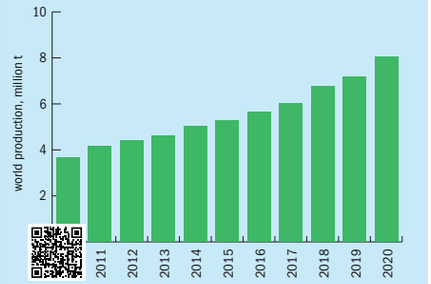
There are three 'races' of avocados – Guatemalan, Mexican and West Indian – as follows[1]:

- The **Mexican** avocado is the hardiest and most tolerant of the cold. Mature trees can withstand temperatures down to minus five centigrade without damage, although its flowers are frost-prone. *Zutano*, *Bacon*, *Shephard* and the rootstock *Duke* are all Mexican types.
- The **Guatemalan** avocado originated in the tropical highlands and requires a cool tropical climate without extremes of humidity and temperature. Trees can withstand light frosts down to minus 2°C. *Gwen* and *Reed* are two common varieties.
- The **West Indian** avocado originally came from the humid lowlands of tropical Central America. This race is the most tolerant to saline soil/water conditions while being the least tolerant of cold weather.

Despite their distinctive features, all three avocado races can be cross-pollinated to develop new varieties. *Hass* – the most popular variety grown today – is one such hybrid.

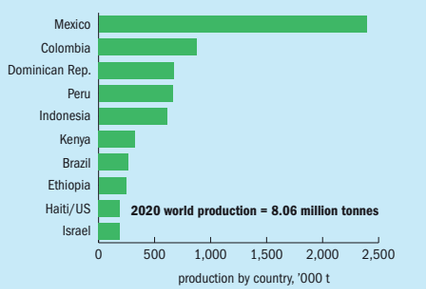
Avocados can contain from between 5-40 percent oil, the percentage depending on the variety and the growing and seasonal conditions. Only ripe olives have a higher oil content. This oil is rich in mono and poly unsaturated fatty acids with *Hass* fruit containing up to 83 percent, for example. Avocados are also vitamin-rich with high levels of B complex, vitamins A and E, folic acid and iron. The fruit is also cholesterol free.

Fig. 1: **World avocado production, 2010-2020**



Source: Statista/FAO

Fig. 2: **Top 10 avocado producers, 2020**



Source: Statista/FAO

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Australian fertilization practice

Young trees

These require small amounts of fertilizers supplied regularly, particularly on sandy soils. Fertilizers can be spread evenly around the tree by hand. Applying a nitrogen fertiliser such as urea every eight weeks at 20 grams per tree, for example, encourages vegetative growth. Organic fertilisers (e.g., 10 litres of matured poultry manure per tree) can also be applied on top of the mulch layer[1].

Mature trees

NPK mixtures can be applied from the third year, based on soil/leaf analyses. This needs to take account of nutrient removal by the crop (fruit crop, root and shoot growth) and losses from leaching, soil erosion and nutrient fixation. For every one tonne per hectare of fruit yield, the total nutrient replacement under normal growing conditions is: nitrogen 7 kg, phosphorus 1.5 kg, potassium 8 kg, calcium 3.5 kg and magnesium 1.5kg. For fertigation, these total quantities can be reduced by around 25 percent as this method can deliver nutrients to plants more efficiently[1].

Nitrogen and potassium fertilizers are applied following the summer fruit drop through to the end of autumn, while phosphorus is applied four times per year. Lime or dolomite may be required in the autumn/winter to keep the soil pH within the desired 5.0-5.5 range.

Micronutrients

Boron and zinc are essential micronutrients for tree and fruit development. Boron is applied in spring (October) and again in autumn (April) when leaf levels fall below 40 mg/kg. Either *Solubor* (22 percent boron at 4 grams per square metre of ground area canopy) or *Borax* (11 percent boron at 8 grams dosage) can be used. Foliar spraying with *Solubor* (1 gram/litre) at flowering is recommended. Boron levels in leaf samples must be monitored in the autumn/winter to avoid deficiency[1].

Zinc is usually applied as zinc sulphate heptahydrate and often banded around the drip line of the tree at the end of flowering. Rates per square metre of canopy vary from 10 grams (sandy soils) to 25 grams (clay soils) per square metre[1]. ■

Mexican growing experience

In 2014, Tessenderlo Group published a handbook on avocado crop nutrition[2] in collaboration with its partners Mexico's National Institute of Forestry, Agriculture and Livestock Research (INIFAP) and the Sulphate of Potash Information Board (SOPIB). This Spanish language publication provides useful evidence and advice on avocado nutrient management using soil-applied and foliar fertilizers to increase crop productivity and quality.

The handbook is based on agronomic experience gained in Michoacan, Mexico's foremost avocado growing region. This article partly draws on this handbook and its main findings, as kindly translated into English by Nicolas White, Portfolio & Knowledge Director at Tessenderlo Kerley International.

Maintaining soil fertility in the root zone is particularly important in Michoacan. Many of the region's avocado orchards are grown on 'tupure', a deep and well drained andosol. This soil type is low in organic matter and nutrient deficient – mainly for nitrogen, phosphorus, calcium and micronutrients such as zinc, boron and manganese. Low soil fertility is compounded by high rainfall conditions[2].

Nutrient requirements

In general[3]:

- Adequate nutrition of avocados is very important for sustained performance.
- Inputs of nutrients should be increased when trees have set a heavy crop.
- Avocado trees may not show deficiency symptoms in the orchard. Yet these may reduce crop yield and tree performance.
- Nitrogen, boron and zinc are particularly important in avocado nutrition and target levels in leaves must be maintained.

Example target nutrient levels for *Hass* avocado[3] are shown in Figure 3.

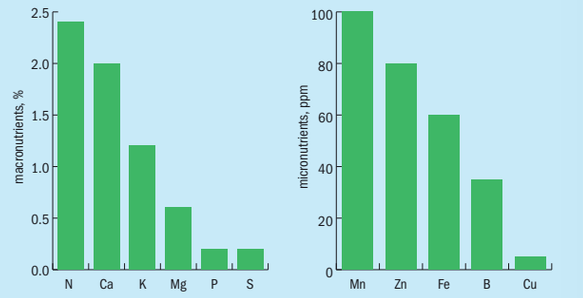
Nutrient deficiencies can negatively affect avocado yield and fruit quality. Deficiencies can reduce fruit yield by up to 80 percent, for example. Sufficient nitrogen supply, in contrast, can increase yield and fruit size by at least 30 percent. Nutrient shortfalls can also make trees more prone to physical damage. Magnesium and manganese deficiencies, for example, are linked to a higher risk of frost damage[2].

Nutrients such as K, Mg and Ca, even when supplied in adequate quantities, may still not be fully plant-available. This can be due to the soil's low cation exchange capacity (CEC) and poor soil moisture levels at the driest time of the year. These three cations also need to be present in the soil at an 'ideal' ratio for good avocado cultivation[2]:

- Ca/Mg = 6.0
- Ca/K = 12.0
- K/Mg = 3.4

For avocado, it is important to provide nutrients in the root zone while maintaining soil moisture levels (60-85%) yet without over saturation, as this promotes leaching and nutrient percolation. Nutrient application timings and application rates are also important factors for fruit quality and yield[2].

Fig. 3: **Target nutrient levels for Hass avocado**



Source: Sale (1996)

Nutrient removal

Nutrient removal by avocado depends on factors such as variety, planting density and productivity. Examples for *Hass* avocados are provided in Table 1 based on a fruit yield of 10 t/ha. Potassium is the most in demand nutrient (45-153 kg) with the quantity removed exceeding that of nitrogen by a factor of 1.5-2. *Hass* avocados, nevertheless, do still take up nitrogen in large amounts (40-70 kg). Phosphorus and calcium removal are lower but broadly similar (6-11 kg) and should also be included in the fertilization programme[2].

Additionally, avocado requires quite a lot of sulphur. Sulphur removal can even exceed that of phosphorus by as much as four times. Sulphur can be supplied alongside potassium in low-chloride products such as sulphate of potash (SOP) and polyhalite.

Table 1: **Nutrient extraction by avocado (kg) for fruit yield of 10 t/ha**

***Hass* cultivar, three examples**	**N**	**P**	**K**	**Ca**	**Mg**	**Fe**	**Cu**	**Zn**
1	70	7.7	153	10.7	0.13	0.12	0.06	0.15
2	41	8	61	7	8	-	-	-
3	35	7	45	6	2	0.50	-	0.35

Source: Tapia Vargas (2014)

Table 2: **Suggested annual fertilization for Hass avocado (Kg/ha). These amounts are needed to replace exported nutrients and maintain soil fertility**

***Hass* cultivar, three examples**	**N**	**P**	**K**	**Ca**	**Mg**	**Fe**	**Cu**	**Zn**
1	200-300	60	200-400	-	-	-	-	-
2	200	200	100	30	10	1	-	2
3	200	200	300	25	5	1	-	1.50

Source: Tapia Vargas (2014)

Nutrient application

Examples of yearly macro nutrient and micronutrient application rates for Hass avocado are shown in Table 2. These are required to deliver a fruit yield of at least 10 t/ha and large size avocados (at least 25 percent of fruit greater than 200 grams). Any annual fertilization programme does however require the monitoring of soil nutrient availability and measurement of nutrient concentration in mature leaves.

Nutritional status

The nutritional status of avocado can be monitored by measuring leaf nutrient concentration (N, P & K etc.). Within leaves, individual nutrients peak at different times during the growing season. In Mexico, nitrogen's maximum concentration occurs in March, for example, while that of phosphorus and potassium takes place in May. Leaf nutrient concentrations for K and P are also more variable than that of N.

Typically, leaf nutrient levels will reflect soil nutrient availability over the preceding 30 days. Plant take-up of N, P and K, and other important nutrients such as calcium, magnesium and zinc, therefore requires frequent fertilizer applications at low doses to maintain nutrient supply[2].

The importance of potassium

While nitrogen is essential for avocado tree growth and development, potassium is the key activator of internal processes within the tree. Although soil nutrient levels of more than 200 ppm are typically maintained in orchards, not all of this potassium will be plant-available. Indeed, uptake of potassium by avocado generally requires soil moisture to be kept above 50 percent[2].

The important functions of potassium include:

- The synthesis of carbohydrates and their transport to reserve bodies during photosynthesis
- The synthesis of amino acids and proteins from ammonium, which requires K availability in the soil
- Increases plant resistance to drought, as it influences the opening and closing of the stomata which regulate water transpiration
- Increases the consistency and hardness of plant tissues
- Strengthens the root system
- Increases the resistance of plants to frost.

Potassium also plays a vital role in quality by intensifying and conserving the colour and flavour of fruits. Excessive K supply should, however, be avoided as it can decrease the availability of Cu, Ca, Mg, P and Zn[2].

Typically, each tonne of avocado fruit extracts 4.5 kg of potassium versus 2.5 kg for nitrogen and 0.6 kg for phosphorus. Potassium generally accumulates in areas of vegetative activity and when there is a shortage will move to areas of greatest activity such as young leaves. Deficiency is therefore usually shown in older leaves first[2].

While potassium influences plant processes as diverse as breathing, photosynthesis, chlorophyll and water content in leaves, its key role is arguably as an enzyme activator. This explains its presence in high concentration in the newly formed parts of branches.

Potassium deficiency can be prevented by:

- Supplying 100-450 g/tree/year to young trees (1 to 4 years)
- Supplying 900-1,100 g/tree/year to adult trees (over 6 years).
- Trees also respond well to foliar application of K.

High-chloride fertilizers such as potassium chloride (MOP) cannot be used for avocado. Trees will not tolerate high levels of chloride, either in the soil or in the irrigation water. The maximum chloride tolerance in leaf dry matter is 0.25 percent with plants showing toxicity symptoms above this level[2].

Potassium sulphate (SOP)

The application of Tessenderlo's foliar booster product *K-Leaf*® (K_2SO_4, 00-00-52+18.5S) has been trialled on avocado in Michoacan, Mexico, with results. Foliar K was applied as a three percent spray solution with a leaf penetrant (HCA). This foliar application was to supplement not replace soil fertilization with potassium. Recommendations (K_2O) are to maintain this at 150-300 kg/ha using Tessenderlo's soil-applied SOP product *Granupotasse*®[2].

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OMEX foliar programme finds success in Mexico

Mexican avocados grown with OMEX foliar products.

Avocados are mainly produced in the central areas of Mexico – with two regions, Michoacán and Jalisco, accounting for 90 percent of the country's avocado cultivation. Avocado fruit are produced all year round from 2-3 flowering seasons.

Drawing on its experience in Mexico, OMEX Agrifluids offers a complete programme of foliar fertilizers and biostimulants for avocado, including:

- The seaweed-based biostimulant *Bio 20* containing macro and chelated micronutrients
- *CalMax Super (Gold)* containing foliar calcium together with nitrogen, magnesium and trace elements plus amino acids
- The high concentration liquid suspension product *Kingfol Zn* for low rate applications
- Highly concentrated suspension fertilizer *K41* containing foliar potassium with nitrogen, magnesium and sulphur
- The potassium phosphite product *DP98* which promotes root growth in young plants.
- Highly concentrated *Sulphomex* fertilizer containing water-soluble sulphur and nitrogen
- All the following foliar fertilizer recommendations for avocado are at an application rate of two litres per hectare unless otherwise stated.

Young avocado trees (1-3 years)

Plant growth and structure benefits from the foliar application of *Bio 20* and *Kingfol Zn* (0.5 litres per hectare) to promote a physiological response in the plant tissues. Treatment with *DP98* also improves plant health and disease resistance.

Mature avocado trees (more than 3 years old)

When flowering begins, *CalMax Super* and *Bio 20* are applied to leaves to promote flowering and fruit set. Avocado fruit size and quality can also be improved by the application of *K41*. Foliar treatment with *CalMax Super (Gold)* (1 litre per hectare), meanwhile, has multiple benefits, including better fruit set, increased yield and improved firmness, storability, colour and finish.

Additionally, OMEX recommends foliar applications of *Kingfol Zn* (0.5 litre per hectare) and *DP98* throughout the crop cycle to promote plant health and stimulate roots.

Finally, *Sulphomex* mixed with fungicide and insecticide can be applied as part of the foliar fertilization program to control (2-3 litres per hectare) or prevent (3 litres per hectare) disease and mites. ■

Supplementary treatment with *K-Leaf*® increased total foliar potassium levels. This improved supply was reflected by a higher fruit yield of 14 kg of fruit per tree, relative to soil applied SOP alone, or a 40 kg/tree increase versus no potassium application at all. This translates to a marketable yield improvement of about 1.4 t/ha or 4.0 t/ha, respectively. The treatment also had a direct effect on fruit quality by increasing oil content and pulp dry matter. This improves shelf life as well as fruit flavour, consistency and colour, all qualities valued by the consumer[2].

Avocado trial results in Michoacan, Mexico, during 2004-2006 have demonstrated the benefits of potassium sulphate (SOP) fertilization as part of a nutrient management programme alongside adequate nitrogen, phosphorus and micronutrients. Supplying 450 kg of *Granupotasse*® in three soil applied applications (150 kg/ha each) combined with 3 percent foliar applied *K-Leaf*® was shown to increase fruit yield by 40 percent versus the control[2] (no potassium application). ■

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Innovative nutrition for Latin American avocado crops

Correct fertilizer usage at each crop stage can helps avocado growers improve their yield, quality and profitability. ICL's **Mateo Martinez** and **Alveiro Salamanca-Jimenez** explain how growers can supply crop nutrients to avocado trees, efficiently and effectively, using economically- and environmentally-sustainable principles.

Avocado (genus *Persea*, family *Lauracea*) is a stone fruit that grows in tropical and Mediterranean climates. Uniquely, avocado fruit is high in 'healthy' monounsaturated fats, compared to other more carbohydrate- and sugar-rich fruit types.

Avocados have surged in popularity in recent years with their global market value expected to hit $23 billion by 2027. Global demand has seen crop production double during the past decade – especially in Mexico, the world's largest avocado producer and exporter.

Mexico produced 2.39 million tonnes of avocados in 2020, valued at $2.8 billion. Mexico is currently responsible for around 60 percent of the global avocado harvest. Chile, Dominican Republic, Indonesia, Peru, Colombia, Brazil and the US are also major avocado producers.

Inside Mexico, Michoacán is by far the country's largest avocado producing state, accounting for three-quarters of total domestic output in 2020. Four other states – Jalisco, Mexico, Nayarit, and Morelos – also contributed another 20 percent to national production.

Nutrient requirements

There is a great opportunity to improve avocado yields in Latin America, by improving nutrient management and adopting agricultural technologies, given the region's relatively low average yield (<12 t/ha).

The nutrient requirements of avocado crops will typically vary according to:

- Soil and climate conditions
- Cultivar type
- Growth stage.

4Rs nutrient stewardship – applying fertilizers at the right dose, right source, right time, right place – is another major consideration. This approach ensures that nutrient supply meets crop demand efficiently and also helps to reduce fertilizer leaching and the negative environmental impacts caused by nutrient losses.

The right dosage (application rate) can be estimated by combining nutrient analyses (soil, foliar and sap) with information on seasonal growth, crop demand and yield potential. The ultimate aim being to enhance nutrient uptake and maximise fruit yield and quality as well as crop profitability. Nutrient removal rates for different avocado varieties grown in different countries are shown in Table 1.

Table 1: **Nutrients removal (kg) by avocado crops for every 10 tonnes of fruit yielded**

Country	Mexico	Mexico	California	Israel
Variety	Hass	Choquette	Hass	Fuerte
Nutrient removal (kg)				
N	26	15	28	11
P	5	3	11	2
K	39	25	67	20
Ca	1	1	6	2
Mg	3	2	11	5
B	0.04	0.02	1	
Zn	0.04	0.03	0.4	

Source: avocadosource.com

Main soil requirements

The following soil properties have a major impact on avocado cultivation:

- Organic matter: greater than three percent ideal
- pH: ideally 5.5-6.5
- Electrical conductivity (EC): below 0.5 dS/m preferred

Avocado crops grow better in soils with **organic matter** higher than three percent. Organic matter contributes to soil productivity in three different ways by providing:

- **Physical benefits**. Improves soil aeration, water infiltration, water holding capacity and reduces runoff.
- **Chemical benefits**. Increases cation exchange capacity (CEC) – an indicator of the soil's ability to hold and supply essential nutrients, such as calcium, magnesium, and potassium. Organic matter also improves soil buffering capacity (the ability to resist pH change) and accelerates mineral decomposition making nutrients more available for plant uptake.
- **Biological Benefits**. Provides food for the living organisms. Organic matter also helps suppress diseases and pests by improving the biodiversity of soil microbes and boosting microbial activity.

PHOTO: ICL

Avocado roots in an organic-rich soil.

An optimum **soil pH** of 5.5-6.5 is ideal for avocado growing. Plants are very sensitive to alkaline soils, as a pH greater than 7 can cause nutrient deficiencies by inhibiting the uptake of phosphorus, manganese, iron and zinc.

Soil acidity is also detrimental. Some growing areas in Mexico and Colombia, for example, exhibit a soil pH below 5.5 and therefore require liming to raise this. In con-

Table 2: **Desirable soil nutrient concentrations for avocado**

Nutrient	Desired range (ppm)
Phosphorus (P)	60-100
Potassium (K)	300-400
Calcium (Ca)	2,000-2,600
Magnesium (Mg)	290-360
Sulphur ($S\text{-}SO_4$)	40-60
Iron (Fe)	20-50
Manganese (Mn)	20-50
Zinc (Zn)	3-6
Boron (B)	0.2-0.6
Copper (Cu)	0.5-1

Source: ICL

Controlled-release fertilizer applied on a young avocado tree.

PHOTO: ICL

Avocado nutrition from ICL Innovative Solutions

Avocado trees are highly sensitive to salinity. The negative effects of salinity are particularly pernicious in young trees as their new roots easily suffer from fertilizer burn when standard commodity products are used. To avoid this risk, innovative technologies such as slow- and controlled-release fertilizers (SRFs/CRFs) are recommended.

CRFs release nutrients in a controlled manner to match and satisfy the nutrient uptake of any crop. Consequently, they are able to:

- Increase crop production
- Reduce plant toxicity and stress
- Cut soil, water and atmospheric pollution.

Indeed, CRFs have been proven to eliminate the problem of avocado root burn and reduce nutrient losses by leaching and runoff[1].

ICL is a leading global manufacturer of CRFs, supplying suitable products such as *Osmocote*, *Agrocote Emax*, *Agrocote Poly*-S, plus smart blends such as *Agroblen*, *Agromaster* etc.

Polysulphate is another innovative ICL product that is well-suited to avocado. This natural fertilizer is approved for organic agriculture and has a very low carbon footprint. It prolongs nutrient availability, improves nutrient use efficiency (NUE) and nurtures and sustains plant roots. Composed of the natural mineral polyhalite, this product contains four of the six essential macronutrients (K, Mg, Ca alongside sulphur) in the flowing proportions:

- 14 percent K_2O
- 6 percent MgO
- 17 percent CaO
- 58 percent SO_4.

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Table 3: **Suggested fertilization plan for avocado tree establishment**

Technology	Formula	Dose g/plant	Nutrients (g/plant/application)					
			N	P_2O_5	K_2O	CaO	MgO	S
Osmocote Plus (8-9 months*)	15-9-12+1.3Mg+6S+ME	150	22.5	13.5	18	0	2.25	9.0
Polysulphate	0-0-14+17CaO+6MgO+19S	50	0	0	7	8.5	3.0	9.5
Total		**200**	**22.5**	**13.5**	**25**	**8.5**	**5.25**	**18.5**

** Months taken for complete nutrient release from the fertilizer* *Source: ICL*

trast, the application of elemental sulphur before planting, or the supply of acid via fertigation, is required to reduce soil alkalinity (>pH 7) in other areas. The management of high pH is, however, generally more problematic in areas without an irrigation system.

Electrical Conductivity (EC) is another important property that deserves consideration – since avocados prefer soils with EC below 0.5 dS/m. High EC levels damage root systems and limit plant growth, especially when associated with high soil sodium (Na) levels.

In general, soil nutrient concentrations need to be within an optimum range to ensure balanced nutrition and proper yields in avocado crops (Table 2). This includes a sodium concentration in the soil CEC of less than three percent.

New Plantations

For new avocado plantations, combining the CRF *Osmocote Plus* with *Polysulphate* (see box) allows growers to supply a complete and efficient nutrition plan for their avocado trees (Table 3):

- **Complete** because *Osmocote Plus* contains N, P, K, Mg, S, Fe, Mn, Zn, Cu and B and *Polysulphate* provides K, Ca, Mg and S – supplying the entire nutrient requirements for this growth stage.
- **Efficient** because *Osmocote Plus* release nutrients in a precise manner according to the longevity selected. That can be any period from between one and 12 months. *Polysulphate*, in contrast, releases its nutrients gradually for 2-3 months.

Furthermore, the combination of *Osmocote* CRF technology and natural *Polysulphate* offers growers a promising nutrient management alternative. Used together, these two products improve nutrient supply and decrease environmental pollution, while maintaining high crop yields and benefitting crop quality. Both technologies deliver higher yield, quality and/or profitability when compared with conventional fertilizers, as has been thoroughly demonstrated in trials on many crops.

The fertilization programme in Table 3 provides avocado plantations with a well-balanced first year nutrition plan that is also safe for new roots. However, the application frequency and rate can be varied – depending on soil and water analyses and plant size. Uniformly spreading fertilizer at three different depths in the planting hole is also recommended to improve nutrient uptake:

- One third at 5-10 cm above the hole bottom
- One third in the middle of the plant hole
- One third at 5-10 cm below soil top.

Young avocado tree.

Young Avocado Trees

Similarly, young avocado trees also require a complete and balanced nutrition programme. More macronutrients are demanded at this stage. This includes more nitrogen and potassium to promote new growth and stronger branches, as well as more phosphorus and calcium to produce abundant root growth.

ICL has designed and developed Special *Agroblen* CRF formulations to supply avocado trees with an optimal amount of nutrients. These contain N, P and K combined in different ratios to match each phenological stage. *Agroblen* contains a blend of *Agrocote Emax* and *Agrocote Poly-S*. Encapsulated granules provide all of the essential nutrients for young avocado trees at precise grades.

The addition of *Polysulphate* to the fertilization programme is also recommended to supplement nutrients provided by *Agroblen*, as shown in Table 4. This programme is designed to fertilize plants at high nutrient use efficiency. The recommendation is to spread fertilizer granules around tree stems and then cover/incorporate these beneath the soil at a depth of 2-5 cm. The programme is flexible and application rate and frequency can be adjusted in response to soil and water analyses, plant size and rainfall.

Table 4: **Nutrition programme for young avocado trees**

Product	Formulation	Application rate (g/plant/year)
Agroblen	14-11-11 + 3.5Mg + 9S + ME (8-9 months*)	500-1,000
Polysulphate	0-0-14 + 17CaO + 6MgO + 19S	200-500
Total		**700-1,400**

** Months taken for complete nutrient release from the fertilizer* *Source: ICL*

Adult avocado tree.

Adult avocado trees

Fertilizer demand in adult trees (> 3 years old) increases due to higher nutrient removal by fruits. Crop nutrition plans can also vary greatly due to multiple factors such as:

- Plantation density
- Tree age
- Soil fertility
- Whether the crop management system is irrigated or rainfed.

In Mexico, most farmers have an avocado fertilization programme that combines the application of granulated fertilizers during the rainy season (summer-autumn) with water-soluble fertilizers during the dry season (winter-spring). Depending on local circumstances, the total NPK application rates used by farmers (N, P_2O_5 and K_2O) may range between:

- 60-120 kg/ha/year
- 150-250 kg/ha/year
- 200-350 kg/ha/year.

Table 5: **Nutrition programme for adult avocado trees using two applications of CRF* and *Polysulphate* blends**

Granular application	Fertilizers	Application rate (kg/tree)
1	*Local Blend* 14-11-11+ME (40% N, 10% P_2O_5, 30% K_2O as CRF)	2.0-3.0
	Polysulphate 0-0-14+17CaO+6MgO+19S	1.0-2.0
2	*Local Blend* 14-7-22+ME (40% N, 10% P_2O_5, 30% K_2O as CRF)	2.0-3.0
	Polysulphate 0-0-14+17CaO+6MgO+19S	1.0-2.0

**CRFs used are Agrocote Emax N 43-0-0 (3-4 months), Agrocote P 9-47-0 (3-4 months), Agrocote K 0-0-56 (3-4 months), Agrocote Emax K 0-0-48 (3-4 months).*
Source: ICL

Table 6: **ICL Fertigation programme for avovado**

Crop stage	Product	Application rate (kg/ha)
Flowering-fruit setting	*Agrolution* 9-45-15+ME	25
	PeKacid	15
Fruit setting-marble size fruit	*Agrolution* 9-45-15+ME	25
	PeKacid	10
	Calcium nitrate	15
Marble size fruit-egg size fruit	*Agrolution* 20-20-20+ME	75
	PeKacid	10
	Calcium nitrate	25
	Magnesium nitrate	15
Egg size fruit-harvest	*Agrolution* 11-8-36+3CaO+ME	75
	Calcium nitrate	35
	Magnesium nitrate	15
For the entire dry season	*H2Flo**	10 L

**H2Flo is a liquid surfactant blend that improves penetration and lateral movement of water within the root zone. It is applied to soil via fertigation to improve water and nutrient use efficiency.* *Source: ICL*

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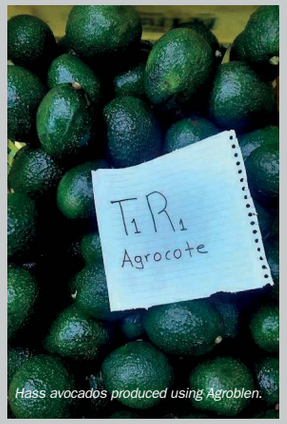
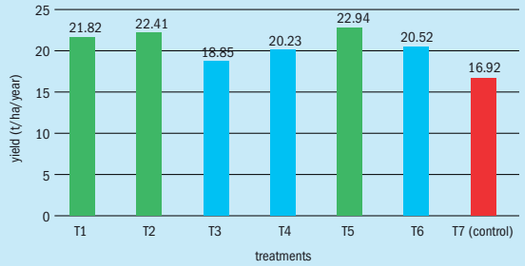
Case study: *Agroblen* trials for Hass avocados, Periban, Mexico



Hass avocados produced using Agroblen.

Fig. 1: **Hass avocado trials at Periban, Michoacan, Mexico, 2016-2018: average annual avocado yields for six CRF treatments at different N and K applications rates vs control. See Table 7 and main article for details**



Source: ICL

The use of the CRF *Agrocote* for the fertilization of Hass variety avocados was validated at Periban, Michoacan (19°26'16.5"N 102°26'02.9"W) in 2016-2018. Different CRF formulations and application rates were compared with conventional fertilizers, all using standard growers practice (Table 7). The evaluation was on 10-15 years old rainfed avocado trees grown in a loamy soil with the following characteristics:

- pH of 6.5
- EC of 13.1
- Major elements – Ca 9.7, Mg 1.3, K 1.8, Na 0.15 (cmol/kg)
- Minor elements – Fe 39, Mn 6, Cu 4, Zn 4.1, B 1.3, P 43, S 19 (ppm).
- The plant density was 200 trees/hectare.

Trials involved seven treatments (Table 7) on four replication plots of 20 avocado trees each. The resulting 28 experimental units were distributed according to a completely randomised design. Six avocado trees in each replication plot were monitored at harvest to determine the crop yield. The trial period covered four harvests in total.

The accumulated yields at harvest during the first two years were recorded. This information was averaged and converted to tonnes of fresh fruit per hectare per year.

Results demonstrated that all CRF treatments increased yields by 10-26 percent, versus the control, with treatment five (T5, 40% N-CRF) producing the highest yield (Figure 1). Results also confirm that avocado growers – by adopting *Agroblen* – can potentially reduce their N and K application rates by 15-30 percent, and still obtain better yields. This is due to the higher nutrient use efficiency delivered by *Agroblen* and the consequent reduction in both nutrient losses and negative environmental impacts. ■

Table 7: **Hass avocado trials at Periban, Michoacan, Mexico, 2016-2018: six CRF treatments vs one control**

Treatment	CRF-N %	CRF-K %	N rate	K rate	Overall application rates (kg/ha)					
			% of control	% of control	N	P_2O_5	K_2O	MgO	CaO	S
1	40	40	70	70	92.2	100.8	92.4	89.2	91.8	68.5
2	40	40	85	85	112.0	100.8	112.1	89.2	91.8	73.3
3	70	70	70	70	92.2	100.8	92.4	89.2	91.8	85.1
4	70	70	85	85	112.0	100.8	112.1	89.2	91.8	93.4
5	40	0	70	100	92.2	100.8	131.9	89.2	91.8	46.4
6	70	0	85	100	112.0	100.8	131.9	89.2	91.8	46.4
7 (control)	0	0	100	100	131.8	195.1	229.1	27.6	375.0	111.4

Source: ICL

Table 8: **ICL's complete nutrition recommendation for avocado**

ICL Innovative Solutions	Nursery	Planting	Young trees	Adult avocado trees		
				Before flowering	Fruit setting	Fruit growing
Granulated fertilizers (soil application)	*Osmocote Plus* 15-9-12+ME *Polysulphate*	*Osmocote Plus* 15-9-12+ME *Polysulphate*	*Agroblen* 14-11-11+ME *Polysulphate*	*Agroblen Starter* 13-25-6+ME *Polysulphate*	*Polysulphate*	*Agroblen* 14-7-22+ME *Polysulphate*
Fertigation	*Agrolution* 9-45-15+ME *H2Flo*	*PeKacid Agrolution* 20-20-20+ME *H2Flo*	*PeKacid Agrolution* 20-20-20 *H2Flo*	*PeKacid Hipeak* 0-45-45 *H2Flo*	*PeKacid Hipeak* 0-45-45 *H2Flo*	*PeKacid Agrolution pHLow* 11-8-36+3CaO+ME *H2Flo*
Foliar	*Nutrivant Starter* 11-36-18+ME	*Nutrivant Balanced* 18-24-18+ME	*Nutrivant Balanced* 18-24-18+ME	*Nutrivant PeaK* 0-49-32	*Nutrivant PeaK* 0-49-32	Nutrivant Booster 8-16-39+ME

Source: ICL

Granular fertilizers are supplied
split soil applications during the
season:

- **June**. The first application of
fertilizers takes place at the
of the rainy season, with farme
focusing on supplying phospho
NPK ratio of 1-2-1 or similar.
- **August**. The second applicatio
balanced at an NPK ratio of 2
- **September**. The last applicati
focusses on supplying potass
NPK ratio of 2-1-3.

> **Nowadays, however, the adoption of drip systems has become more common in response to water shortages.**

Traditionally, farmers have formulated their NPK blends by combining fertilizers such as urea, ammonium sulphate, ammonium nitrate, monoammonium phosphate, diammonium phosphate, potassium sulphate etc.

Innovative and responsible farmers are, however, looking to optimise their fertilizer consumption and improve nutrient use efficiency, as well as reduce the groundwater pollution caused by intense runoff during periods of high rainfall. These farmers are therefore starting to adopt slow- and controlled-release fertilizers (SRFs and CRFs) instead – substituting these for standard commodity products – to obtain the best balance between efficiency and economic viability.

ICL has successfully demonstrated the advantages of adding CRFs and *Polysulphate* in avocado nutrition programmes through trials and commercial plots. The use of *Agrocote Emax N, Agrocote P* and *Agrocote K* can, respectively, supply 30-50 percent of the nitrogen (N), 5-10 percent of the phosphorus (P_2O_5) and 25-40 percent of the potassium (K_2O) nutritional needs of plants. These CRFs allow growers to supply properly formulated blends at the correct NPK ratios (Table 5).

Another advantage of using CRFs and *Polysulphate* is that they allow growers to cut the number of fertilizer applications. These are reduced to just two during the rainy season instead of the three applications usually necessary.

Fertigation and foliar nutrition for avocado

Many avocado growers have introduced fertigation as part of their irrigation systems. Previously, sprinkler systems were largely favoured by growers. Nowadays, however, the adoption of drip systems has become more common in response to water shortages – and due to their ability to deliver precise crop nutrition via fertigation, especially during the dry season.

ICL has developed a unique range of water-soluble products designed to work well in fertigation systems and via foliar application to plant leaves. These treatments complement soil fertilization and provide excellent results.

Water-soluble fertilizers (e.g., *Agrolution*, *Pekacid* and *HiPeak* fertigation products, the *Nutrivant* foliar fertilizer range and the surfactant agent *H2Flo*) are an ideal source of plant nutrients, especially where growth-limiting conditions apply (hard water, nutrient deficiencies, light soil texture etc.). An example fertigation programme for avocado featuring ICL's product range is shown in Table 6.

This is a generic fertigation plan and adjustments are typically necessary based on plant nutrient status, as determined from soil and foliar analyses. ICL's technical teams are available to help with local implementation, make suitable fertilizer recommendations and define the correct application rates.

Conclusions

ICL's complete nutrition plan for avocado (Table 8) is being implemented by more avocado growers. Adopting the correct fertilizer sources for each crop stage allows growers to improve avocado crop yield, quality and/or profitability. This plan also benefits agriculture and nature by delivering crop nutrients using economically and environmentally sustainable principles. ■

About the authors

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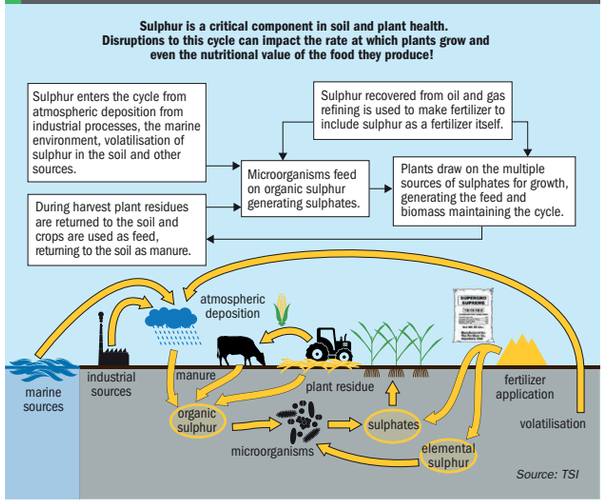
Sulphur fertilizers: a growing need

Sulphur is becoming an increasingly vital crop nutrient – due to a combination of lower sulphur deposition from the atmosphere, the increasing prevalence of high-analysis fertilizers and higher cropping intensity.

Fig. 1: **The sulphur cycle**



The sulphur cycle

Similar to nitrogen and phosphorus, sulphur follows a cycle (*Sulphur* 392 p16). This cycle (Figure 1) illustrates:

- How sulphur moves between land, air and sea in different forms
- Key processes such as crop uptake, leaching and volatilisation
- The microbial action which makes sulphur plant-available by changing it from organic to inorganic form.

Crops access and remove sulphur through their roots in sulphate form. It can also be taken up as sulphur dioxide gas.

Sulphur typically enters the soil solution by the mineralisation of organic matter. Every one percent of soil organic matter can supply around 1.4-2.3 kilograms of sulphur via mineralisation. Some soil microbes and plants immobilise (fix) sulphur while others mineralise (oxidise) it into sulphate. These mineralisation and immobilisation processes often occur simultaneously within soils as part of sulphur removal and replenishment. Because 95 percent of sulphur found in soils is associated with organic matter, low organic matter soils are typically sulphur deficient (*Sulphur* 392 p16).

From 2005 to 2014, the average amount of fertilizer sulphur used annually in global crop production was 10.6 million tonnes, with some 53 percent (5.6 million tonnes) of this applied to cereals[1]. However, recent calculations suggest that, on average, only one million tonnes of the total sulphur applied in cereal crop production was subsequently recovered in the grain – suggesting a sulphur use efficiency (SUE) of around 18 percent[1]. Reasons for low SUE include sulphur:

- Leaching
- Adsorption
- Retention in residues
- Immobilisation
- Failure to adhere to best agronomic practice, e.g. the 4Rs.

The fourth crop nutrient

Sulphur has become increasingly valued by the farm sector in recent years, to the extent that some now describe sulphur as 'the fourth crop nutrient' (*Fertilizer International* 497, p24).

Sulphur is present in all crops and plays an important metabolic role. It is essential for the formation of proteins, amino acids, vitamins and enzymes, and vital for photosynthesis, energy metabolism and carbohydrate production. Sulphur also contributes to the flavour and aroma of crops such as onions and can therefore influence the quality of farm produce.

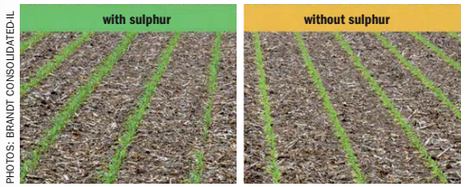


Fig. 2: Young corn plants growing with and without sulphur.

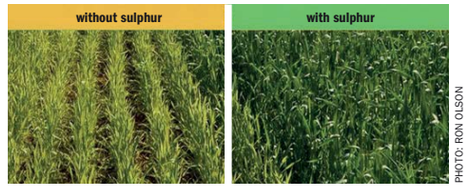


Fig. 3: Wheat crop showing the impact of sulphur deficiency.

Importantly, sulphur does not act alone as a plant nutrient, as it works in tandem with nitrogen to enable the formation of amino acids during protein synthesis. Sulphur is also part of the plant enzyme required for nitrogen uptake.

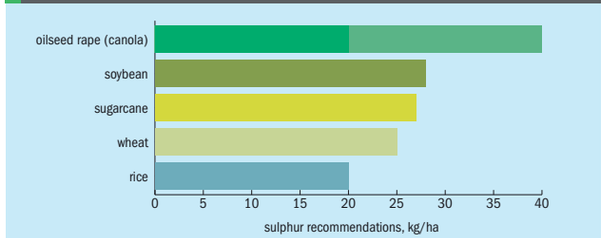
In crop nutrition, sulphur plays a critical role in early crop establishment and improves resistance to environmental stress. Deficiency stunts early plant growth, leading to later yield losses, and is exacerbated by the following conditions:

- Light and sandy soils with low soil organic matter
- Sulphur leaching during high winter rainfall
- Low sulphate mobility during dry spring conditions
- Slower mineralisation at low temperatures
- Low input of organic matter and mineral sulphur
- Low atmospheric deposition of sulphur to soils.

The main signs of sulphur deficiency – pale green colouration, stunted growth and delayed maturity – mirror the symptoms of nitrogen deficiency. However, sulphur deficiency affects in newer growth, typically in the top leaves or whorl, while nitrogen deficiency shows up in the bottom leaves of the plant. A lack of sulphur in corn and wheat slows down photosynthesis and root/plant development as shown by a pale green colour and a lack of vigour (Figures 2 and 3).

Crops can typically remove between 15 to 30 kilograms of sulphur per hectare from soil. Root vegetables, onions and brassica, especially oilseed rape (canola), have a particularly high demand for sulphur. Pasture and other widely-grown crops such as coffee, corn, cotton, rice, soybean, sugarcane and wheat also require moderately high sulphur applications (Figure 4). For these crop types, sulphur requirements can match or even exceed demand for phosphorus.

Fig. 4: **General sulphur recommendations for crops (kg S /ha)**



Source: TSI and others

A bushel of corn, for example, removes 77 grams of sulphur in total – 36 grams in the grain and 41 grams in the stalk. That means 200 bushels of corn will remove sulphur at a rate of 38 kg/ha. This is equivalent to an actual removal rate of plant-available sulphate (SO_4) of 114 kg/ha (*Sulphur* 392, p16).

Increasing agricultural value

Sulphur is becoming an increasingly important crop nutrient due to three main factors (*Fertilizer International* 497, p24):

- **Falling atmospheric deposition**. Soil sulphur deficiency, a relative rarity 20 years ago, is becoming more common. The deposition of sulphur dioxide emissions from the atmosphere used to guarantee that soils in many regions were automatically enriched and replenished with sulphur. This is no longer the case as increasingly stringent environmental regulations and the introduction of low-sulphur fuels have sharply cut emissions.
- **The prevalence of high-analysis fertilizers**. Farmers are continuing to switch to high-analysis products, containing little or no sulphur, at the expense of sulphur-rich, lower analysis products. This long-term buying trend has also put sulphur replenishment on a downward path.
- **Rising cropping intensity**. Improving crop yields are withdrawing ever larger amounts of sulphur from the field.

These three factors are, however, opening up opportunities for fertilizer producers. A number of leading manufacturers are capitalising on the value of sulphur by broadening their portfolios and supplying sulphur-enhanced fertilizers as premium products to meet growing market demand.

Global and regional consumption

Accurate and up-to-date figures on sulphur fertilizer consumption are hard to come by. Despite this, the market is mainly divided between the following products, in order of popularity:

- Ammonium sulphate
- Single superphosphate (SSP)
- Sulphate of potash (SOP)
- NPS products
- Ammonium thiosulphate (ATS).

The total world market for sulphur-containing fertilizers was estimated at more than 66 million tonnes in 2015. On a

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SPOTLIGHT ON THIOSULPHATES

Fertigation, the application of nutrients via an irrigation system, is a niche but high-value agricultural market for sulphur. Thiosulphates, in particular, are widely-used as liquid sulphur fertilizers in the broad acre and speciality crop market in North America and Europe. Their use is also on the increase in Latin America.

Tessenderlo Group is a global leader in speciality liquid fertilizers and manufactures four main thiosulphate products:

- Ammonium thiosulfate, *Thio-Sul* (12% N + 26% S)
- Potassium thiosulphate, *KTS* (25% K + 17% S)
- Calcium thiosulfate, *CaTs* (6% Ca +10% S)
- Magnesium thiosulfate, *MagThio* (4% Mg + 10% S)

Thio-Sul is suitable for most irrigation systems and, alongside nitrogen, delivers sulphur in both elemental and sulphate form. It also improves phosphorus uptake, and can be added to urea ammonium nitrate (UAN) as a nitrification inhibitor to reduce nitrogen losses. *KTS*, another of Tessenderlo's leading thiosulphate products, is marketed as a high-analysis potassium and sulphur fertilizer for fertigation. It is suitable for booster or starter formulations and can also be applied as a foliar fertilizer when crop demand for potassium is high.

Thiosulphates offer sulphur in both immediately plant-available form and in slower release form available to plants over a longer period of time. Thiosulfates also have a modest acidification effect, benefitting crops growing on alkaline (calcareous) soils. Providing sulphur to crops by applying thiosulphates offers a number of specific benefits:

- Enhances crop protein and chlorophyll content
- Assists the synthesis and functioning of enzymes in the plant
- Optimises fertilizer efficiency by stabilising nitrogen
- Improves availability of nutrients in the soil, particularly phosphorus and micronutrients and their uptake by the crop
- Energy efficient assimilation in the plant
- Provides prolonged sulphur nutrition
- A controlled and localised pH adjustment effect in the soil.

Thio-Sul has the most powerful acidification effect because it combines the ammonium cation with thiosulfate. *Thio-Sul* can be combined with UAN solutions to provide two main benefits:

- It brings sulphur as a nutrient into the mix – the correct N/S ratio being very important for most crops
- It acts as nitrogen stabiliser improving nitrogen use efficiency.

Thio-Sul and *CaTs* both have the ability to inhibit the urease reaction, thereby reducing nitrogen loss through ammonia volatilisation, as well as slowing down nitrification by reducing the loss of nitrogen though nitrate leaching.

CaTs, as well as offering a nitrate- and chloride-free source of calcium, and providing thiosulfate sulphur, also acts as a soil conditioner. Being a highly-soluble liquid form of calcium – unlike gypsum – *CaTs* is effective at penetrating the soil profile where it acts as a flocculant, opening up soil pores and improving soil structure and drainage. It can also help displace undesirably high levels of sodium in soils.

KTS is one of the most concentrated forms of liquid potassium and sulphur available in the market. When combined with liquid ammonium polyphosphate (APP), it can be applied as a very effective starter fertilizer early in the plant's growth cycle. The presence of *KTS* improves phosphorus use efficiency by effectively regulating the rate at which polyphosphates turn into orthophosphates and becomes plant available. ■

Note: *Thio-Sul, CaTs, MagThio* and *KTS* are registered trademarks of Tessenderlo Group NV/SA.

nutrient basis this equates to global agricultural sulphur consumption of around 11.1 million tonnes. Sulphur consumption is greatest in Latin America (2.4 million tonnes), East Asia (2.1 million tonnes) and Southeast Asia and Oceania (1.8 million tonnes), with these three regions accounting for 57 percent of global agricultural sulphur usage[2].

However, worldwide agricultural consumption of sulphur could be closer to 13.3 million tonnes (Figure 5), according to a first-of-its-kind assessment by the International Fertilizer Association (IFA)[3]. This volume is much higher than the frequently quoted estimate of 10-11 million tonnes. However, this latest tonnage is probably still an underestimate, suggests IFA, as it excludes data for some NPK+S products[3].

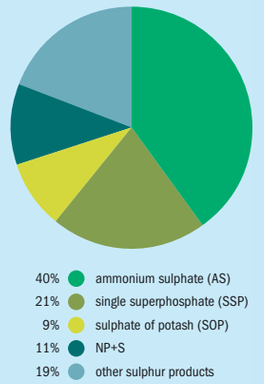
Market trends

The sulphur fertilizer market divides into two main categories – traditional sulphate fertilizers and sulphur-enhanced fertilizers. These have a wide range of nutrient compositions (Figure 6). Liquid sulphur products – thiosulphates – are also favoured in some countries and regions, particularly in North America and Europe (see box).

Traditional sulphate fertilizers have long dominated global demand (*Fertilizer International* 476, p19). They include:

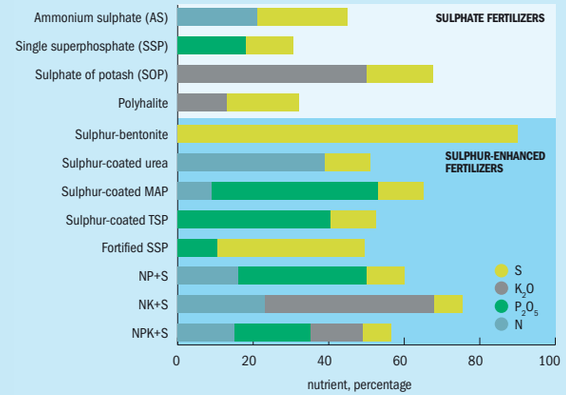
Single superphosphate (SSP) is the second largest-selling phosphate fertilizer on

Fig. 5: **Agricultural sulphur consumption by product, 2015**



Source: IFA (2017)

Fig. 6: **Nutrient content (NPK+S) of selected sulphate and sulphur-enhanced fertilizers**



Source: Various

the market after diammonium phosphate (DAP). Consumption is concentrated in four main markets, China, Brazil, India and Australia, which collectively account for around 85 percent of total global demand. SSP is a low-analysis fertilizer with a nutrient content of around one-fifth (18-22% P_2O_5). Because of this, it tends to be consumed in the country of origin, and export volumes have declined due to increasing competition from more economic high-analysis phosphates. SSP consumption has contracted by almost a third in the past twenty years.

- **Ammonium sulphate (AS)** consumption, in contrast, is on the rise even though its nitrogen content is much lower than urea and ammonium nitrate. World supply (26.4 million tonnes) has been boosted by the massive growth of 'involuntary' production capacity in China. Consumption of AS is concentrated in the Americas (the US, Brazil, Mexico and Canada) and East and Southeast Asia (China, Indonesia, Viet-

Rising NPS fertilizer use

The last five to six years has seen the emergence of speciality NPS products. These have established a strong market presence in India, Brazil and the US during the last decade. Demand from Australia and Ethiopia is also on the increase.

Mosaic blazes a trail

Incorporating sulphur into ammonium phosphate fertilizers to create NPS products has become an increasingly popular way of addressing sulphur deficiencies. The Mosaic Company has pioneered this market through *MicroEssentials*, its successful and pioneering sulphur-enhanced monoammonium phosphate (MAP) product range, These value-added products typically sell at a $45/t premium over standard MAP.

The North American market for *MicroEssentials* broke through the one million t/a barrier at the end of 2013. Mosaic's sales of 8.2 million tonnes of finished phosphates in 2019 included 3.2 million tonnes of its *MicroEssentials* speciality product. These versatile premium fertilizers are now applied to more than 10 percent of US farmland. They are suitable for both direct application and bulk blending and their increasing use is backed by more than a decade of field data and over 1,200 crop trials globally. The company offers three main formulations:

- *MicroEssentials SZ* with 12% N, 40% P, 10% S and 1% Zn (12-40-0 10S 1Zn)
- *MicroEssentials S15* with13% N, 33% P and 15% S (13-33-0 15S)
- *MicroEssentials S10* with 12% N, 40% P and 10% S (12-40-0 10S).

The sulphur content in all three of these is a 50:50 mix of elemental sulphur and sulphate.

OCP and PhosAgro look to capture price premiums

Envious of Mosaic's attractive NPS margins, rival phosphate producers OCP and PhosAgro have also move into this value-added sector – although their NPS products, unlike Mosaic's, only contain sulphur in sulphate form at present. Both companies have been ramping up their NPS export capabilities to meet market demand.

During the 2020 pandemic, for example, Russia's January-September NP/NPS exports rose 16 percent year-on-year to exceed 600,000 tonnes. The NPS grade 20-20-0+13S – mainly targeted at India – accounted for 64 percent of NP/NPS exports over this period. While India produces significant volumes of its own 20-20-0+13S domestically, these are topped up with NPS imports from Indonesia, Russia, China and – more recently – Saudi Arabian product[4].

PhosAgro's Cherepovets plant was Russia's largest exporter of the NPS grade 20-20-0+13S in 2020, although EuroChem's Belorechensk plant also contributed significantly to export volumes. PhosAgro has increased its annual NP/NPS sales volumes from around 50,000 tonnes in 2010 to more than 200,000 tonnes currently. This sales growth has been driven by higher 20-20-0+13S deliveries to India, Turkey, Romania and Poland, as well as rising 14-40-0+7S deliveries into Brazil and Mexico[4].

Similarly, OCP has ramped up NPS production and exports at its Jorf Lasfar complex, partly to meet demand from large African tenders. The Moroccan phosphate giant exported 990,000 tonnes of NPS in 2019. Some 70 percent of this volume went to fulfil Ethiopian tenders, with the remainder destined for Brazil, the US, Canada and Australia[4]. ■

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Techno-S® and Techno-Z® water dispersible granules (WDGs). PHOTO: SULPHUR MILLS

Micronised water-dispersible granules

Sulphur Mills Limited (SML) is the world's largest manufacturer of water-dispersible granules (WDGs). The Mumbai-based company has been expanding rapidly and increasing the availability of these technologically innovative, sulphur-based products across the globe. WDGs are extremely fine, 2-4 micron size granules manufactured by SML using a patented process.

SML's flagship products, *Techno-S®* and *Techno-Z®*, are the world's first low-dose WDG fertilizers. They represent a technological leap forward in soil-based fertilizer applications, according to the company, and are helping to change the way sulphur-based fertilizers are conventionally perceived. Both products have excellent water dispersion properties and are offered as either standalone sulphur microgranules (*Techno-S®*) or zinc-fortified microgranules (*Techno-Z®*),

> **"*Techno-S®* and *Techno-Z®* fertilizers function at very low dosages, offer high nutrient use efficiency and undergo quick oxidation – making sulphur and zinc readily available to crops throughout the growing season."**

Techno-S® is a 90 percent sulphur fertilizer, while *Techno-Z®* combines 15 percent zinc with 70 percent sulphur. Both fertilizers function at very low dosages and offer high nutrient use efficiency. They undergo quick oxidation, making S and Zn readily available to the plant throughout the season from early crop stages onwards. SML has thoroughly tested WDGs agronomically – across countries, crop types and on different soil types. This has demonstrated their ability to improve various growth and quality parameters, including: better crop yields, increases in the protein and oil content of oil seed crops, higher starch content in tubers, and prolonging the shelf life of final produce such as onions.

The versatility of both micron-sized granular fertilizers, particularly their flexibility when it comes to the choice of application method, is an added advantage. This means they are suitable for various farming practices across the world – including micro-irrigation (drip) systems, sprinklers, overhead irrigation equipment, or conventional broadcasting and seed drill applications.

"Our R&D is continuously working towards providing more and more innovative solutions in the plant nutrient as well as the crop protection space," Bimal Shah, SML's managing director, told *Fertilizer International*. "Our products reduce the overall impact on the environment while providing the most efficient, efficacious and cost-effective solutions to the farming community."

SML's product range is now trusted by farmers in over 80 countries. Advantageously, being OMRI-certified, *Techno-S®* and *Techno-Z®* are approved for organic farming too. ■

nam and Malaysia). Turkey and Germany also offer sizeable markets for AS (*Fertilizer International* 469, p20). The use of AS in NPK blends has become increasingly popular as awareness of sulphur deficiency in soils has become more widespread. Rapid growth in world oilseed rape (canola) production has been a notable factor behind the rise in AS demand.

- **Sulphate of potash (SOP)** is valued as a chloride-free source of potash for lucrative cash crops such as tobacco, tree nuts and citrus fruits. Agricultural consumption is 7-8 million tonnes currently. China accounts for more than half of global use and has been responsible for much of the expansion in SOP demand globally in recent years. North America and Europe are also sizable markets accounting for some 60 percent of demand outside of China (*Fertilizer International* 475, p49). Global demand is supply-constrained meaning that SOP trades at a premium.
- Global demand for **sulphate of potash magnesia (SOPM)** has grown strongly in recent years. The market for SOPM, similar to SOP and SSP, is highly concentrated with just four countries, China, the US, Canada and Germany, accounting for the lion's share of consumption. Production is also mainly located in three countries, China, the US and Germany.
- **Ammonium phosphate sulphate (APS)**, a fertilizer with a 60 percent ammonium sulphate and 40 percent MAP composition, is a commonly produced grade of NP+S fertilizer (16-20-0-14S). It is directly applied to forage crops in many countries, particularly legumes, and is also a popular choice of fertilizer for small grains and oilseed rape (canola).

The global sulphur fertilizer market is still dominated by AS, SSP and SOP, with these three products combined being responsible for 70 percent of agricultural sulphur consumption (Figure 5).

Sulphur-enhanced fertilizers

Crop requirements for sulphur were projected to exceed 24 million tonnes by 2020. Fertilizer producers have reacted to this widening demand gap by developing sulphur-enhanced fertilizers. Many of these premium products are manufactured by incorporating elemental sulphur into high-analysis fertilizers, either within granules or as an external coating. Introducing a liquid sulphur spray to urea, TSP, MAP or DAP during drum or pan granulation, for example, results in NPS products with a 5-20 percent elemental sulphur content.

Sulphur-enhanced fertilizers combine nutrient availability with high use-efficiency, and also have good storage and handling properties. Examples include:

- Sulphur-bentonite
- Sulphur-coated urea, MAP or TSP
- Sulphur-enriched SSP
- Sulphur-enhanced MAP enriched with sulphate

Sulphur-enriched SSP is popular in countries such as New Zealand and can contain twice as much sulphur as ordinary SSP. Added elemental sulphur complements SSP's existing sulphate content and helps meet crop needs during the whole growing season by providing both immediate and reserve stores of sulphur. This makes it particularly suitable for applications in areas with high leaching losses.

> **"Speciality NPS products have emerged in recent years. These have established a strong market presence in India, Brazil and the US.**

Controlled release fertilizers (CRFs) can be produced by coating highly-soluble nutrients with relatively insoluble elemental sulphur. **Sulphur-coated urea (SCU)**, for example, combines 77-82 percent urea (36-38% N) with a 14-20 percent sulphur coating. SCU is suitable for multiple nitrogen applications on sandy soils under high rainfall or irrigation conditions. It is marketed as a CRF for grass forage, turf, sugarcane, pineapple, cranberries, strawberries and rice.

To be of value to crops as a nutrient, the elemental sulphur (S_8) present in sulphur-enhanced fertilizers firstly needs to be oxidised into plant-available sulphate by *thiobacillus* soil bacteria. This process requires the availability of oxygen and moisture and only occurs within a certain temperature range.

Fine elemental sulphur (40-150 microns) can be combined with 5-10 percent swelling clay to form **sulphur-bentonite** pastilles. The minor clay component promotes microbial conversion into sulphate early in the growing season by dispersing and releasing sulphur particles into the soil. This helps guarantee the supply of sulphur throughout the season and minimises leaching losses. Sulphur-bentonite is widely-used to treat sulphur deficiency in the US and India and is suitable for blending as well as direct application. ■

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Urea-ES® – the answer to global soil sulphur deficiency?

The ability to incorporate elemental sulphur within urea granules to create a fertilizer carrier has excellent potential as an answer to global soil sulphur deficiency. This technology is already available for commercial implementation and offers many benefits, as **Bernd Peuckmann** and **Harald Franzrahe** of thyssenkrupp Fertilizer Technology explain.

The need to feed the world's growing population is creating higher fertilizer demand – which, in turn, is driving the need for extra fertilizer production capacity.

Yet the production and use of fertilizers still contribute significantly to the carbon dioxide emissions responsible for climate change. Therefore, both the fertilizer industry and fertilizer users need to find innovative ways to reduce their emissions. In our view, developing nutrient-rich products with a higher use efficiency is part of the answer and can help the fertilizer industry achieve this goal.

thyssenkrupp Fertilizer Technology is helping the industry improve efficiency and meet its climate goals by providing fertilizer producers with process options that add value to urea fertilizer products. In this article, we highlight new technologies capable of incorporating elemental sulphur at existing fluidised bed urea granulation and prilling plants. These show great potential to fill the growing global sulphur supply gap.

The global sulphur gap

Various factors are responsible for optimising plant growth and maximising crop yields. Suitable climate and weather conditions, soil texture, irrigation and the supply of nutrients are all essential. Sulphur is one of the six macronutrients necessary for plant growth, along with nitrogen, phosphate, potassium (NPKs), calcium and magnesium. A deficiency in just one of these essential nutrients can very easily become a limiting factor – one that cannot be compensated for by higher fertilization with the other nutrients.

New fertilizer products need to be developed in response to a clear market need. This can be judged by looking closely at crop nutrient requirements and the corresponding availability of nutrients for plant growth. Doing so clearly reveals that there is major global deficiency in the plant availability of sulphur. Various factors are responsible for this:

- Increased crop cultivation and higher sulphur removal from soils
- Greater use of sulphur-free mineral fertilizers
- A simultaneous reduction in the use of conventional organic fertilizers.

All three factors are leading to the depletion of sulphur in soils. The successful reduction of industrial sulphur dioxide emissions – by reducing the sulphur deposition that replenishes soils – has also significantly exacerbated these effects. The increase in heavy rainfall events globally, linked to climate change, is another influence on sulphur reduction in agricultural soils, as it causes severe leaching of plant-available water-soluble sulphate.

Urea-ES® – urea containing elemental sulphur

While the fertilizer industry has taken measures to address the problem, the global sulphur nutrient shortage has not been eliminated. Indeed, the sulphur containing products currently available on the market are not sufficient to close the ever-growing sulphur deficit in soils.

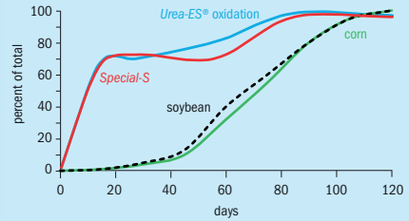
In 2015, this sulphur deficit was estimated to be approximately 10 million tonnes globally, according to The Sulphur Institute (TSI). As a result, the continuing lack of soil sulphur availability is reducing crop production in many areas.

Yet using a readily-available and commonly-applied fertilizer as a carrier product could offer a holistic answer to the global sulphur shortage. Urea makes an ideal and obvious candidate as a sulphur nutrient carrier, in our view, due to its large-scale availability, distribution and use, regionally and globally.

Elemental sulphur needs to be oxidised into sulphate form to make it available to crops. To improve the oxidation rate – and therefore plant-availability – the surface area of elemental sulphur particles must be significantly increased, e.g. by micronisation. This enables soil bacteria to oxidise sulphur more intensively and in a shorter time.

Shell and thyssenkrupp Fertilizer Technology (tkFT) have jointly developed a continuous *Urea-ES*® fluid bed granulation process for the production of sulphur-enhanced urea granules (*Fertilizer International* 492, p44). This integrated process combines Shell's *Urea-ES*® technology with tkFT's *UFT*® fluid bed granulation technology. In this innovative process, micron-sized particles of elemental sulphur (ES) are integrated into urea and homogeneously distributed via a sulphur dispersion unit.

Fig. 1: **Sulphur oxidation vs crop sulphur needs over time**



Source: Kent (2019)

Fig. 2: Urea-ES® product produced at tkFT's pilot plant in Leuna, Germany.

Table 1: **Advantages of *Urea-ES*® over urea ammonium sulphate (UAS)**

Urea + Ammonium Sulphate (UAS)	Urea + Elemental Sulphur (*Urea-ES*®)
• Grinding/milling step necessary (when using solid AS)	• Only liquid processing steps required
• Additional heating required to maintain heat and water balance • Close control of granulation temperature	• Lower heat release in granulator • Increases capacity • Granulator operation not changed
• Erosion of nozzles • Corrosion of piping	• No erosion • No corrosion
• CRH* lower than urea • Double moisture absorption in storage • Limited in S content of final product (<10 % S) • Leaching of sulphate	• CRH similar to urea • No effect on moisture absorption • Can add up to 20% S • No leaching of sulphate
• High costs for quality raw materials • Not locally available in large quantities • Additional storage	• Low cost raw material • Local resource
• Rapid degradation of urease inhibitors due to low pH	• No degradation of urease inhibitors

**CRH = critical relative humidity* *Source: tkIS*

This ensures a high availability of the sulphur nutrient throughout the entire growth phase of crops (Figure 1). The availability profile for micronised elemental sulphur ensures in-season sulphur supply and limits nutrient losses.

Shell's *Urea-ES*® process produces micronised sulphur particles with an average particle size of less than 30 microns. This emulsion is stabilised with the help of an additional Shell additive (*ThioAdd*®) before being granulated to the final product in the *UFT*® fluid bed granulation plant (Figure 2).

In this process, expensive urea solution is partially substituted with less expensive elemental sulphur, thereby reducing the overall cost for the producer. The sulphur-containing products obtained are also known to sell at a premium in various markets such as in North and South America and Europe.

Nutrient-rich compositions

Urea-ES® with a formulation of 40-0-0-13S contains 53 percent nutrients – compared to standard urea (46-0-0) which contains 46 percent nutrients. Another *Urea-ES*® formulation (35-0-0-24S) has an even higher nutrient density of 59 percent. Consequently, nutrient-rich *Urea-ES*® products, by saving on transportation and handling costs, have the potential to reduce the CO_2 impact of fertilizer products throughout the distribution chain.

The higher agronomic effectiveness of *Urea-ES*® fertilizer has also been demonstrated in the many agronomic trials conducted worldwide since 2014. Crop trial results show an equivalent and/or improved performance compared to existing nitrogen and sulphur fertilization practice.

Advantages of *Urea-ES*® vs urea ammonium sulphate (UAS)

A commonly asked question is: does *Urea-ES*® offer a competitive alternative to other urea products containing sulphur? – especially urea ammonium sulphate (known as UAS or urea-AS). This question can be answered with certainty in the affirmative, as urea with elemental sulphur, compared to urea with ammonium sulphate, has a wide range of known advantages (Table 1).

Importantly, the product does not need to be blended, unlike other sulphur-containing nitrogen products, creating an all-in-one source of nitrogen and sulphur. In addition, *Urea-ES*® is fully compatible with urease inhibitors, whose use is being increasingly required in more and more markets. Unlike the addition of ammonium sulphate, urease inhibitors are not degraded by elemental sulphur. In summary, this technology has the potential to add significant value for the fertilizer producer, throughout the distribution chain, and ultimately at farm level[1].

Conclusions

The innovative *Urea-ES*® fertilizer technology described in this article is making a valuable contribution to new legal and environmental requirements for efficient resource use. The ability to incorporate elemental sulphur within urea granules to create a fertilizer carrier shows excellent potential for reversing global sulphur deficiency in soils. This technology is already available for commercial implementation – enabling fertilizer producers to be well positioned to take advantage of changing market demand. ■

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Urea plant efficiency and reliability

Improvements to equipment and materials are driving greater operational performance and higher efficiencies at urea plants. Recent advances are reviewed.

Operational reliability is essential for the consistent production of urea in large volumes at the lowest possible cost. This is true in both newly built urea plants and older revamped units. Safety, reliability and efficiency have therefore emerged as primary considerations in urea plant design, process engineering, the selection of materials, and subsequent operational support.

For plant operators, three main considerations are uppermost:

- To ensure profitability and market competitiveness, the operation of urea plants needs to be predictable in terms of throughput and product quality
- The production process should also be capable of achieving the highest performance with the minimum operational expenditure
- Finally, the process must comply with the newest environmental and safety regulations and be designed to meet efficiency targets.

Critically, modern urea plants operate at much harsher pressure and temperature conditions than in the past. This requires the use of superior materials designed for higher durability. Greater care also needs to be taken during process operations and maintenance work if the highest safety and reliability standards are to be maintained throughout the plant's entire working life.

Historically, titanium and zirconium alloys have been widely used in urea plants because of their excellent corrosion resistance. More recently, super austenitic urea-grade steel has become widely adopted in critical equipment and plant components to reduce costs and further improve reliability.

CASALE

Uremium29 – a leap forward in equipment reliability

M. Fumagalli, L. Rugnone and P. Bertini

Casale, as a leading global technology licensor, brings added value to urea projects. This is thanks to its long-standing technology and mechanical engineering capabilities developed over several decades.

Casale, by improving process schemes, construction materials and its approach to mechanical design, has been able to drive down the consumption of medium pressure steam in urea plants. Urea production can also benefit from Casale's wide range of digital services for remote monitoring and optimisation of plant operations.

The benefits of super duplex steel

Casale in a joint collaboration with its partner Tubacex has developed and extensively tested *Uremium29*, a super duplex material for high pressure (HP) urea service.

The introduction of super duplex steel as a construction material has brought about a leap forward in urea plant equipment reliability. Super duplex steel is distinguished by its higher chromium content and lower nickel content relative to the super austenitic steels previously used. Steel alloys with this composition exhibit superior corrosion resistance by allowing ferritic and austenitic layers to be bonded in a 'sandwich' structure.

The use of *Uremium29*, when combined with the latest equipment designs, offers great benefits in newly constructed urea plants. The same approach can be implemented at vintage urea plants too – enabling small-to-medium capacity units to remain competitive after decades of service. The goal of most owners of vintage urea plants is to prolong the operational lifetime of their facilities, and reduce their opex to help them compete with the most modern installations. This can be achieved via maintenance interventions, end-of-life equipment replacement and debottlenecking revamps.

It is important to recognise that plant performance is determined by both mechanical and process reliability. For example, reliability issues (e.g., unexpected mechanical failure, prolonged downtime or a production slowdown) at an efficient but costly modern urea plant can cause a more drastic decline in gross margins relative to a less efficient vintage plant.

Uremium29 – multiple uses and benefits

Casale has accrued a number of *Uremium29* orders for critical HP equipment since this material was first introduced to the market in 2016. Its reliability and suitability was extensively investigated for a range of urea process conditions, in both stringent lab and plant tests, before being released to the market. Casale was determined to exploit the material's superior mechanical and chemical properties to boost the life expectancy of critical urea equipment – without compromising plant efficiency.

Uremium29 find its most natural use in those parts of the synthesis section of CO_2 stripping plants which are in contact with process fluids. In addition to critical equipment items, it is also highly suitable for piping, fittings, control valves and the critical components of process instrumentation. Its range of applications are described below.

High pressure Uremium29 stripper.

PHOTO: CASALE

Improving urea reactor conversion

A major benefit of super-duplex materials such as *Uremium29* is that they drastically reduce the oxygen required for passivation. In CO_2 stripping plants, those parts in contact with the process fluids of the HP stripper are traditionally made of *310 MoLN* steel. However, the required oxygen fraction (0.6-0.8 vol-%) in the CO_2 feed has a detrimental effect on conversion in the urea reactor. The use of *Uremium29*, in contrast, reduces the oxygen fraction to 0.3 volume percent. This improves conversion with a corresponding reduction in medium pressure (MP) steam consumption of 2-3 percent.

Thinner, lower weight tubing

Additionally, the increased resistance to corrosion and the superior mechanical strength of *Uremium29* allows thinner tubes to be used, so reducing the stripper's overall weight. This is extremely useful when replacing vintage strippers as it makes it possible to increase the number of tubes without the need for reinforcement of the support structure and foundations.

Capacity increases

The HP stripper is frequently the capacity bottleneck in vintage urea plants. Simply replacing this with a modern stripper equipped with *Uremium29* tubes can deliver moderate plant capacity increases. These tubes have a higher maximum load due to their larger internal diameter.

The same concept also applies to other critical items in urea stripping plants. Replacing a traditional *310 MoLN* carbamate condenser, for example, with a new condenser equipped with thinner *Uremium29* tubes increases surface area at comparable equipment weight. By generating low pressure (LP) steam at significantly higher pressure, the new HP condenser should make it possible to debottleneck downstream equipment and increase plant throughput.

Two-phase flow piping

Uremium29 is also ideally suited for process locations where two-phase liquid-gas flow and high fluid velocity may cause erosion-induced corrosion. This makes it a useful choice for two-phase flow piping, especially as a material for synthesis let-down valves which need to withstand heavy duty service for many years.

Self-stripping technology

The use of *Uremium29* in HP stripper construction is not limited to CO_2 stripping: the material can also be applied in self-stripping technology, also known as NH_3 stripping. This traditionally relies on zirconium, titanium or bimetallic (25Cr.22Ni.2Mo + zirconium) tubes to withstand the high temperature at the stripper bottom.

In Casale's view, *Uremium29* has great potential as a replacement material in bimetallic equipment when also combined with an improved NH_3 stripping process configuration. The latter involves installing a new level in the reactor top, typically by replacing the reactor cover. This separates the oxygen-containing vapour phase from the liquid phase at the reactor outlet. This is then driven to the new *Uremium29* stripper bottom to provide oxygen for passivation purposes.

This new configuration is advantageous as it enables the passivation air compressors to be idled. These require frequent maintenance and can also cause the undesirable entrainment of oil into the process. This type of configuration also delivers great benefits in terms of condensation and ammonia capture capacity – by reducing the overall pressure of inert gases in the synthesis loop and ammonia recovery sections of the urea plant. ■

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TOYO

Toyo's approach to improving urea plant reliability

Kenji Yoshimoto

Toyo Engineering Corporation (Toyo) is a leading global engineering contractor and urea process licensor. The Japanese-headquartered company has increased operational efficiency of urea plants by developing a range of technologies for improving reliability and safety. Its innovative technology line-up includes:

- *DP28W*™ super duplex stainless steel
- A leak detection system
- *AOCM*™ (Advanced Online Corrosion Monitoring)
- *IDCS*™ (Image Diagnosis for Corrosion Screening).

In Toyo's view, two recently introduced innovations, *AOCM*™ and *IDCS*™, will enhance the maintenance of critical equipment at urea plants.

DP28W™ – an advanced duplex stainless steel

Toyo has more than 40 years of experience on the use of duplex stainless steels at urea plants. These materials enhance equipment reliability and safety due to their excellent corrosion resistance to urea-carbamate solution. Their use also reduces the amount of passivation air required.

Building on this experience and responding to industry demand, Toyo and Nippon Steel Corporation (NSC) have developed *DP28W*™ (28Cr-8Ni-1Mo-2W) for urea plants. This advanced duplex stainless steel can greatly improve the safety and economics of urea plants over their lifecycle. It has outstanding features in terms of composition, mechanical properties and corrosion resistance:

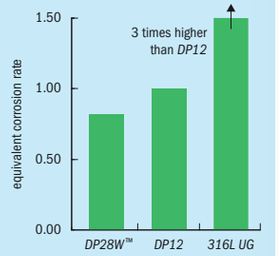
- **Composition:** *DP28W*™ shows excellent corrosion resistance due to its combination of the high chromium content, the addition of tungsten and a well-balanced ferrite/austenite structure. The molybdenum content is intentionally reduced to ensure good corrosion resistance in the heat-affected zone (HAZ). While the addition of tungsten compensates for the adverse effect of reduced molybdenum on corrosion resistance elsewhere.
- **Mechanical properties:** *DP28W*™ has remarkable mechanical properties compared to other stainless steels (Table 1). Its high mechanical strength, compared with austenitic stainless steels, such as 25Cr-22Ni-2Mo and *316L*, is a great advantage when it comes to the mechanical design of equipment.
- **Corrosion resistance:** the resistance of *DP28W*™ to corrosion by urea-carbamate solution has been proven in commercial plants, with, for example, a lower corrosion rate than alloys such as *DP12* and *316L-UG* (Figure 1).

Table 1: **Tensile test results for *DP28W*™ and other materials**

	Tensile strength, MPa	Yield strength, MPa	Elongation, %
DP28W™	934	647	42
DP12	822	610	42
25Cr-22Ni-2Mo	676	352	50
316L	518	234	52

Source: Toyo

Fig. 1: **Corrosion rate of *DP28W*™ versus other materials**



Source: Toyo

Lifetime advantages of *DP28W*™

DP28W™ provides advantages which contribute to the safety and economics of the urea plant throughout its lifetime. Its corrosion rate is lower relative to conventional duplex stainless steels. In particular, the corrosion resistance in the HAZ and weld metal are greatly improved. These positive features enhance equipment reliability and maintenance by:

- Prolonging the life of components exposed to urea-carbamate solution
- Decreasing maintenance frequency
- Reducing the risk of active corrosion.

Other notable operational advantages include:

- **Decrease of passivation air:** *DP28W*™ is easily passivated with less dissolved oxygen in urea-carbamate solution. As a consequence, the passivation air – which restricts operational efficiency due to lower conversion in the synthesis section and ammonia loss in the recycle section – can be reduced.
- **Design allowance:** *DP28W*™ has a higher allowable stress value and stress intensity value than austenitic stainless steels and conventional duplex stainless steels. This high mechanical strength provides a larger design allowance.

Operational experience with *DP28W*™

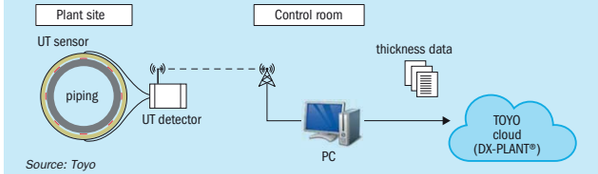
Toyo has applied *DP28W*™ at its urea plants since the mid-2000s with excellent performance to date. One operator, for example, replaced its existing titanium-lined urea reactor (used in the total recycle process) with a new one lined with *DP28W*™. Titanium requires little passivation air even at high temperature. Nevertheless, under the same severe operating conditions (200 bar, 200°C), the corrosion rate of *DP28W*™ has been far lower than titanium. The new *DP28W*™ fabricated reactor has reduced maintenance costs by around 90 percent since it first began operating successfully in 2006. The maintenance during each turnaround has mostly involved just visual inspections with no major repairs being required to date.

Leak detection system

The internal walls of high-pressure equipment in the urea plant are lined with proper corrosion-resistant metal plate to protect them during contact with corrosive fluid. This protection is important as any leakage through the lining plate will inevitably damage the outer carbon-steel pressure holding shell.

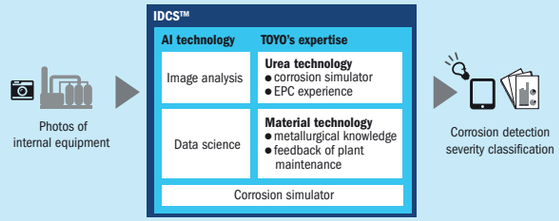
To detect and prevent such leaks, Toyo has developed an on-line leak detection system. This detects ammonia leaking into the nitrogen gas circulating between the lining plate and pressure holding shell. This system is able to detect ammonia leakage in tiny amounts and identify the location of the defect before damage becomes severe. It improves the reliability of the urea plant and helps keep maintenance work easy and simple.

Fig. 2: **Toyo's advanced online corrosion monitoring *AOCM*™ system**



Source: Toyo

Fig. 3: **Toyo's image diagnosis for corrosion screening (*IDCS*™) system**



Source: Toyo

Advanced online corrosion monitoring (*AOCM*™)

Assessing the real-time condition of stainless steels exposed to ammonium carbamate is particularly challenging. Toyo's advanced online corrosion monitoring (*AOCM*™) system is, however, able to predict the condition of such equipment and piping. The system helps to ensure reliable operations and optimise plant inspection plans by providing real-time corrosion monitoring of high-pressure equipment and piping in the urea synthesis loop. For example, *AOCM*™ can measure the corrosion rate in synthesis piping on a real-time basis via ultrasonic testing (UT) sensors installed in the piping (Figure 2).

Image diagnosis for corrosion screening (*IDCS*™)

Toyo's image diagnosis for corrosion screening (*IDCS*™) system is a new way to screen and detect the corrosion of equipment internals during plant maintenance. This system uses image analysis technology and artificial intelligence (AI) to efficiently inspect equipment during plant maintenance (Figure 3). The system provides high speed and reliable analysis by combining a range of AI technologies (image analysis, data science, corrosion simulator etc.) with Toyo's expertise. The advantages of *IDCS*™ include:

- Time saving and accurate visual inspections during plant maintenance
- Dependable estimates of timing for equipment repairs/replacements
- Condition-based maintenance with reduced opex. ■

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THYSSENKRUPP INDUSTRIAL SOLUTIONS

Self-regulating pumps for higher operating stability

C. Will and M. Wieschalla

Avoiding biuret formation is a well-known challenge for urea plant operators. This needs to be kept to minimum to avoid generating off-specification product. Biuret forms as an unwanted but inevitable side reaction when two urea molecules polymerise to eliminate ammonia. Its formation is accelerated by three main operational factors:

- Low ammonia concentrations
- High temperatures
- High residence times.

Every urea plant generally has a few locations where all three factors occur simultaneously. In this article, we focus on the outlet of the evaporation section and the melt transfer line to the granulation unit.

Dedicated transfer pump

A dedicated pump is required to transfer the urea melt leaving the evaporation section to the granulation unit. This is needed to ensure the necessary supply pressure for the granulator spray nozzles.

This transfer pump functions at a high NPSH (net positive suction head) to cope with the boiling melt that leaves the evaporation section under vacuum conditions – with a three metre suction head being a common value. While necessary to prevent cavitation, one undesirable consequence of a high NPSH is increased biuret formation. This is caused by the higher residence time of the urea melt in the pump suction line.

To avoid this scenario, thyssenkrupp Industrial Solutions (tkIS) offers a special self-regulating pump as an option for newly built urea plants. Compared to a conventional centrifugal pump, this self-regulating pump works well independently of the intake rate, i.e., its capacity always corresponds to the intake rate, so maintaining the NPSH at a more desirable value of close to zero metres. As a consequence, the suction head – and therefore the residence time of the melt – is kept to a minimum, leading to less biuret formation. This also avoids low melt levels which can trip the urea plant.

Fig. 1: Self-regulating transfer pump for urea melt: typical setup.

> **Self-regulating pumps provide the security necessary for stable urea plant operations, especially for the downstream granulation unit.**

Unstable urea supply

A nitrogen fertilizer plant consisting of just an ammonia unit and a urea unit will normally run smoothly without significant capacity changes. In more complex plants (e.g., consisting of urea synthesis, urea granulation, diesel exhaust fluid and urea ammonium nitrate units), in contrast, changes to the urea solution and melt supply to certain units are required when their capacity is altered to generate different product volumes.

Any resulting instability in urea solution supply to the evaporation unit can be an issue for the granulation unit. In such cases, the operator needs to adjust the load to the evaporation section, and therefore the transfer pump capacity, accordingly.

Yet care must be taken when reducing pump capacity, especially when using a conventional centrifugal pump. This is because reducing centrifugal pump capacity can easily trigger the dry run protection in the suction line, causing the downstream granulation unit to trip.

Self-regulating pumps offer advantages

This scenario is, however, avoided if a self-regulating pump is used instead. The self-regulating ability of this type of pump allows its capacity to adapt, matching the intake rate, without causing a trip in the pump or the downstream process unit. Self-regulating pumps, by easily handling capacity fluctuations, therefore aid the plant operator by reducing the risk of downstream units tripping.

The elimination of layout constraints at the outlet of the evaporation section is another advantage when using a self-regulating pump. For a conventional centrifugal pump, a long line is generally needed between the outlet of the evaporator and the pumps' suction flange, depending on the plant layout, in order to maintain the suction head. This inevitably increases melt residence time and, consequently, promotes biuret formation.

A self-regulating pump, in contrast, can be located directly below the evaporator outlet – because no specific suction head is required. The only consideration being the overall height of the pump frame and the required head space. A typical pump setup is shown in Figure 1. How close the pump can be placed to the evaporator, visible in the background, can be clearly seen.

Summary

In summary, the self-regulating pump provides security for stable urea plant operations, especially for the downstream granulation unit. This type of pump can be installed in newly built plants and during revamping. tkIS has gained a lot of good experience using self-regulating pumps in recent years, particularly with respect to efficiency and reliability. Furthermore, their use has improved plant layout, specifically the outlet of the evaporation section. tkIS holds the patent rights to install a self-regulating pump at this challenging location. ■

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STAMICARBON

Leak detection to ensure plant safety

Paul Jorissen

Ammonium carbamate – corrosion risks

Unlike the urea solutions ultimately obtained, ammonium carbamate, an intermediate in urea synthesis, is highly corrosive. Loose stainless steel liners are therefore commonly fitted to protect high pressure synthesis equipment from corrosion. Nonetheless, these liners still become thinner over time due to carbamate corrosion. They are also vulnerable to:

- Corrosion in the heat affected zones (HAZ)
- Condensation corrosion.

All of these types of liner corrosion can potentially cause ammonium carbamate to leak. A hazardous situation can then quickly arise, if carbamate-containing fluids enter the space between the liner and the carbon-steel pressure shell. Due to the risk of active and rapid corrosion of the carbon-steel pressure vessel, the urea plant needs to be shut down immediately when this happens – to keep operational staff out of danger and avoid damage to the pressure shell and the surrounding environment. Having a dependable leak detection system in place to monitor such leakages is therefore of paramount importance.

The benefits of leak detection

Stamicarbon, the innovation and license company of Maire Tecnimont Group, has designed a reliable leak detection system (LDS) that continuously monitors the lining for leakage. The system signals whenever a leak is detected.

The benefits of installing Stamicarbon's LDS include:

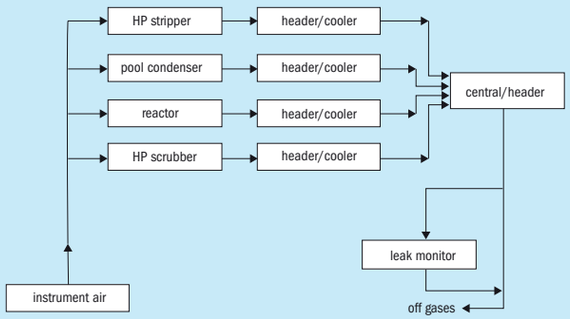
- Usage of a single system for more than one piece of high-pressure equipment
- Continuous monitoring for leaks
- Detection of a gas leak of $1*10^{-7}$ STD. cc/sec is possible
- Quick response time (under 60 minutes)
- The leakage rate can be calculated
- The location of the leak can be traced
- Improves reliability of the high-pressure equipment
- Significantly lower repair costs, due to early detection of a leak
- Reduced turndown period and production losses.

Stamicarbon also provides additional services, including:

- Inspection of the current leak detection system
- Assistance with installation, commissioning, and start-up of the LDS
- Training of operators and technicians
- Troubleshooting support.

In the event of a leak, Stamicarbon can also help repair damaged equipment and carry out relining to replace corroded liners.

Fig. 1: **Pressurised-type leak detection system**



Source: Stamicarbon

General operation and types of LDS

Leak detection systems use a gas monitor (analyser) to continuously measure gaseous ammonia concentrations. The gas monitor is connected to the annular space between the carbon-steel pressure shell and liner (together with the leak detection holes) via a header/cooler. The gas analyser detects ammonia concentrations as low as 1 ppm up to 1,000 ppm.

Stamicarbon offers leak detection systems based on three concepts:

- Pressurised-type leak detection
- Vacuum-type leak detection
- Combined (hybrid) leak detection.

Pressurised-type leak detection

The pressurised-type LDS is suitable for new high-pressure vessels. These generally have grooved passageways and at least two leak detection holes in each liner compartment.

In this system, instrument air is circulated in the gap between the liner and pressure shell (Figure 1). A pressure reducer regulates the supply of air into the system, while a safety valve prevents pressure in the system becoming too high. Tubing from each liner compartment ends in a header/cooler where the air is cooled to ambient temperature. A small part of the air is dried and fed into the leak monitor to continuously analyse for ammonia. The remaining air (off-gases) is released into the atmosphere.

The resistance met during circulation is not the same in each liner compartment. To equalize this and optimise the flow in each liner compartment, a flow meter and a control valve are incorporated into the tubing to the header (Figure 2).

Key features of pressurised-type leak detection:

- Ideal for newer high-pressure vessels with grooves (passageways) in the carbon-steel wall
- Highly reliable and accurate
- Easy to use and maintain
- Provides continuous readings to the distributed control system (DCS)
- Good diagnostics – receive proof of segment communication via a flowmeter
- Flowmeter readings immediately identify passageway blockages behind the liner – whereas vacuum-type or combined (hybrid) systems only identify these periodically
- Eliminates false alarms in tests from tube leakages caused by the entry of ambient air containing ammonia.

"During urea production, early warning of leaks is essential as they could lead to a catastrophic failure of high-pressure vessels.

Vacuum-type leak detection

The use of a vacuum-type leak detection system is advised if there is no passageway system between the lining and pressure shell, as is typical of older high-pressure equipment (Figure 3). In this type of LDS, fluids leaking into the liner are sucked continuously into a gas monitor using a vacuum pump. Tubing from each liner compartment ends in a header/cooler where the air is cooled to ambient temperature. A small part of the air is fed into the leak monitor to continuously analyse for ammonia. The remaining air (off-gases) is released into the atmosphere.

Key features of the vacuum leak detection:

- Ideal for older high-pressure equipment which have leak detection holes but no grooves
- Highly reliable and accurate
- Limited diagnostics – needs periodic tests to check segment communication
- Continuous DCS readings.

Combined leak detection

This type of integrated leak detection system is ideal for monitoring several pieces of older and newer high-pressure equipment. The newer equipment is monitored by the pressurised system and the older equipment with the vacuum system. Both systems work independently.

LDS maintenance

It is important to commission and operate the leak detection system according to the guidelines. Pressurised systems need safeguarding at 0.5 barg pressure, for example, while the vacuum system is inherently safe. Particular care must be taken not to over-pressurise the leak detection system during commissioning and plant shut down.

Leakage detections systems must be checked on a regular basis to ensure they are functioning properly. Blockage of the LDS (e.g., due to crystallised product leaking behind the liner), by hampering leak detection, may lead to a dangerous situation. Stamicarbon does not, however,

PRODUCTION TECHNOLOGY

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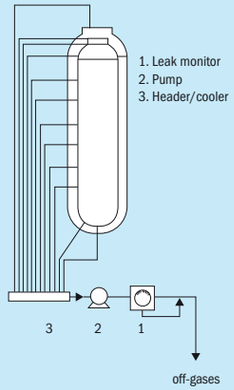
PHOTO: STAMICARBON

Fig. 2: Pressurised-type leak detection system. Header located at the bottom of a urea reactor. Flowmeters and control valves shown.

Fig. 3: **Vacuum-type leak detection system**



Source: Stamicarbon

recommend using steam condensate to unblock leak detection systems.

Potential leaks must be monitored closely. When a leak is identified and located, the plant must be shutdown to confirm and repair the leakage. This is necessary to avoid corrosion damage to the carbon-steel pressure shell.

Locating leaks

Within the liner compartment, leaks can be traced by searching each compartment with help of the valves on the header. When the leaking compartment is identified, the leak rate can be calculated from the ammonia content. This leak rate will determine the likelihood of finding the leak and the selection of the best method to discover it. Leaks mostly occur in liner welds and are commonly caused by welding defects such as porosities and so-called wormholes.

It is important to recognise that synthesis composition varies throughout the high pressure (HP) loop. It follows that the composition of fluid leaking through liner – particularly its ammonia concentration – will also differ from one place to another. The influence of synthesis composition on measured ammonia concentration therefore needs to be taken into account when calculating the leak rate.

Leak detection systems also need to have a quick response time. This is partly because any synthesis solution leaking between the liner and the carbon-steel pressure shell will contain urea as well as corrosive ammonium carbamate. This solution can dissociate and crystallise (as biuret or triuret) to block passageways and risks making detection impossible.

There are three recommended methods for finding a leak:

- Bubble leakage test
- Ammonia leakage test
- Helium leakage test

A bubble test is the appropriate method for bigger leaks. The pressure in the gap between the liner and carbon steel shell is increased to a maximum 0.3 barg using air or nitrogen. Leaks are then searched for by applying a soap solution on the liner welds of the suspected liner compartment. The detectable leak rate using the bubble method is in the range of $1*10^{-3}$ STD.cc/s.

An ammonia leak test is advised for smaller leaks. Air is firstly evacuated from behind the liner using a vacuum pump. Ammonia is then introduced behind the liner up to a maximum pressure of 0.03 barg. A coloured ammonia sensitive spray or paste is applied onto inspected welds. Leaks are then detected by a colour change.

In this leak test, the ability to detect small leaks depends on the 'dwell time' – the time taken for the ammonia to penetrate the leak. With a dwell time of 8-10 hours, for example, it is possible to detect leaks with a leak rate as small as 0.02-0.03 cc/hr.

The detectable leak rate using an ammonia leakage test is about a thousand times more sensitive compared to the air bubble test (i.e., around $1*10^{-6}$ STD. cc/s). However, a different strategy such as a helium leak test is necessary for the detection of even smaller leaks (down to $1*10^{-7}$ STD.cc/s).

Conclusions

During urea production, early warning of leaks is essential as they could lead to a catastrophic failure of high-pressure vessels, if left undetected. Stamicarbon therefore strongly advises that a state-of-the-art leak detection system (LDS) is installed to monitor high-pressure equipment protected with a liner. These systems are valuable as they can update operators continuously on the integrity of protective liners during everyday plant operations. Stamicarbon's LDS is reliable and, due to its ability to detect small leaks, enables plant managers to quickly find and repair leaks. Their reliability does, however, depends on correct operation and proper maintenance. The careful inspection of protective liners during normal plant turnaround also remains necessary. ■

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phosphates & potash INSIGHT

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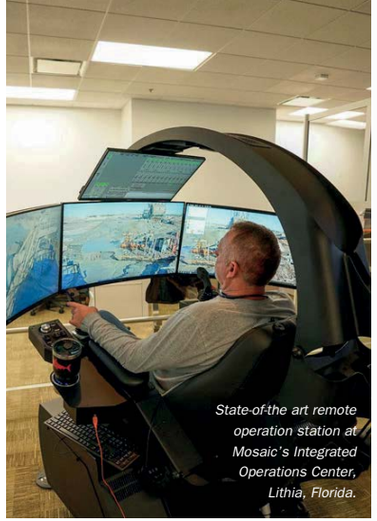
Crushing, conveying & screening

Efficient size preparation and ore transport are key prerequisites for successful potash and phosphate production. We highlight the range of equipment options.



State-of-the art remote operation station at Mosaic's Integrated Operations Center, Lithia, Florida.

PHOTO: MOSAIC

Phosphate and potash mining technology is undoubtedly changing. Wider mining industry innovations are being taken up by P and K producers to improve their operational and resource efficiency and meet sustainability objectives.

Mosaic for example, has opened an Integrated Operations Center at Lithia, Florida. This allows operators to remotely control high-pressure water guns used to extract phosphate ore from mining areas located many miles away (see photo).

Other phosphate producers such as PhosAgro have introduced in-pit crushing & conveying (IPCC). This improves mining efficiency, introduces mine electrification/ decarbonisation and reduces reliance of diesel-powered trucks.

New entrants to potash production such as EuroChem have also invested heavily in electrically-powered mining machines to extract potash ore underground.

The mining technology sector is also seeing merger and acquisition activity. In a major move, Denmark's FLSmidth agreed to purchase thyssenkrupp's mining business in July last year. Both businesses will, however, continue to operate independently as competitors until the necessary regulatory clearances are granted. This is expected to happen later this year.

Table 1: **Phosphate mining: Main excavator types and typical specifications**

Equipment type	Specifications	Equipment type	Specifications
Dozers		**Front-end loaders**	
Power	<650 kW	Payload capacity	12-40 m³ (<70 t)
Blade capacity	Up to 45 m³	Operating weight	110-270 t
Operating weight	110 t		
Electric rope shovels		**Bucket-ladder excavators**	
Payload capacity	19-130 t	Max. throughput	14,500 bcm/hr
Dipper	8-80 m³	Max. cutting height	+40 m to -30 m
Operating weight	1,500 t		
Large excavators		**Bucket wheel excavators**	
Power	477-3,280 kW	Typically for softer materials	
Bucket size	7-45 m³ (<90 t)		
Max. cutting height	20 m		
Walking draglines		**Continuous surface miners**	
Payload capacity	360 t	Power	450-3,340 kW
Bucket	12-170 m³	Max. cutting rate	2,800 bcm/hr
Boom	53-130 m	Max. cutting width	7.4 m
		Max. cutting height	2.9 m
		Working weight	40-540 t

Source: Dohm (2018)

Phosphate mining: excavation

The main digging equipment options for phosphate mining are set out in Table 1.

Selection criteria for digging equipment include[1]:

- Capital cost
- Material handling characteristics
- Type of face and bench operations
- Required ore throughput
- Productivity (cycle time per pass)
- Ease and cost of electricity distribution at the mine site.

German engineering giant **thyssenkrupp** has a strong equipment offering for phosphate mining. The company introduced its new *Barracuda* range of bucket wheel excavators in 2016 (*Fertilizer International* 495, p37). These compact mining machines use a larger number of teeth per bucket to cut materials with a compressive strength of up to 50 MPa.

The *Barracuda*'s innovative design allows harder materials to be excavated, including phosphate rock, potash and limestone, without the need for drilling or blasting operations. By combining ore excavation, loading and the transport within a single machine, the *Barracuda* can seamlessly replace a complex system of multiple machines with a single mining unit.

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PHOTO: THYSSENKRUPP

Operational Barracuda bucket wheel excavator.

thyssenkrupp offers four versions of the *Barracuda*, each with different ore transport configurations. They range from a compact machine and conveyor – for a basic extraction process – to the advanced *Barracuda C* machine. This combines a compact bucket wheel excavator with a discharge boom operating in tandem with a conveyor system.

The *Barracuda* has three particular features that make it an attractive excavation option for mine operators, according to thyssenkrupp:

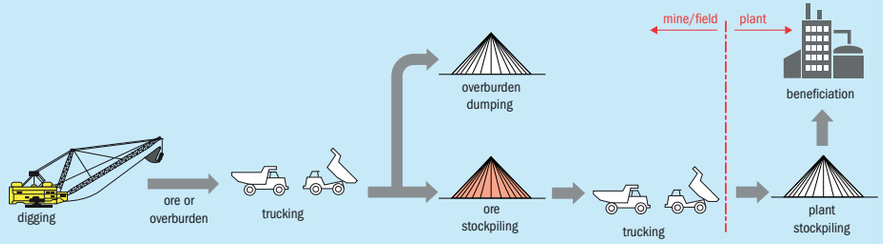
- Streamlines ore transportation
- Offers predictable operational costs
- Able to eliminate pre-blasting.

In ore transport, integrating the *Barracuda* with continuous mining/conveyor systems widens the range of potential mine applications and also delivers major cost reductions in comparison to conventional truck transportation. The machine's electrical drive can also reduce the carbon footprint of mining operations. One *Barracuda* machine, by potentially replacing more than 10 other mining equipment units, also streamlines both operations and maintenance efforts, according to thyssenkrupp.

But is the elimination of pre-blasting that is the main overall factor which makes the *Barracuda* a leaner, more cost effective and safer mining process option. Conventional bucket wheel excavators are unable to cope with harder ore materials and – unlike the *Barracuda* – still require blasting to fracture rock in-situ prior to extraction. The need for pre-blasting can add more than $0.2 per tonne to extraction costs – a major cumulative cost for multimillion tonne mining operations.

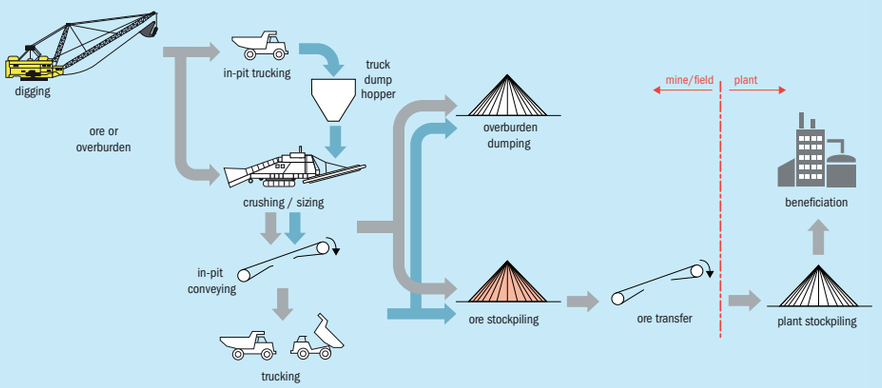
The *Barracuda*, by removing the need for drilling and blasting, can therefore offer significant cost reductions, especially for mine expansions or new mine projects which require investment in new equipment anyway. The use of *Barracuda* mining machines also offers a more sustainable alternative to blasting, which is subject to increasingly stringent environmental regulations for noise, fumes, dust and vibrations.

Fig. 1: **Phosphate mining with conventional diesel-powered truck haulage**



Source: Dohm (2018)

Fig. 2: **Phosphate mining by in-pit crushing & conveying (IPCC)**



In-pit crushing & conveying (IPCC)

Conventional phosphate mining is heavily reliant on diesel-driven truck haulage and is typically divided between several separate and discrete stages (Figure 1):

- Excavation of ore and overburden
- Trucking of these excavated materials to ore stockpile and overburden dumping area, respectively
- Trucking of ore from the mine stockpile to the plant stockpile for onward beneficiation.

In-pit crushing & conveying (IPCC) (Figure 2) can offer an attractive alternative to truck haulage due to its ability to[1]:

- Reduce operating costs and lower carbon emissions
- Substantially cut diesel consumption
- Reduce expensive consumables (tyres, filters, lubricants etc.) associated with truck haulage.

In certain circumstances, IPCC can also be a viable alternative to slurry pipelines as it[2]:

- Eliminates large-scale water use and consumption during mining and onward transport
- Improves efficiency of draglines and minimise delays in ore transport
- Achieves maximum operational efficiency by immediately evacuating ore from the vicinity of the dragline
- Offers the ability to measure and segregate ore based on quality using cross-belt analysers.

thyssenkrupp's IPCC system

In-pit crushing & conveying is a key capability offered by thyssenkrupp Mining (*Fertilizer International* 475, p54). The company's market leading IPCC system is designed to limit truck haulage to the movement of ore materials within the mine pit. Truck use is generally restricted to shuttling material, horizontally or downwards, to the semi-mobile crushing plant.

In terms of operational expenditure (opex), IPCC has the following advantages versus a conventional system using diesel trucks:

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- It is electrically driven with a higher efficiency than diesel motors
- Has a lifetime of up to 40-50 years with regular maintenance
- Significantly reduces operating personnel due to partial automation
- Increases mine safety
- Increases utilisation
- Reduces CO_2 emissions, the amount depending on the origin of the electricity used.

Although the investment costs are generally higher for a mobile or semi-mobile IPCC system, opex reductions can typically generate a return on investment within 2-4 years.

In 2015, thyssenkrupp successfully installed an IPCC system at the Koashvinsky phosphate mine near the city of Kirovsk on the Kola Peninsula in northern Russia. This is operated by OJSC Apatit, a subsidiary of fertilizer producer PhosAgro (*Fertilizer International* 475, p54).

The IPCC system designed for the Koashvinsky mine is a combined crushing unit with the capacity to handle up to 30 million tonnes of waste a year. The system needed to be able to accept materials with compressive strengths averaging 50-190 MPa up to a maximum of 320 MPa.

The hoppers installed have sufficient design capacity to accept trucks with a payload of up to 220 tonnes. The direct-feed crushing plant is also equipped with a gyratory crusher designed to accept 6,200 tonnes of material per hour.

IPCC also replaced previous truck haulage of waste materials outside of the mine. Instead, these materials are crushed to a conveyable size and transported by a curved conveyor over a distance of around four kilometres to an external waste site. At the end destination, a crawler-mounted spreader with an hourly capacity of 6,200 tonnes then discharges material from the conveyor.

The IPCC system has substantially cut the Koashvinsky mine's operating costs, maintenance costs and CO_2 emissions. It also provides a higher level of operational safety.

Conveying

Conveying is an integral function for:

- The movement of potash and phosphate ore and waste during mining operations
- Transporting materials between equipment and process stages during fertilizer production.

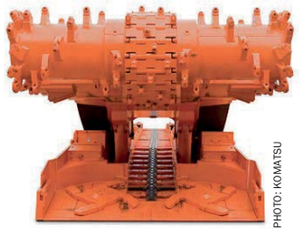

PHOTO: KOMATSU

Komatsu's Joy 12HM46 electrically-powered continuous mining machine is specifically designed for mining salt, potash, gypsum and trona.

For IPCC systems at phosphate mines, equipment options for in-pit conveying are generally selected based on the following criteria[2]:

- Capital cost
- Mobility requirements
- Whether there is the flexibility for re-configuration
- Potential for standardising the main equipment components and modularisation
- Incorporation of features that reduce opex costs and downtime
- Ability to upgrade the system to increase production.

Portable modular conveyors, mobile conveyors, beltwagons and bridge conveyors can all be installed as part of an IPCC system[2].

Portable modular conveyors are short (<60 metre) relocatable or crawler-mounted structures. Multiple units can be connected in series to mine irregular areas, or to extend the reach of the mine face conveyor. They can also be used when transfer angles make it difficult to connect two conventional relocatable conveyors. Mobile conveyors, in contrast, are up to two kilometres long, capital intensive, yet can be easily moved out of the way during blasting.

Beltwagons and bridge conveyors are typically used for cross-bench conveying. Beltwagons are available in various configurations and lengths and can be used to convey materials up or down a bench, or transfer material between the face conveyor and a mobile sizer/crusher unit. Bridge conveyors can move material up or down two benches maximum. They can also be used for the dumping of materials cross-pit.

Continuous potash mining and haulage machines

Continuous miners have a long history. They were first popularised by the underground coal industry in the 1960s and have since become a mainstay of potash, gypsum and salt mining (*Fertilizer International* 475, p54). **Caterpillar**, for example, supplied four *CM345N* continuous miners for the Vanscoy potash mine in Saskatchewan, then owned by Agrium, while a fleet of five automated Sandvik (formerly Marietta) continuous miners were put into operation at the province's Rocanville mine formerly owned by PotashCorp's. PotashCorp subsequently ordered a fleet of **Sandvik** *MF420* borer miners for the now mothballed $1.5 billion Picadilly mine in New Brunswick. These massive borers were the world's largest self-propelled mobile underground mining machines at the time.

The productivity of continuous miners has more than tripled in the last decade. Increases in their size, weight and power means they can now operate at more economic production rates than traditional drill and blast methods.

Joy Global, the US mine machinery manufacturer, has sold over 6,000 continuous miners globally. The company was purchased by its Japanese rival **Komatsu** for $3.7 billion in 2016. Joy introduced the first single-operator continuous haulage system, the Flexible Conveyor Train (FCT), to the industry in the late 1980s. This optimised production by offering true continuous mining and haulage without the delays typical of batch loading. The firm also pioneered innovations such as radio remote control and AC traction drive systems in continuous miners.

Potash miners have placed more than 70 orders for Joy continuous miners, FCT systems and other equipment. The firm's continuous miners are used by US producer Intrepid Potash at its New Mexico mine in the US and by ICL at its Boulby mine in the UK.

Komatsu's *Joy 12HM46* electrically-powered continuous mining machine, released in 2016, is specifically designed for excavating salt, potash, gypsum and trona (see photo). It incorporates upgrades, designed to increase service life and reduce total cost of ownership, as well as delivering a production increase of up to 20 percent on earlier models.

The *12HM46* has a production rate of up to 1,000 tonnes per hour. It also provides greater cutting stability, due to its greater mass, and also employs an upgraded traction drive system. Outputs above 8,000 tonnes per day should now be achievable, suggests Komatsu, by combining the *12HM46* with continuous haulage in a herringbone or multi-pass production system.

Continuous haulage

When it comes to continuous haulage, the 1,200 t/h capacity *Flexiveyor* designed and produced by Prairie Machine and Parts (PM&P) in Saskatoon has proven to be a popular choice in the potash industry (*Fertilizer International* 475, p54).

The *Flexiveyor* employs a number of interconnected 20-foot-long cars. These form a fixed-length, train-like haulage system. Each *Flexiveyor* consists of a loading car, which accepts ore from the miner, and conveys this via a series of intermediate cars to a final car which discharges the ore onto a panel belt. They can be used in combination with PM&P's continuous miners, the *Xcel* series rotary boring machines, or installed behind other types of mining machine.

Some 20 *Flexiveyor* systems are installed in potash mines in Saskatchewan – Nutrien's Vanscoy mine being one – and other locations worldwide, including the UK and New Mexico. A 300-foot long 15-car *Flexiveyor* configuration is typically used in Saskatchewan's potash mines. Haulage is controlled via an operator interface using an industrial computer.

Potash mining machine investments

In the last few years, EuroChem has invested heavily in the latest generation of electric mining machines at its $2.1 billion Usolskiy potash mine in Russia's Perm region its sister $2.9 billion VolgaKaliy mine in the Volgograd region The same potash mining equipment is being installed at both mines (*Fertilizer International* 495, p37). The following mining machines, transfer hoppers and shuttle cars have been installed at both sites to excavate and transport potash ore to the main underground conveyor systems:

- ***Ural-20R* mining machines.** These cut an arched roof 3.1 metres high and 5.1 metres wide. Each machine is approximately 12 metres long and weighs 100 tonnes. They are crawler-mounted and electrically-powered each with an average annual capacity of around 600,000 tonnes.
- **Transfer hoppers.** These operate immediately behind the *Ural-20R*. Being electrically-powered, and approximately 8.4 metres long and 2.3 metres wide with a capacity of 16 tonnes, they are equipped with a conveyor system to transfer ore to waiting shuttle cars.
- **Shuttle cars.** These shift the mined potash to the conveyor system, which in turn transports the ore to the shaft where it is lifted to the surface. The cars operate using a trailing cable on a reel, allowing them to travel a distance of up to 400 metres. Each shuttle car is approximately 9.0 metres long and 2.6 metres wide, weighs 19 tonnes, and has a 17-tonne payload capacity.

Ural-20R mining machines are manufactured by **Kopeysk Machine- Building** in Russia's Chelyabinsk region. The Usolskiy mine, for example, originally purchased 20 *Ural-20R* units, with these being added to during its ramp up to full capacity. ■

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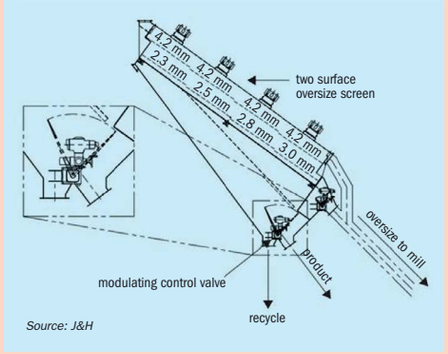
Screening at phosphate granulation plants

Fig. 3: **A double-deck screening machine with modulating control valve in hopper & product discharge**



Source: J&H

J&H Equipment, Inc

J&H was founded in 1974 by Allen Jackson and Cliff Hollyfield. The company has since grown to become a world leading supplier of screening equipment to fertilizer granulation plants globally. Notably, J&H was the first company to design and manufacture rotary-driven vibrating wire screening machines. These overcame many of the shortcomings of conventional machines, such as noise, high maintenance requirements and poor efficiency.

Thousands of J&H screening machines now operate around the world. The company's wide range of plant machinery also includes crushers, bucket elevators, lump breakers, feeders, stream splitters and modulating control diverters – all of these essential components of modern fertilizer granulation plants (*Fertilizer International* 490, p54).

J&H offers complete screening equipment packages for the fertilizer industry. These operate as fully-controllable and integrated screening process systems. J&H chain mills also optimise the crushing of oversize fertilizer product. For the phosphate industry, a screen fines hopper fitted with an integrated modulating control valve allows precise computer-control of recycle material to the granulation process. This in turn reduces oversize, generates a closer sized final product and – most importantly of all – increases production by ensuring that the other machinery in the granulation plant is operating optimally.

The major design innovation and biggest performance breakthrough in process screening in recent years has been the adoption of double-deck oversize screening machines. This configuration was first introduced by WMC Resources (subsequently BHP and Incitec Pivot) in Australia. The top deck of these machines has a standard 4.2-4.4 mm opening. The openings in the bottom deck, in contrast, vary across their length, starting at 2.2 mm in the first panel and ending with 2.7-3 mm in the last panel (Figure 3). This double-deck arrangement, when used in conjunction with modulating control valves in the hoppers below the fines deck, allows the operator to select the size and amount of recycle returned to the granulator.

The RHEWUM Company

Germany's **RHEWUM** has been manufacturing screens for more than 70 years now. Founded in Remscheid in 1927, its name is derived from 'Rheinische Werkzeug und Maschinenfabrik' – which simply translates as 'tool and machine production company'. The company's overriding goal is to maximise customer satisfaction by delivering the highest quality standards in screening technology.

RHEWUM has been able to react to changing market preferences by constantly improving its equipment portfolio to meet the new demands of customers. It has remained a market leader in screening technology for fine particles such as fertilizers by developing modular 'plug-and-play' screens.

The latest modern screening technologies introduced by RHEWUM are designed to maximize quality and efficiency. Its *RHEsono* and *RHEmoto* screening machines (see photos), for example, can meet the demanding specifications required for screening phosphate fertilizers.

These two types of machine prevent clogging by direct excitation of the screening meshes at high acceleration. Inclining the mesh at an angle (see bottom photo) maximises throughput by allowing materials to flow at high velocities. Their static machine body, meanwhile, allows maintenance to be carried out without stopping production. This intelligent design allows the replacement of motors and settings to be changed while operations continue.

PHOTO: RHEWUM

RHEWUM's RHEmoto screening machine.

PHOTO: RHEWUM

Vibrating screen on RHEWUM's RHEsono screening machine.

The main requirements for phosphate screening machines are to deliver a high-quality product at high throughput with minimal downtime for maintenance. The desired size separation (typically 90 percent sized between 2-4.5 mm) is a screening challenge due to factors such as clogged meshes. Furthermore, customers demand a high-quality, closely-sized product to ensure that the fertilizer will function efficiently and have a low environmental impact.

Directly-excited screens

The main design concept behind the *RHEsono/RHEmoto* screening machines is directly-excited screen meshes. These are positioned at an angle to ensure the transport of materials across the whole screen. With direct excitation, it is possible for the screen to reach an oscillation frequency of 50 Hz with particle accelerations of up to 15g. These performance values – which cannot be replicated by other screening machine designs where the whole body moves – result in much higher screening efficiencies per unit area.

Key features are as follows:

- **RHEWUM drives**. The screen oscillation and beating movement is generated by two available types of drive – the *RHEsono* and *RHEmoto* drives – each of which is suited to different tasks. The *RHEsono* drive is a special, easy-to-install technology developed by RHEWUM. It can be adjusted electrically via a potentiometer and needs little maintenance. The simple and more robust *RHEmoto* drive, meanwhile, is based on an unbalanced motor. It is more suitable for dry and easy flowing materials that tend not to clog the meshes.
- **Mesh tensioning system**. Each deck has its own screen cloth. These can be changed individually without requiring the removal of other cloths. This is a very useful option, as different wear rates mean every screen cloth will have its own individual maintenance interval. Overflows from each deck are collected and discharged via an overflow chute. This is pivoted to allow access to the cloth tensioning system for the outlet half of each deck. The inlet half, in contrast, is easily accessed via back inspection doors on top of the screening machines. The tensioning system is also designed for quick tensioning and the easy changing of the cloths.
- **Flexible screening process**. The capability to adjust every single drive is what keeps the screening process flexible. Ensuring that the inlet drives are on a stronger setting than the outlet drives, for example, mixes up materials and breaks down agglomerates. A lower amplitude outlet setting also improves the probability that near-sized particles will pass the mesh. The steep deck angle keeps material moving across the screen, even if individual drives are switched off. This maintains screen availability even when individual drives fail. The timing of the cleaning cycle, being flexibly programmed, is adjustable during production. The cycle is generally determined by how long and how often the drives need to be turned to maximum to free clogged particles from the mesh. ■

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Serra do Salitre project profile

PHOTO: EUROCHEM

EuroChem Group recently completed the purchase of the Serra do Salitre project from Yara International for $452 million. This one million tonne capacity Brazilian phosphate project is due to be completed in 2024.

Above: The Serra do Salitre fertilizer complex includes a sulphuric acid plant, phosphoric acid plant and a fertilizer granulation plant.

Brazil's growing phosphates supply/demand deficit over the next decade will have to be met by more imports and/or increases in domestic production capacity. The latter is set to receive a substantial boost when the Serra do Salitre project becomes operational in 2024.

Flagship investment project

Swiss-headquartered EuroChem Group is the new owner of the under-construction Serra do Salitre phosphate project in south-eastern Brazil. This follows the completion of the purchase from Norway's Yara International for $452 million on 22nd February. The acquisition was originally announced last August (*Fertilizer International* 504, p9).

This well-advanced flagship project is said to be the largest ever private sector investment in Minas Gerais state. It is also ideally located, being close to Brazil's major fertilizer-consuming markets. Serra do Salitre started life in 2014 as a joint venture between Yara and Brazilian producer Galvani, before becoming 100 percent Yara-owned in October 2018 (*Fertilizer International* 488, p45).

The project represents a major expansion of Brazilian fertilizer production capacity. Once operational, its output will displace one million tonnes of phosphate fertilizer imports, helping to reduce the country's reliance on international supply and yawning trade deficit in fertilizers.

The purchase is part of EuroChem's growth strategy for Latin America, one of the world's largest and fastest-growing regional fertilizer markets. It follows the company's buy-out of Fertilizantes Tocantins for $230 million in 2020 and the acquisition of a controlling share in Fertilizantes Heringer last December – two of Brazil's leading fertilizer distributors.

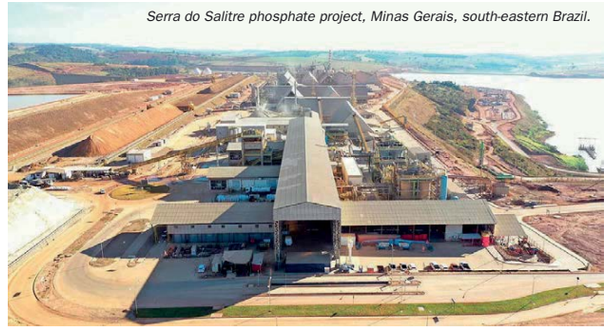
Brazil is the region's pre-eminent fertilizer market and a global agricultural powerhouse. The country consumed 46.0 million tonnes of fertilizers in 2021, a year-on-year increase of 5.4 million tonnes.

Commenting on the acquisition of Serra do Salitre last August, EuroChem said:

"Brazil is one of the world's biggest fertilizer markets, and phosphates are considered to be one of the three primary nutrients… that plants require for healthy growth. Due to nature of the crop mix in Brazil – 44 percent of which is soybean – Brazilian demand for phosphate-based fertilizers is higher than in other regions, with half of consumed phosphate fertilizers within the country covered by imports.

"Serra do Salitre is strategically located within Brazil's agricultural heartland, where domestic demand is robust. The phosphates it supplies will slot seamlessly into EuroChem's production and distribution operations."

Serra do Salitre is one of the largest industrial investments currently underway in Brazil. Previous owner Yara invested $229 million in the project in 2020, following similar substantial investments in 2018 and 2019 (*Fertilizer International* 502, p26). EuroChem says it will now invest a further $452 million (approximately) to bring the project into production.



Serra do Salitre phosphate project, Minas Gerais, south-eastern Brazil.

PHOTO: YARA

Two phase project

The Serra do Salitre project is divided into two phases. The initial phase, which came onstream in 2018, involved the completion of a 1.2 million tonne capacity phosphate rock mine and associated beneficiation plant. This delivered its first 150,000 tonnes of mined rock in early 2018. A one million tonne capacity production plant for finished phosphate products is now scheduled to be completed, as part of the project's second phase.

Building a fully integrated fertilizer production plant in Brazil is a costly, complex and highly ambitious venture. Almost inevitably, there has been some slippage in project delivery, partly due to the Covid-19 pandemic, with finished phosphate production originally due to start the first-quarter of 2020. This was subsequently rescheduled to the second-half of last year. Under a new timetable, EuroChem now plans to start production by 2024 and then ramp up to full capacity in 2025.

EuroChem buys Serra do Salitre from Yara

EuroChem Group completed the purchase of the Serra do Salitre phosphate project from Yara International for $452 million in February. The deal was originally announced in August last year.

Serra do Salitre is an integrated phosphates project located in Minas Gerais state in south-eastern Brazil. It combines a 1.2 million tonne capacity phosphate mine – and access to more than 350 million tonnes of reserves – with a one million tonne capacity phosphate fertilizer plant. This is capable of manufacturing MAP/NP and SSP/TSP products.

The project also includes a sulphuric acid plant, a phosphoric acid plant, and a 400,000 tonne capacity storage unit for granulated fertilizers such as urea and potash.

Although Serra do Salitre is a well-advanced project that has been under construction since 2015, further capital expenditure of around $452 million will be required to complete the project. "Salitre remains an attractive project, but as previously communicated the project's progress has been impacted by Covid 19, and significant construction time and capital expenditure remains to reach completion," Yara said in a statement last August.

The project's mine and beneficiation plant are already operational (*Fertilizer International* 502, p26) and currently producing around 500,000-600,000 tonnes of phosphate rock. This is generating positive earnings from third-party concentrate sales. The under-construction phosphate production complex, meanwhile, is now due to become operational in 2024.

Brazil is an agricultural powerhouse with a high demand for phosphate fertilizers due to the scale of crop production and its crop mix, particularly the prevalence of soybean cultivation. As a domestic producer, Serra do Salitre should be strong position to capture market share, given that the country currently depends on imports for half of its phosphate requirements. The project is also strategically located within Brazil's agricultural heartland, where domestic fertilizer demand is strong.

"This expansion will allow us to reduce dependency on third-party phosphate supplies, and also creates the potential for phosphates and complex fertilizer production in Brazil," said Vladimir Rashevskiy, EuroChem's CEO. "It significantly improves our competitive position in Brazil, and enables us to leverage the extensive blending and distribution capabilities brought by the acquisition of Fertilizantes Tocantins, which we completed last year."

Yara said the divestment was a strategic move that would allow the Norwegian fertilizer giant to focus on new priorities such as premium products and the hydrogen economy.

Once brought on-stream and fully ramped-up, Serra do Salitre will add an extra one million tonnes to EuroChem's existing annual phosphate and complex fertilizer output of five million tonnes. EuroChem already operates two phosphate mines – the Kovdorskiy GOK facility in northern Russia and EuroChem Fertilizers in Kazakhstan. The Swiss-headquartered company currently manufactures a range of premium-quality MAP, DAP, NP and feed phosphates at several production sites in Russia and Lithuania. ■

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The widespread cultivation of soybean in Brazil requires large applications of phosphate fertilizers – which have to be supplied domestically or imported.

PHOTO: UNITED SOYBEAN BOARD

The scale of the project is such that it will increase national P_2O_5 production by around 20 percent when it does finally start up. Once fully operational, Serra do Salitre will generate:

- 900,000 tonnes of sulphuric acid
- 1.2 million tonnes of phosphate rock
- 250,000 tonnes of phosphoric acid
- One million tonnes of granulated finished phosphate products
- More than 1.2 million tonnes of gypsum
- 1,500 jobs during the operational phase
- Around 29 MW of energy.

Mining and beneficiation

Serra do Salitre's transition-to-operation (TTO) began in 2017. This set 20 milestones and was vital to ensuring the successful on-time delivery of phase one of the project (*Fertilizer International* 488, p45). With the completion of the first phase of the project, phosphate rock is now being extracted and upgraded using froth flotation to produce a phosphate concentrate. This was being supplied to Yara's Paulínia production plant in Sao Paulo state.

With ore reserves of more than 350 million tonnes, Serra do Salitre's phosphate mine has an estimated life of 25 years. Friable ore is extracted by excavators at the open-pit site and transported using a fleet of 30-tonne Volvo articulated trucks and 35-tonne Mercedes-Benz trucks. The ore is crushed at the mine before being transported to the beneficiation plant via a two-kilometre belt conveyor. Apatite-bearing ore with a P_2O_5 content of 4.7 precent is then upgraded in the beneficiation plant to produce a high-grade phosphate concentrate containing 33 percent P_2O_5 (*Fertilizer International* 502, p26).

Phosphate fertilizer production

Following successful completion of the first phase in 2018, a second construction phase to complete the project's fertilizer production complex was due to finish in the second half of 2021 (*Fertilizer International* 502, p26). However, this timetable has been revised by new owners EuroChem with the project now expected to become fully operational in 2024.

The Serra do Salitre complex includes a sulphuric acid plant, phosphoric acid plant and a fertilizer granulation plant. The project was around 50 percent complete, as of last August, although the mine and beneficiation plant are already producing positive earnings.

Serra do Salitre will eventually ramp-up to annual production of 1.2 million tonnes of phosphate concentrate and one million tonnes of finished phosphates. Its product mix will include diammonium phosphate (DAP), monoammonium phosphate (MAP), nitrophosphate (NP), single superphosphate (SSP) and triple superphosphate (TSP).

The amount or piping alone provides some indication of the scale-up in construction work between phases one and two of the project. in phase one, the mineral processing plant required 700 tonnes of piping, whereas around 3,000 tonnes of pipework are being installed during phase two construction (*Fertilizer International* 502, p26).

Once operations begin and production then ramps-up, granulated fertilizers will be stored on site in two purpose-built 180,000 tonne capacity warehouses constructed from treated eucalyptus wood and reinforced concrete. These conical shaped and 30 metre-deep structures are partly underground and feature a fully-automated loading and unloading system. Materials enter the upper part of each warehouses and exit at the base, via a conveyor built within an underground concrete tunnel (*Fertilizer International* 502, p26).

Controlling share in Fertilizantes Heringer

EuroChem bought a 51.48 percent share in the major Brazilian fertilizer distributor Fertilizantes Heringer in December last year. The part-purchase will substantially strengthen EuroChem's production and distribution reach in one of the world's largest crop nutrient markets.

Fertilizantes Heringer is Brazil's fourth-largest fertilizer distributor on a capacity basis. The company has the ability to distribute more than four million product tonnes annually via a total of 14 storage, blending and distribution units in Brazil's southeast, mid-west, south and northeast regions.

The controlling share in Fertilizantes Heringer forms part of EuroChem's wider growth strategy for the Brazilian market. It follows an agreement to purchase the Serra do Salitre phosphates project from Yara in August last year (*Fertilizer International* 504, p9), as well as the complete buy-out of distributor of Fertilizantes Tocantins in 2020.

"This acquisition …will enable EuroChem to better serve the total market of Brazil – from north to south – even more reliably, while providing more outlets for our full product line of standard and premium fertilizers," said Charles Bendaña, EuroChem Group's global head of sales and distribution.

He added: "It will also help us achieve higher efficiency in our shipping and logistics programs in order to provide reduced costs to our customers in Brazil, as well as increased netbacks to our global production facilities. Taken with our recent full acquisition of Fertilizantes Tocantins and the purchase of the Serra do Salitre phosphates project, this move will help anchor the Group as a leader both locally and abroad."

Lieven Cooreman, the CEO of EuroChem Fertilizantes Tocantins, and the head of EuroChem's South American commercial division, said: "With Heringer joining a South America distribution base that already includes EuroChem Fertilizantes Tocantins in Brazil and EuroChem Emerger Fertilizantes in Argentina, this deal, once approved, will cement our reputation as the crop nutrient supplier of choice across great swathes of the continent. This naturally gives our customers added confidence in our ability to cater to any crop anywhere, in a timely manner."

The acquisition – which is valued at nearly BRL 555 million – will require the approval of CADE, Brazil's antitrust authority.

Heringer reported 12-month fertilizer sales of 1.5 million tonnes last year (October 2020 to September 2021). ■

Author's note

This article was prepared and written in mid-February prior to the start of the Russia-Ukraine conflict.

EXCLUSIVE INTERVIEW

Lieven Cooreman, CEO EuroChem Fertilizantes Tocantins, Head of Commercial Division, EuroChem South America

How important is Serra do Salitre for ensuring long term phosphate supply, and how will it strengthen EuroChem's strategic position in Brazil? Brazil imports approximately 75-80 percent of the fertilizers necessary for its agricultural production. Serra do Salitre's production capacity of one million tonnes a year means that agriculture, which contributes significantly to Brazil's GDP, will be less dependent on external fertilizer sources. The project also provides EuroChem with a competitive advantage – by adding a technologically advanced asset to the company's portfolio and improving our phosphate market position globally. Within Brazil, the project's location is also a strategic advantage, being at the logistical centre of an important agricultural area.

What are the main project challenges, and how confident is EuroChem that it can complete Serra do Salitre to the new 2024 timetable and have it operating at full capacity by 2025? EuroChem's track record in project delivery is remarkable and will be crucial for Salitre's swift delivery. The local and global project teams are in close contact, exchanging lessons and evaluating what actions need to be implemented.

The main challenge right now is for the project to resume as quickly and as safely as possible, and to conclude the most advanced stages without further delay. The most critical aspect of construction will be the coordination between sites, such as the chemical (sulphuric and phosphoric acid) production plants and the fertilizer granulation plant.

We believe the plant will be working at full capacity by 2025. The key to success will be the rigorous selection of suppliers and contractors, as well as a dedicated and experienced team fully committed to the deadline and the delivery of results.

According to some estimates, Brazil could face a two million tonne (P_2O_5) supply deficit by 2030. How vital, therefore, is Serra do Salitre for cutting the growing fertilizer import reliance of this global agricultural powerhouse? The projected deficit for 2030 will be mitigated by Serra do Salitre coming into operation by 2024. The project is of great importance as its one million tonne per year output will give Brazilian farmers access for the first time to locally-produced, high-quality nutrients.

Does Serra do Salitre offer logistical and cost advantages that will help displace higher cost phosphate imports – and reduce the risk of supply shortages that can occur with the current reliance on long distance truck haulage from the coast? The project is located in a privileged place: in the heart of Minas Gerais state close to the country's agricultural frontiers. This is undoubtedly a competitive advantage as it will allow farmers easier and faster access to a supply of lower cost nutrients. Fertilizer distribution will also be more dependable and sustainable due to the shorter transportation distance and the consequent reduction of emissions.

What phosphate product mix will the project provide and what particular crop types will be specifically targeted? The Serra do Salitre plant, due to its highly flexible capacity, will be capable of producing a wide range of fertilizers. These will be mainly aimed at soybeans and corn crops. There are also plans to produce more sophisticated and specific fertilizer compounds for other crops too.

How will production at Serra do Salitre link up with existing distribution and blending infrastructure? The project will offer clear synergies due to its ability to be perfectly integrated into EuroChem's distribution network and blending facilities in Brazil. In fact, this crucial advantage influenced EuroChem's investment decision. Having an asset the size of Salitre, together with EuroChem's other plants, allows us to better serve Brazil's farmers by combining competitively priced, high quality products with predictable deliveries. ■

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