POLY4

PRODUCT HANDBOOK

POLY4 — A GAME-CHANGING FERTILIZER

POLY4 is the trademark name for polyhalite product from Anglo American's Crop Nutrients business.Polyhalite is a naturally-occurring, low chloride, multi-nutrient fertilizer containing four of the six essential macro nutrients required for plant growth.

Using POLY4 as the source of potassium, sulphur, magnesium, and calcium is more efficient and effective for farmers, delivering flexible and more sustainable fertilizer practices. It allows farmers to maximise the economic potential of their land by providing increased crop yield and quality, and improved soil structure with one simple product.

K_2O	S	MgO	CaO
14%	19%	6%	17%

$K_2SO_4MgSO_42CaSO_42H_2O$

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THE POLY4 CORNERSTONES

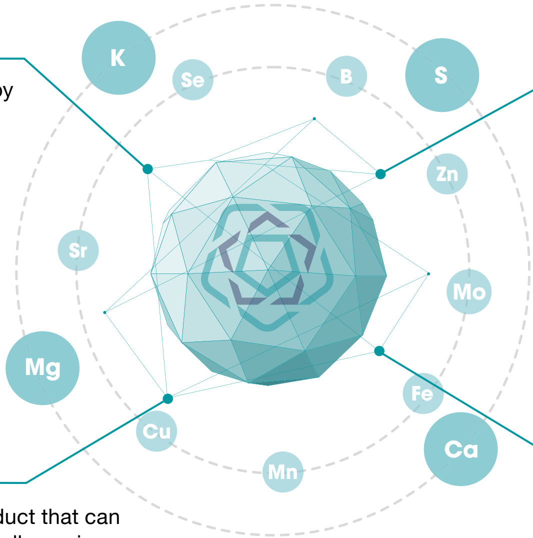
POLY4 has four key attributes that benefit farmers by increasing their profits in a sustainable way through improved yields, reduced costs or both. Using POLY4 as a source of nutrients in fertilizer plans also improves crop quality. This is due to the wide spectrum of macro and micro nutrients which are available over a timeframe that reflects crop requirements.

EFFICIENCY

- Improves fertilizer use efficiency by delivering greater nutrient uptake.
- High nutrient density – supplies four macro nutrients in one easy-to-use, cost-effective granular delivery system.

EFFECTIVENESS

- Improves both yield and quality.
- Improves macro and micro nutrient uptake.
- Minimises crop losses through disease resilience.
- Has a desirable nutrient release profile which matches crop demand.
- Granular product that handles, stores, blends and spreads effectively.



FLEXIBILITY

- Low chloride and pH neutral product that can be used on all plants and soils in all growing climates.
- Successful as a straight fertilizer or as a component of blend formulations.
- Excellent compatibility profile.
- Allows farmers to choose the timing of application.

SUSTAINABILITY

- Improves soil strength, structure and nutrient legacy.
- Reduces the impact of agriculture on the environment by improving fertilizer use efficiency and decreasing erosion and nutrient loss.
- Certified for organic use.
- Excellent environmental profile.

EFFICIENCY

POLY4 IS AN EFFICIENT MULTI-NUTRIENT FERTILIZER:

- Improves fertilizer use efficiency by delivering greater nutrient uptake;
- High nutrient density – supplies four macro nutrients in one easy-to-use, cost-effective granular delivery system.

Trial results showed that POLY4 has delivered better nutrient uptake of both macro and micro nutrients. This is a key profit driver as more nutrients are delivered to the crop generating improvements in yield and quality.

POLY4's multi-nutrient properties help farmers to control costs by decreasing fertilizer and farm inputs, while reducing nutrient waste by delivering nutrients over a timeframe that more closely aligns with the needs of a plant.

POLY4's nutrient release profile supports the crop from establishment through to harvest as opposed to conventional fertilizers, which tend to be applied and deliver nutrients ahead of crop demand.

EFFECTIVENESS

POLY4 IS AN EFFECTIVE MULTI-NUTRIENT FERTILIZER:

- Improves both yield and quality;
- Improves macro and micro nutrient uptake;
- Minimises crop losses through disease resilience;
- Has a desirable nutrient release profile which matches crop demand;
- Granular product that handles, stores, blends and spreads effectively.

By improving the availability of a broad spectrum of nutrients for plants, POLY4 promotes yield, quality and nutritional health, and can minimise crop losses through disease resilience. These macro and micro nutrients also become available over a longer timeline, which more closely meets the nutrient uptake pattern of the plant.

Available in granulated or standard form, POLY4 is compatible with all major input sources for NPK blending, demonstrating both chemical and physical compatibility. A POLY4 blend far exceeds the typical storage period of a conventional NPK blend. Our product also spreads effectively, up to 36 metres, preventing uneven fertilizer distribution and subsequent reduction in crop yields.

FLEXIBILITY

POLY4 IS A FLEXIBLE MULTI-NUTRIENT FERTILIZER:

- Low chloride and pH neutral product that can be used on all plants and soils in all growing climates;
- Successful as a straight fertilizer or as a component of blend or complex compound formulations;
- Excellent compatibility profile;
- Allows farmers to choose the timing of application.

As a low chloride, multi-nutrient fertilizer, POLY4 avoids toxicity issues commonly associated with the application of high-chloride fertilizer sources. Many crops benefit from a reduction of chlorides in the soil. POLY4 also has no detrimental effect on the electrical conductivity or pH of soil, both of which can be harmful to crops.

POLY4 can be used directly or in an NPK blend to supply potassium, sulphur, magnesium, calcium and a range of valuable micro nutrients. Farmers can rely on POLY4 to maintain its physical integrity until it reaches the field. As there are no negative interactions with other fertilizers, POLY4 is a beneficial addition to any fertilizer blend.

SUSTAINABILITY

POLY4 IS A SUSTAINABLE FERTILIZER:

- Improves soil strength, structure and nutrient legacy;
- Reduces the impact of agriculture on the environment by improving fertilizer use efficiency, reducing erosion and nutrient loss;
- Certified for organic use;
- Excellent environmental profile.

The calcium within POLY4 helps to increase the resilience of soil to compaction, erosion and runoff, which allows plants to access the nutrients they need to thrive and to reduce nutrient waste into watercourses and beyond.

Application of the broad spectrum of nutrients that POLY4 delivers can make soil-bound nutrients more available to the plant and prevent nutrient mining – a common threat to sustainable crop production.

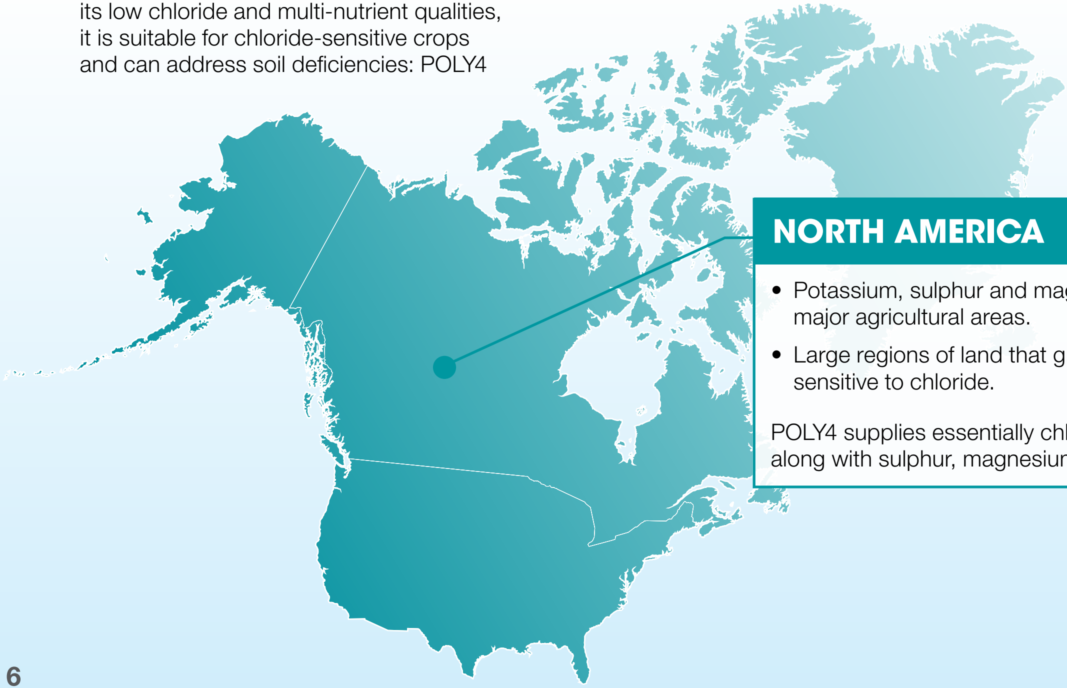
Polyhalite is a naturally-occurring mineral which results in a low carbon footprint offering farmers an effective, yet responsible, fertilizer solution. POLY4 is organically-certified and has no requirement for chemical processing. It has a low embedded CO_2 emission and is more environmentally-friendly than most fertilizer products. POLY4 helps to rebalance and reconstruct the soil structure supporting sustainable land management.

POLY4 — REGIONAL DRIVERS

POLY4 has significant market opportunity and the ability to reshape the fertilizer market. Its unique multi-nutrient content enables a wide range of options for substitution of existing fertilizer products. It is ideal for NPK blending and can reduce blenders' input costs and improve farmers' yields.

POLY4 supports balanced fertilization. With its low chloride and multi-nutrient qualities, it is suitable for chloride-sensitive crops and can address soil deficiencies: POLY4 is a low-cost source of potassium, sulphur, magnesium and calcium readily available for plant uptake.

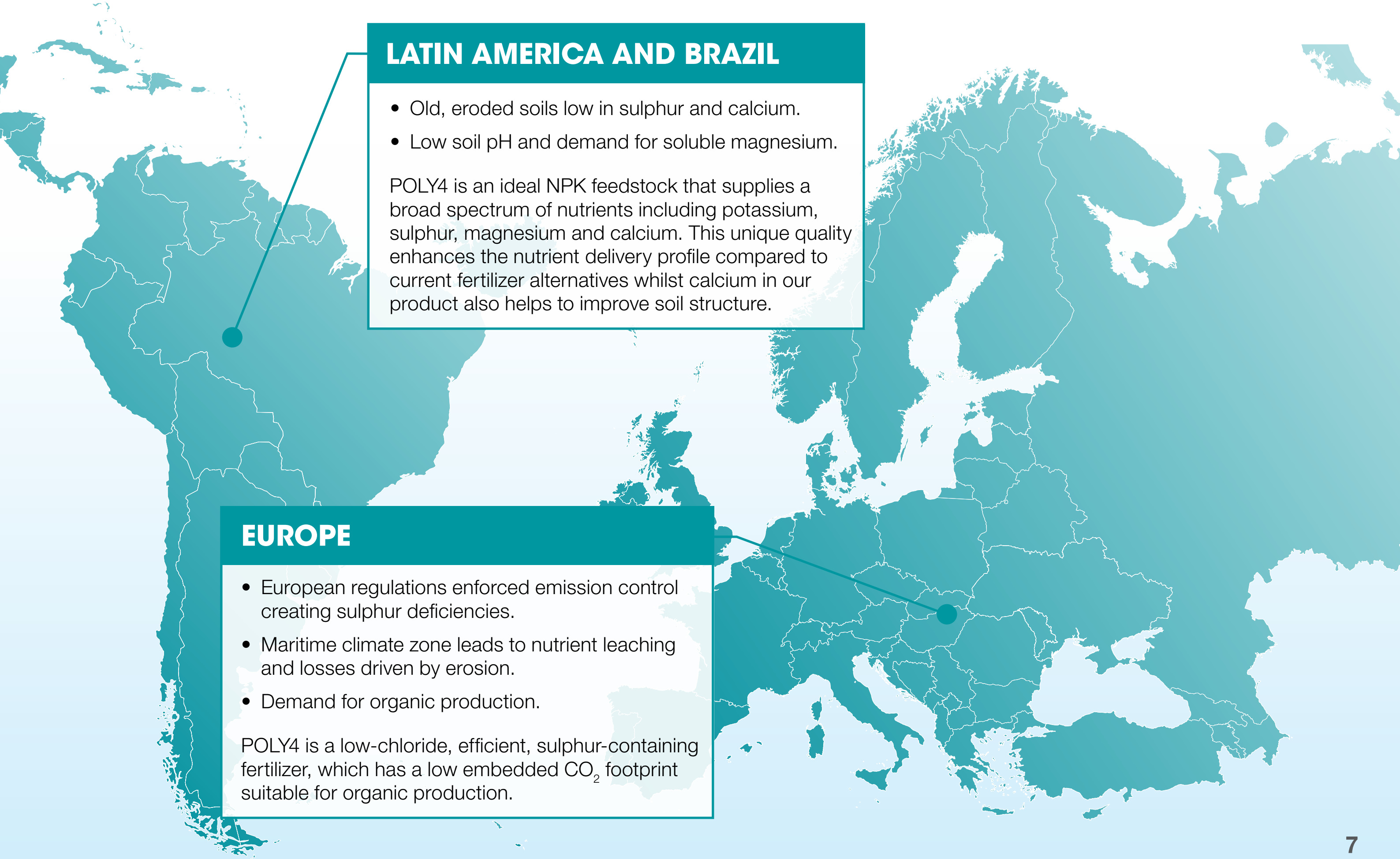
Furthermore, POLY4 is a premium product: it increases yield on broad-acre and high-value crops while improving crop quality compared to current agricultural practices.



NORTH AMERICA

- Potassium, sulphur and magnesium deficiencies in major agricultural areas.
- Large regions of land that grow crops that are sensitive to chloride.

POLY4 supplies essentially chloride-free potassium, along with sulphur, magnesium and calcium.



LATIN AMERICA AND BRAZIL

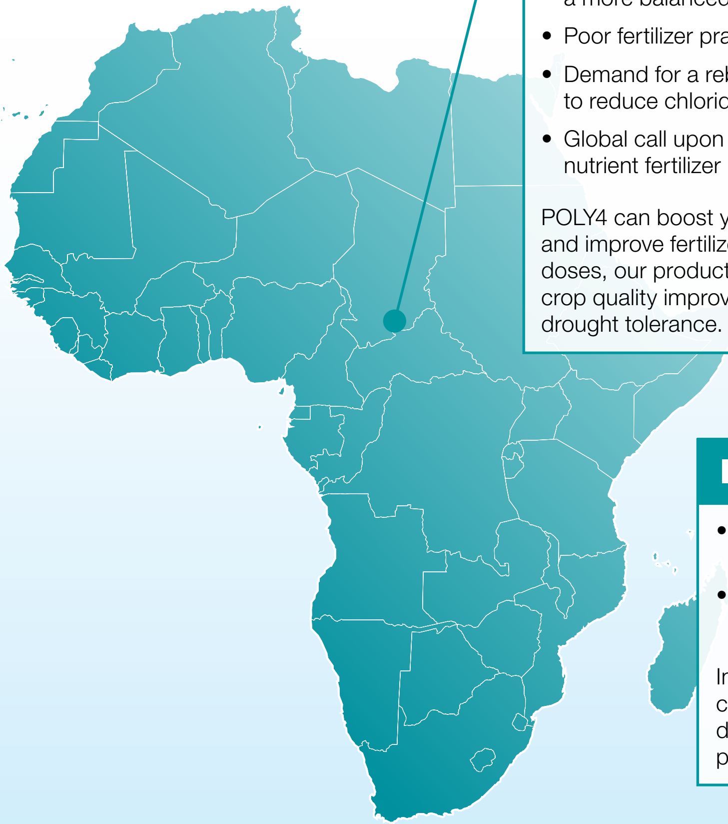
- Old, eroded soils low in sulphur and calcium.
- Low soil pH and demand for soluble magnesium.

POLY4 is an ideal NPK feedstock that supplies a broad spectrum of nutrients including potassium, sulphur, magnesium and calcium. This unique quality enhances the nutrient delivery profile compared to current fertilizer alternatives whilst calcium in our product also helps to improve soil structure.

EUROPE

- European regulations enforced emission control creating sulphur deficiencies.
- Maritime climate zone leads to nutrient leaching and losses driven by erosion.
- Demand for organic production.

POLY4 is a low-chloride, efficient, sulphur-containing fertilizer, which has a low embedded CO_2 footprint suitable for organic production.



AFRICA

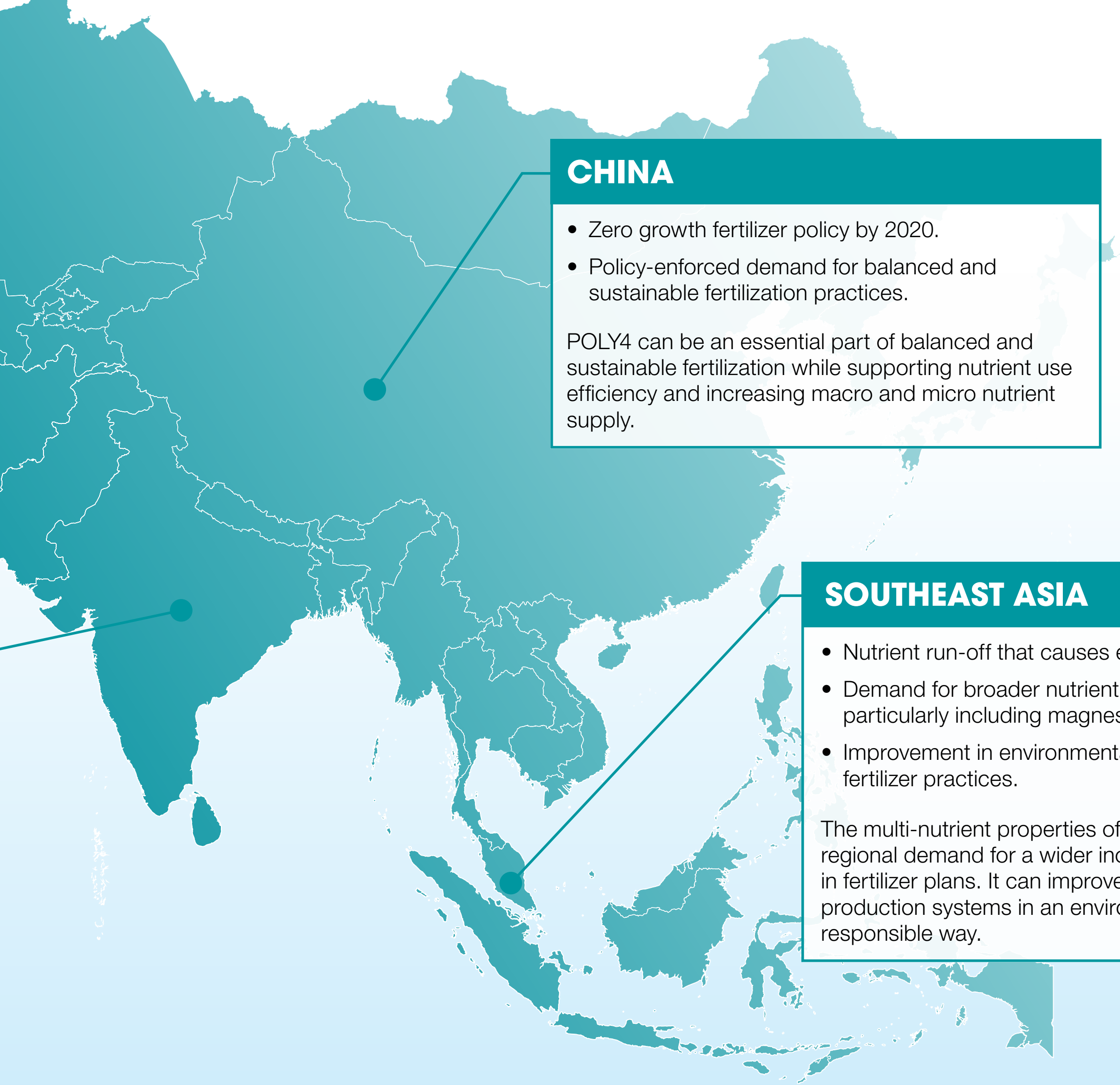
- Soil nutrient degradation and a requirement for a more balanced fertilization.
- Poor fertilizer practices and low yields.
- Demand for a rebalanced NPK application to reduce chloride content.
- Global call upon Africa to adopt 21st century multi-nutrient fertilizer practices.

POLY4 can boost yields, provide balanced nutrition and improve fertilizer practice. Even used in small doses, our product adds value, for example, through crop quality improvements, disease resilience and drought tolerance.

INDIA

- Soils are recognised as lacking in potassium, sulphur and magnesium.
- The current subsidy system encourages overapplication of nitrogen.

Inclusion of POLY4 in fertilizer plans offers a corrective and environmentally-responsible solution delivering potassium, sulphur and magnesium in one product while improving nutrient-delivery profile.



CHINA

- Zero growth fertilizer policy by 2020.
- Policy-enforced demand for balanced and sustainable fertilization practices.

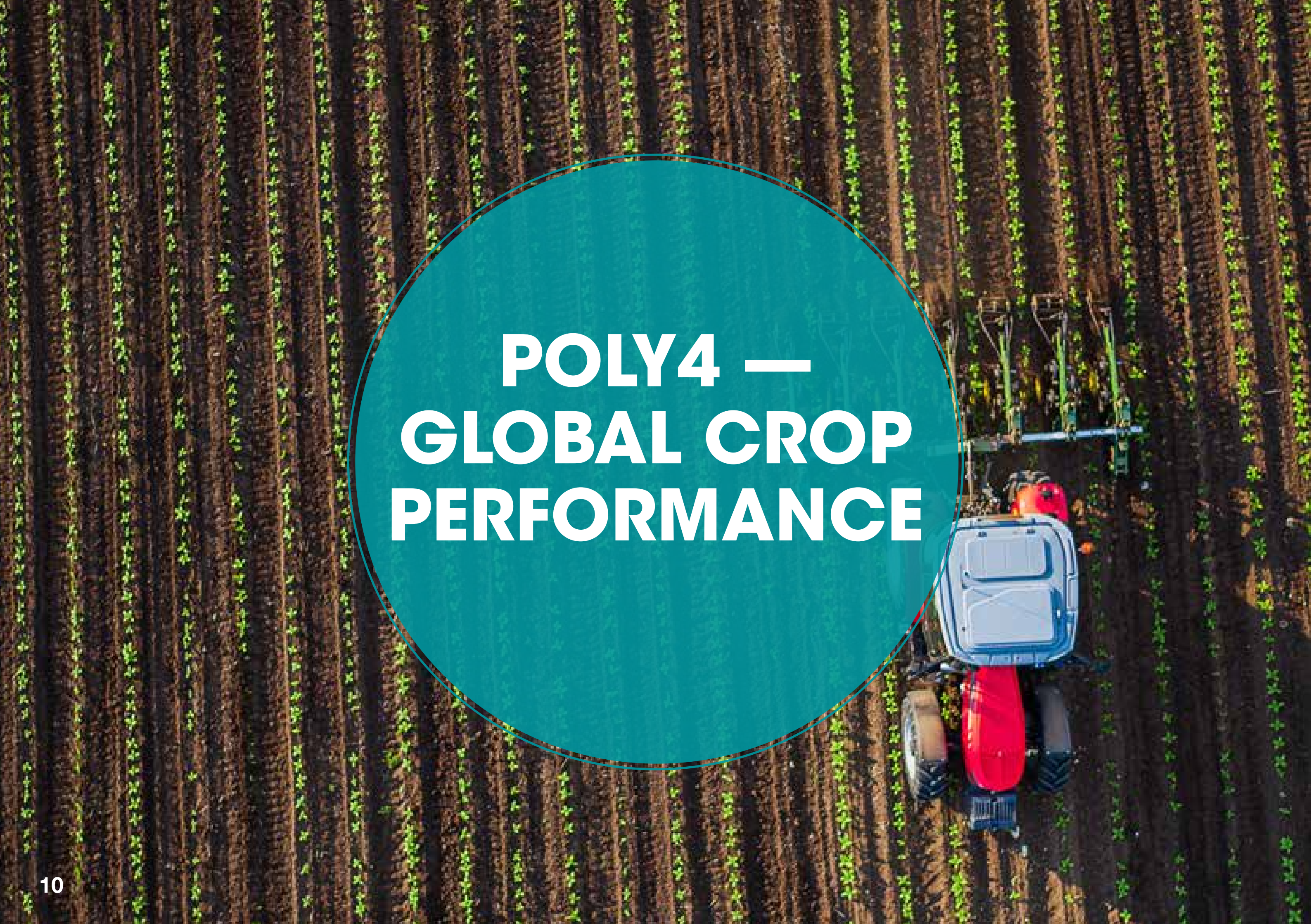
POLY4 can be an essential part of balanced and sustainable fertilization while supporting nutrient use efficiency and increasing macro and micro nutrient supply.

SOUTHEAST ASIA

- Nutrient run-off that causes eutrophication.
- Demand for broader nutrient spectrum particularly including magnesium.
- Improvement in environmentally-responsible fertilizer practices.

The multi-nutrient properties of POLY4 support the regional demand for a wider inclusion of nutrients in fertilizer plans. It can improve agricultural production systems in an environmentally-responsible way.

POLY4 — GLOBAL CROP PERFORMANCE

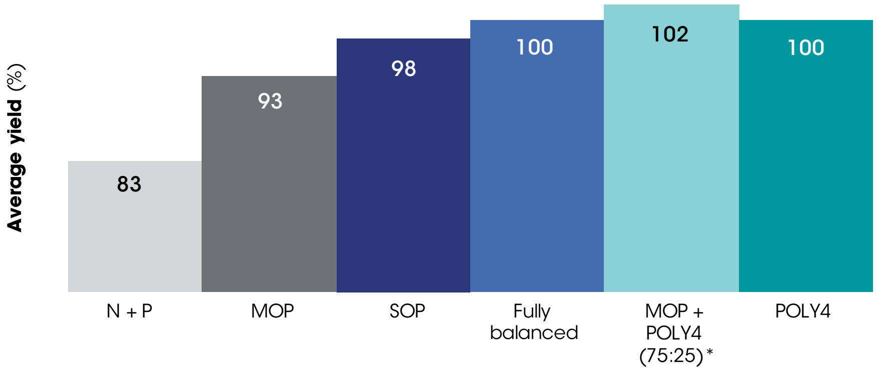


Using POLY4 as a source of nutrients helps to improve crop quality and is more efficient and effective for farmers, whilst offering additional value with the potential for increased economic margins.

With four of the six macro nutrients (potassium, sulphur, magnesium and calcium), fertilizer plans that include POLY4 deliver a better outcome – farmers can see increased crop yield and improved quality as well as enhanced soil structure from one product.

Based on the combined information of 123 field trials[1] from across the world, we can show that, when POLY4 is supplied at the recommended potassium rate, a blend of MOP and POLY4 achieved the best agronomic yield. Data showed that MOP + POLY4 treatments improved yield over MOP-only applications resulting in an average 9% yield gain. Furthermore, in comparison to the SOP plan, POLY4 and MOP + POLY4 improved yield by 4%.

Average POLY4 performance against other K sources



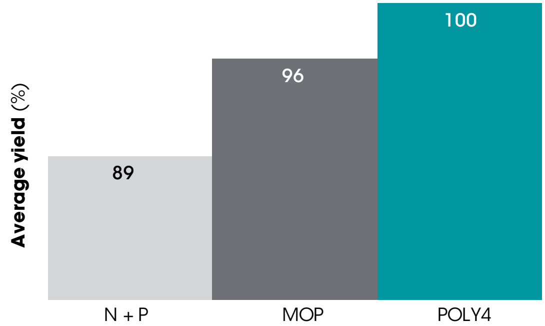
RICE

Rice has the second highest worldwide production after corn. Between 2012 and 2016, global rice production increased by 4.7 Million metric tonnes (Mmt) whilst the total area planted fell by 2.4 million hectares.[2] POLY4 rice trials have been conducted in the United States, Ecuador, Africa, China, Malaysia, Thailand and Vietnam.

China is the top global producer and consumer of rice.[2] The Chinese government continues to ensure self-sufficiency in the staple grains. More than 90% of the rice area in China is irrigated, with only relatively small areas cultivated under rainfed conditions. Rice is produced in different agro-ecological zones, mainly in warm humid subtropics with summer rainfall.

The global rice crop tends to be fertilized with MOP. Amalgamated trial results indicated that using POLY4 as a potassium source increased yield on average by 4% up to a potential 22% yield improvement over MOP.[3,4]

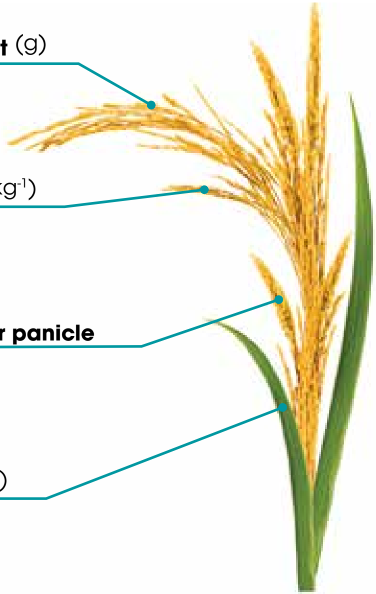
Average POLY4 performance against other K sources



A rice trial[5] in China, in partnership with Nanjing Institute of Soil Science at the Chinese Academy of Sciences, compared K sources and monitored soil K status. The response of rice yield and quality to POLY4 was also assessed.

Rice fertilized with POLY4 produced higher yields compared to MOP as a K source. Fertilizers impact the nutrient uptake of both beneficial and toxic elements. POLY4 increased the uptake of valuable nutrients and showed that it can reduce uptake of toxic elements, such as arsenic and aluminium.

Rice quality



1000 grain weight (g)

Control	24.3
MOP	26.5
POLY4	26.8

Grain protein ($g\ kg^{-1}$)

Control	65.9
MOP	68.9
POLY4	70.2

Grain number per panicle

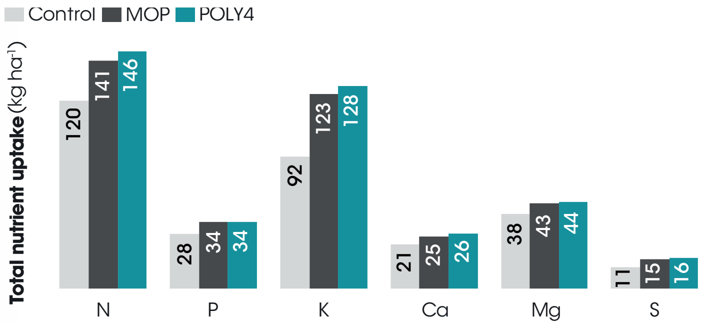
Control	160.2
MOP	166.8
POLY4	174.8

Straw yield ($t\ ha^{-1}$)

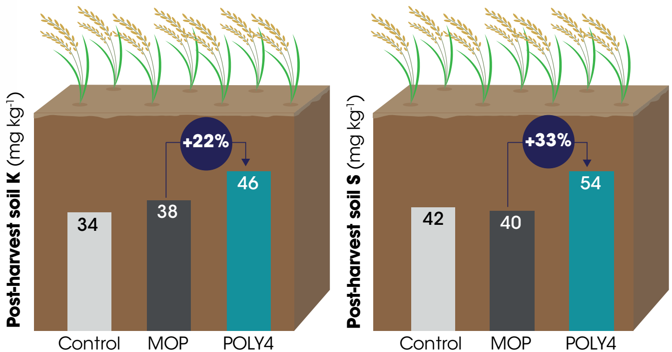
Control	7.5
MOP	8.4
POLY4	8.5

In this trial POLY4 increased the fertilizer use efficiency with greater N and K uptake. Post-harvest soil status also showed that POLY4 significantly increased K and S in the top soil (0-20cm) providing benefits for subsequent cropping.

Total nutrient uptake[6,7]



Post-harvest soil status[6,7]



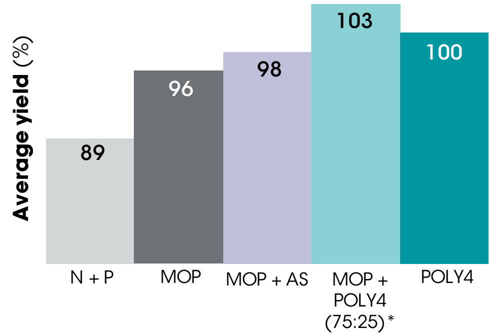
CORN

The world grew 188 million hectares of corn with an average yield of 5.6 tonnes per hectare.[8] In 2016 – 2017 the major producers were the United States, China and Brazil.[9]

POLY4 studies on corn were conducted in the United States, Brazil, Europe, Africa, China and Vietnam. On average,[10,11] an MOP + POLY4 blend generated a 7% yield improvement with a potential to increase yield by up to 14%. The results confirmed that corn was responsive to the K and S in POLY4. This nutrient-management plan increased yield compared to an MOP-K source plan.

Long-term studies also showed that the higher corn yield achieved with the POLY4 blend consistently increased margins thus maintaining the economic benefit.

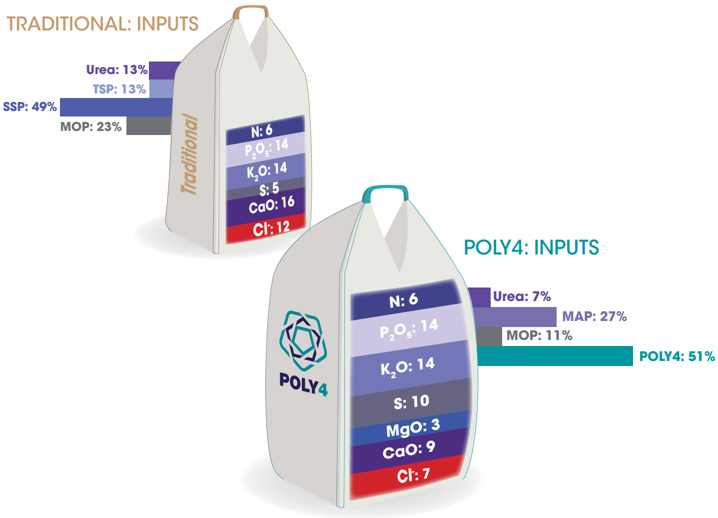
Average POLY4 performance against other K sources



A three-year trial in Brazil, in partnership with Fundação MT, evaluated POLY4 as a fertilizer for corn by comparing 6:14:14 blends made with MOP and MOP + POLY4 as a K source.[12] The corn trialed was a Safrinha crop, which has dominated the main production in Brazil over the past eight years. Brazil has emerged as the largest US competitor in the global corn market and, in the 2016 – 2017 crop season, produced 98.5 Million metric tonnes (Mmt) of corn.[13]

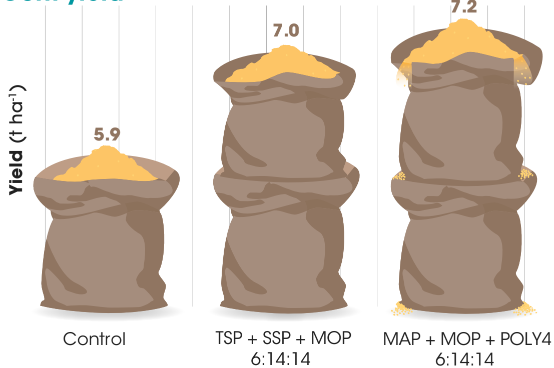
Trials took place in Mato Grosso, the largest corn producing state in Brazil[14] known for low soil K, S and Ca. The POLY4 blend's nutrient spectrum and reduced chloride content supported corn yield increase. The results from the three-year trial showed that the POLY4 blend consistently outperformed the conventional NPK option.

6:14:14 blend composition[15]

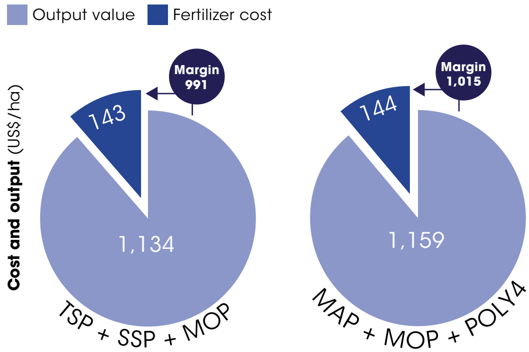


The POLY4 blend increased margin more than the MOP blend. The higher corn yield meant greater margin over the fertilizer cost by US$24/ha. The increase in margin over the three-year trial reflected the consistency of the POLY4 blend maintaining the economic benefit.

Corn yield[16-18]



Fertilizer cost output and margin[19-21]

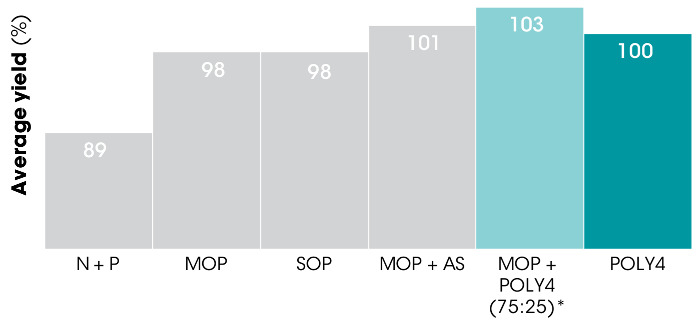


SOYBEAN

FAO data estimates that 335 Million metric tonnes (Mmt) of soybean was produced globally from 121 million hectares. The United States, Brazil and Argentina have the largest crop areas. The global agronomy programme studied the value of POLY4 on soybean in the United States, Brazil, Argentina and Canada.

An MOP + POLY4 plan outperformed an MOP-only option. The average[22,23] yield increase was 5%. Increased response to the MOP + POLY4 blend was attributed to the K, S and Mg nutrients in POLY4. These studies showed that the best application method for POLY4 was to broadcast it across the field before planting the crop. This is in line with common practice.

Average POLY4 performance against other K sources



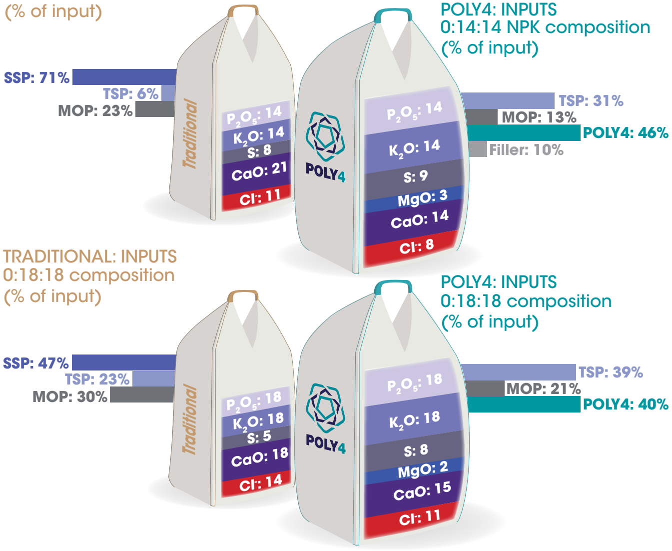
Brazil produced 31% of the world's soybean in 2016 – 17 and is projected to become the world's largest soybean producer by 2026.[24] Soybean production accounts for about 35% of K_2O fertilizer use in Brazil, with the crop typically removing approximately 75 kg K_2O ha^{-1}. Trials took place in Mato Grosso, the region with soils low in K, S and Ca, and these nutrients are recommended in local fertilizer plans.

The three-year trial[25] evaluated POLY4 as a fertilizer for soybean in Brazil where treatments were equivalent to commercial blends (0:14:14 and 0:18:18) with the K derived from either MOP or POLY4.

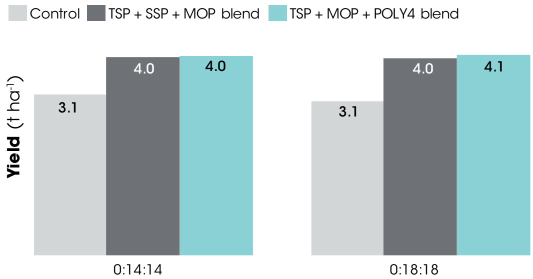
Soybean was grown in rotation with corn in soil with a low K and S concentration. POLY4 produced higher yield for both fertilizer programmes.

Expenditure on POLY4 programmes was the most efficient by both margin-fertilizer cost and marginal benefit-fertilizer cost ratios thus increasing financial efficiency for both fertilizer programmes.

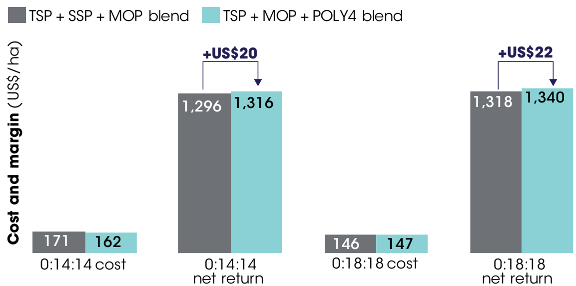
NPK blends composition[26]



Soybean yield[27,28]



Fertilizer cost and margin[29-31]

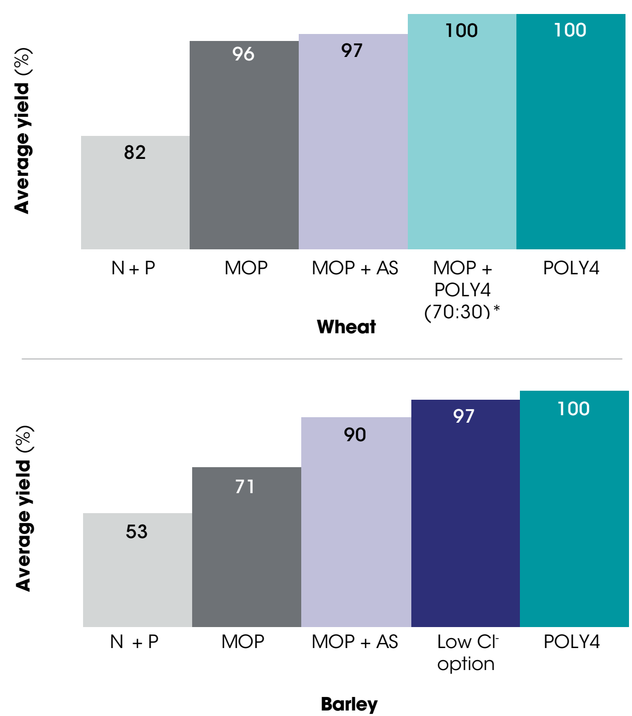


SMALL GRAINS

POLY4 studies have repeatedly shown that fertilizer application timing affects crop performance. Early spring application on overwintered crops had the highest NDVI (normalised difference vegetation index), tiller number, yield and harvest index.

The trials showed that small grains, such as wheat and barley, had greater yields when POLY4 was applied on soils with modest K status. Amalgamated trial results showed that our product, as a K source, improved yield on average by 4% for wheat[32,33] and 58% for barley[34,35] over MOP on sulphur-deficient sites.

Average POLY4 performance against other K sources



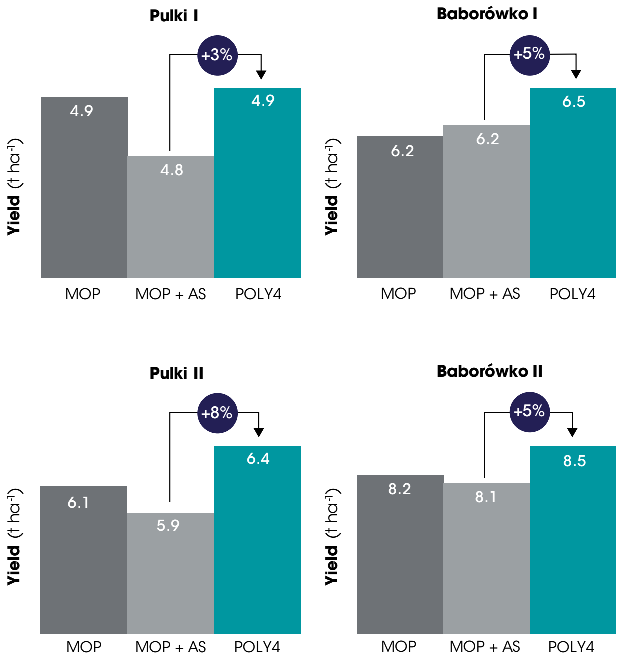
In 2016, Poland cultivated about 2.4 million hectares of wheat with an average yield of 4.5 t ha^{-1}.[36] Polish farmers typically apply MOP as their wheat K fertilizer. The POLY4 trial[37] on winter wheat, conducted at four locations in partnership with Institute of Soil Science and Plant Cultivation, evaluated the effect of POLY4 on the yield and quality of the crop compared to the alternative K and S fertilizers.

The POLY4 fertilizer programme delivered greater yields at all four sites with an average increase of 5% compared to MOP + AS.

POLY4 also improved Hagberg falling number, which is an important measure of wheat quality and a significant parameter for determining premium payments for bread-making wheat. Millers prefer higher numbers typically targeting >250. The POLY4 had the highest mean Hagberg falling number of 282 seconds.

Treatment	Hagberg falling number(s)			
	Pulki I	Pulki II	Baborowko I	Baborowko II
MOP	283	248	225	240
POLY4	350	297	248	233

Winter wheat yield[38,39]

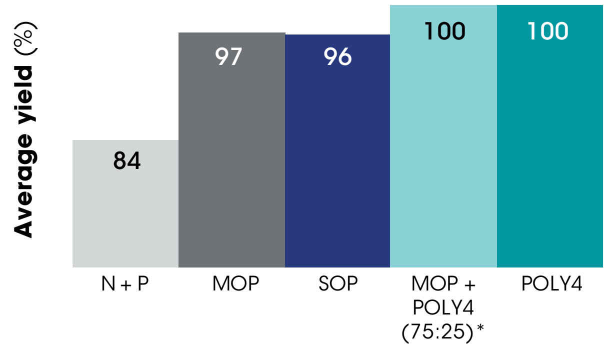


POTATO

Potatoes are sensitive to chloride, and currently growers utilize a mixture of SOP or MOP to boost tuber quality and economics.

Global trials on potato were carried out in the United States, UK, Brazil and India. POLY4 is a low-chloride K source that satisfies the crop's S and Mg needs to economically maximise yield and quality. Amalgamated data showed that POLY4 treatments improved yield over SOP applications with an average yield gain of 4%.[40,41] Our product also supported the rapid establishment of potato crops in respect to emergence. Earlier ground cover naturally suppressed weeds thus creating better yield potential.

Average POLY4 performance against other K sources

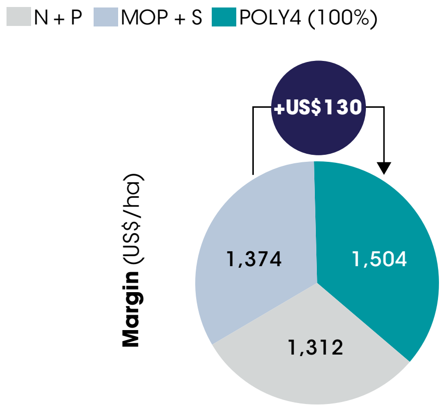


India produced 49 Million metric tonnes (Mmt) of potatoes in 2016 – 2017.[42] 14 Mmt of potatoes were produced in Uttar Pradesh. In partnership with Sardar Vallabhbhai University of Agriculture and Technology, this trial[43-45] in Meerut was grown with a locally-typical variety Chipsona 1 suited for potato frying. POLY4 was applied to deliver 75, 150 and 225 kg K_2O ha^{-1} with nutrient inputs matched to local fertilizer practice (MOP-K and S from elemental sulphur bound by bentonite).

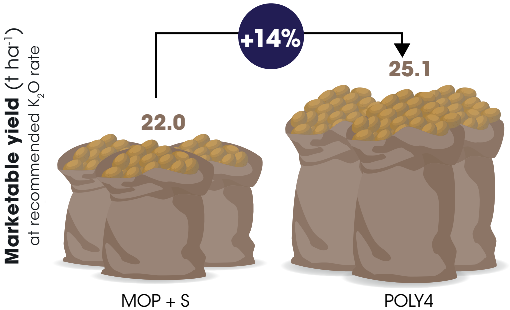
Potato marketable yield was higher after POLY4 fertilizer was used instead of MOP + S.[43-45] This reflected earlier measurements of increased crop canopy and leaf greenness.[46]

Higher dry matter content (DM%) is the most important requirement to achieve premium prices from the potato frying industry. The DM% of potatoes fertilized with POLY4 was 7% greater than when MOP + S was used.[43-45] The increased potato yield led to greater financial returns for the farmer by US$130/ha at the recommended fertilizer rate.

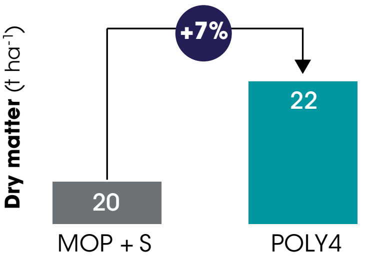
Potato margin[47]



Marketable yield



Dry matter content of tubers

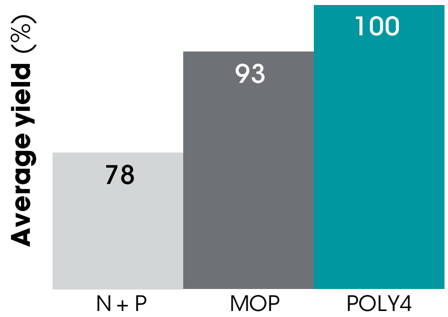


COTTON

Potassium is an essential nutrient for cotton fibre development and is critical for water relations. K demand rises when bolls are set and water pressure is needed for fibre elongation. Commonly, MOP is chosen as a K source. POLY4 trials were established in China, India and the United States, who lead the global cotton market.

Increasing sulphur uptake through the cotton plant and into the cotton is essential for yield improvements. Incorporating POLY4 into a fertilizer plan to supply S need, and to support the K, Mg and Ca requirements, is more effective than conventional fertilizer options.[48] Amalgamated trial results showed that POLY4 increased yield over MOP achieving up to 76% yield improvement.[49,50]

Average POLY4 performance against other K sources



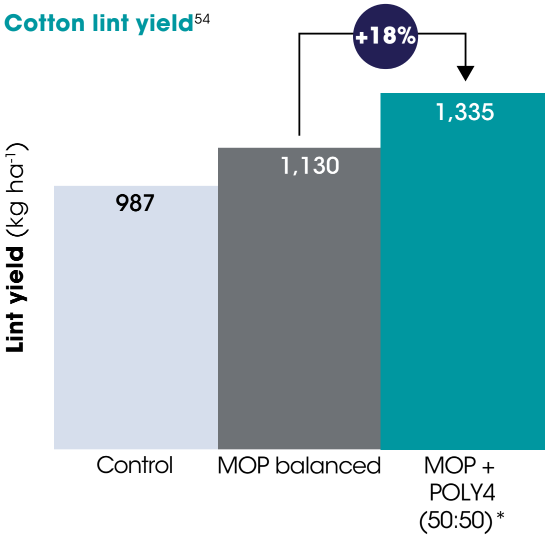
The United States is the third largest cotton producer in the world. Cotton is produced in 17 southern US states from Virginia to California.[51]

This trial[52] took place over three years in partnership with Virginia Tech University. The performance of MOP + POLY4 on cotton was compared to common fertilizer plans containing MOP. The POLY4 blend delivered Mg, S and Ca more effectively than the MOP balanced blend, which included gypsum and kieserite, and gave increased lint yields each year.

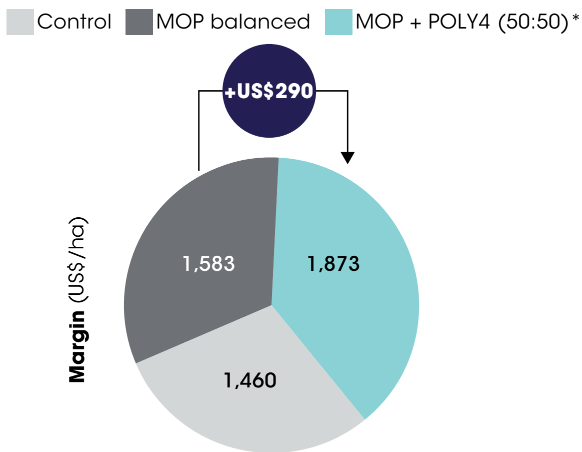
In the 2016 growing season, where adverse weather conditions hampered the overall cotton yields, the MOP + POLY4 blend particularly supported lint yield. In this case[53] the POLY4 blend gave a 74% increase in yield at a recommended K_2O rate compared to the balanced MOP treatment. Amalgamated three-year data showed that the MOP + POLY4 increased yield by 18% compared to the balanced MOP plan.

POLY4 with MOP in a 50:50 ratio generated greater economic margin than MOP balanced blend increasing margin by US$290/ha thus reflecting cost-effectiveness of the POLY4 option.

Cotton lint yield[54]



Cotton margin of the three-year trial[55]



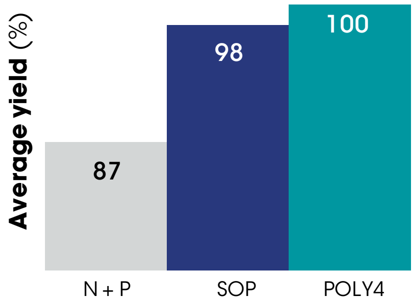
TEA

Tea is a high-value tropical crop that benefits from low-chloride fertilizer. Indonesia, India, China, Sri Lanka and Kenya were the largest tea-exporting countries in 2016.[56]

Trials showed that the POLY4 fertilizer plan outperformed SOP by as high as 6%[57,58], but it is quality that drives value for the tea grower.

Potassium plays a significant role in increasing tea quality. POLY4 tea trials in China either maintained or improved quality parameters such as amino acid: polyphenol ratio and water extractable solids thus improving tea taste.[59] Furthermore, Ca and Mg status was elevated in spring leaf and in soil with the use of our product.

Average POLY4 performance against other K sources

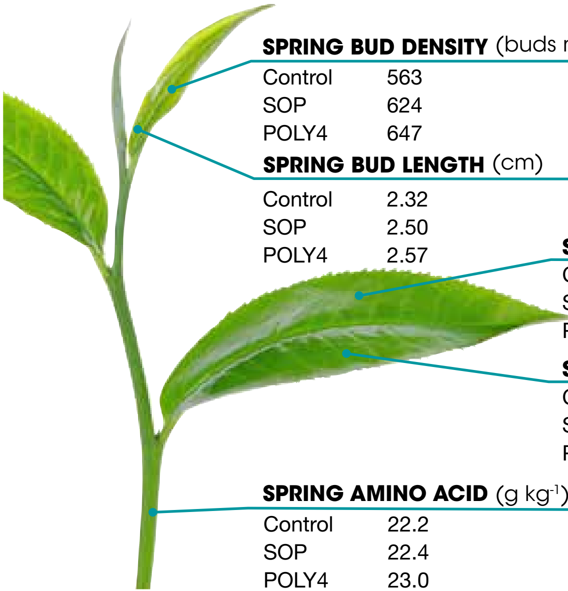


In 2016, China produced 2.35 Million metric tonnes (Mmt) of tea and exported tea valued at US$1.49 billion, making China the leading exporter of tea worldwide.[60] In partnership with Soil and Fertilizer Institute at the Sichuan Academy of Agricultural Science, a second year of tea crop assessments compared POLY4 to SOP and its effect on tea growth and quality.[61]

The POLY4 plan offered an alternative fertilizer choice that limited chloride input and delivered K, S, Mg and Ca in one product whilst improving spring dry leaf yield by 5% compared to SOP.[62,63]

Application of our product as a split base and side dressing improved several parameters that supported tea quality and yield.

POLY4 also showed significant increases in residual soil nutrients compared to SOP: testing showed increase in Ca by 34%, Mg by 58% and S by 31%.



SPRING BUD DENSITY (buds m^{-2})

Control	563
SOP	624
POLY4	647

SPRING BUD LENGTH (cm)

Control	2.32
SOP	2.50
POLY4	2.57

SPRING PROTEIN (g kg^{-1})

Control	345
SOP	360
POLY4	368

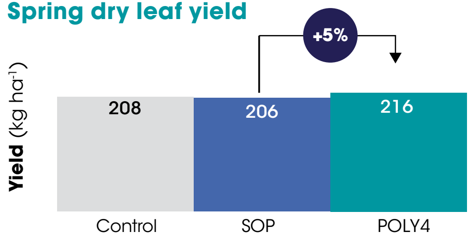
SPRING LEAF AREA (cm^2)

Control	1.49
SOP	1.56
POLY4	1.87

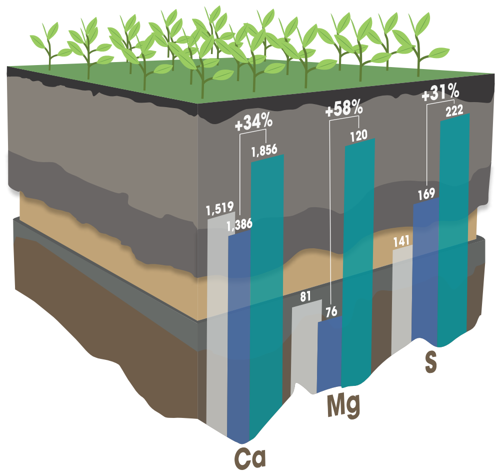
SPRING AMINO ACID (g kg^{-1})

Control	22.2
SOP	22.4
POLY4	23.0

Spring dry leaf yield



Post-trial soil analysis[62,63]



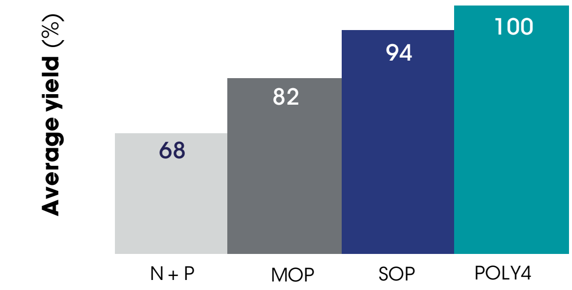
TOMATO

Tomato is the most consumed vegetable worldwide. 177 Million metric tonnes (Mmt) of tomatoes were grown globally in 2016, with approximately five million hectares of crop planted. The largest producers were China, the United States and India.[64] The European Union produced around 18 Mmt of tomatoes in the 2016 – 2017 season, 40% of which were sold on the fresh market.[64]

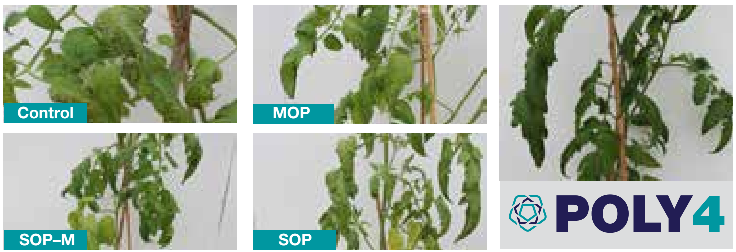
Tomato trials have been conducted in the United States, Brazil, UK, Tanzania and India. Amalgamated trial results[65,66] showed that the POLY4 option outperformed MOP or SOP, with an average yield improvement of 18% compared to MOP and of 6% compared to SOP. In addition, POLY4 improved parameters of tomato quality such as a 1.3% firmness improvement leading to a longer shelf-life, 3.8% reduction of titratable acidity and 1.6% higher Brix measure offering a less acidic, sweeter taste.[67]

POLY4 can also minimise crop losses through disease resilience. POLY4 study on tomato bacterial spot, in partnership with University of Florida, showed that our product lowered the infection by up to 89% compared to other fertilizer sources.

Average POLY4 performance against other K sources



Tomato bacterial spot: visual assessment of leaves[68-72]

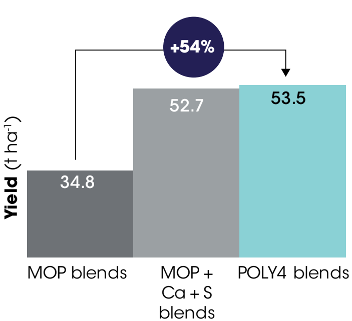


The United States is one of the world's leading producers of tomatoes, second only to China. Fresh and processed tomatoes sales in the United States account for more than US$2 billion.[73] Virginia is the third

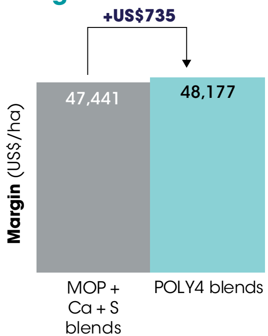
largest tomato-producing state after California and Florida. Tomatoes are produced on coastal plain soils with high K and S deficiencies. Virginia tomato growers typically use NPK blends containing MOP.

This tomato trial,[74] in partnership with Virginia Tech, looked at the response of fresh market tomatoes to POLY4 and MOP in two NPK blends (6:3:12 and 11:4:17). NPK blend with MOP was augmented with CaO and S. POLY4 fertilizer programme delivered greater yield with up to 54% increase compared to MOP blends whilst also supplying S, Mg and Ca. Blends containing S and CaO delivered higher yields and higher net margins. The POLY4 option generated US$735 greater margin compared to the nutrient-balanced MOP blends (MOP + Ca + S).

Tomato yield[76-79]

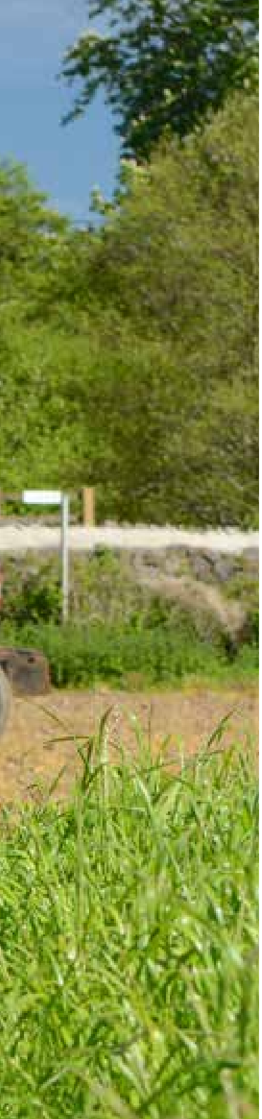


Margin[80-81]



NPK blends composition[75]

PRODUCT CHARACTERISTICS



NUTRIENT CONTENT

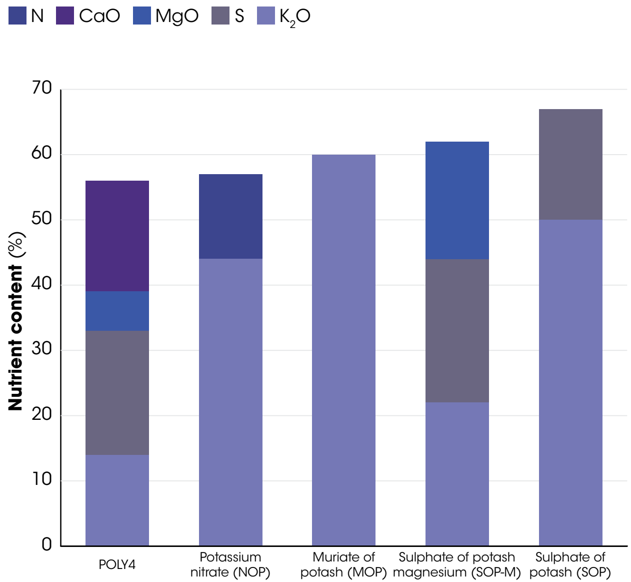
The declared nutrient content, as stated on the POLY4 label, is 14% K_2O, 19% S, 6% MgO and 17% CaO.[82]

Label declared analysis of a fertilizer is the minimum content of its nutrients or, in the case of undesirable elements, the maximum content of that element. It is most commonly expressed as a percentage by weight.

POLY4's chemical formula:

$K_2SO_4MgSO_42CaSO_42H_2O$

Nutrient content of major potash fertilizers



SOLUBILITY

All fertilizers are characterised by their solubility in water at a given temperature.

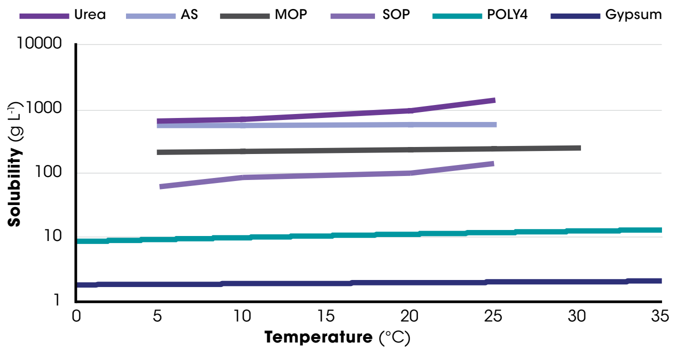
The solubility of POLY4 was tested over a range of temperatures[83] against the water solubility reported for other common fertilizers.[84-88] POLY4 has a solubility of 27 g L^{-1} at 25°C, which corresponds to the amount of POLY4 that would dissolve in the plough layer of a moist, medium textured soil at a 10 t ha^{-1} application rate. With this solubility, POLY4 effectively delivers K, S, Mg and Ca at commercially-required rates.

Dissolution rate characterises the transition of a solid fertilizer into a solution. This rate is largely governed by physical parameters controlled during the patented granulation process. POLY4 was compared to MOP, SOP and SOP-M at 20˚C. Its dissolution rate was similar to MOP.

Since POLY4 is a mineral, dissolution resulted in simultaneous nutrient release. Both tests demonstrated that all nutrients are available, with near full dissolution of its nutrient content within six hours. The format of material clearly impacted the release profile.

Crops benefit from this characteristic as nutrients are delivered at a pace that is more compatible with their metabolic requirements, supporting plant growth throughout the growing season.

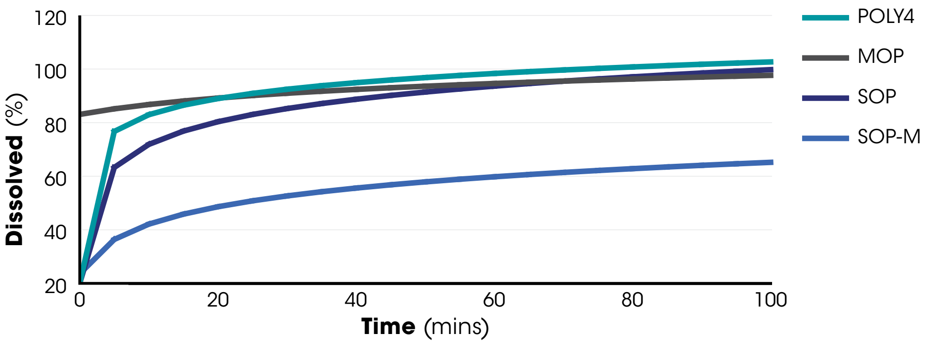
Solubility of POLY4 in water (g L^{-1}) over a range of temperatures compared to other commercial fertilizers[83-88]



Summary of commercial fertilizer solubility at 25°C[83-88]

Fertilizer	Solubility at 25°C (g L^{-1})
POLY4	27
AS	750
MOP	264
SOP	120
Urea	1200
Gypsum	2.55

Dissolution of granular POLY4 in water over time compared to other potassium-based fertilizers at concentrations of 10 g L^{-1} [83-88]



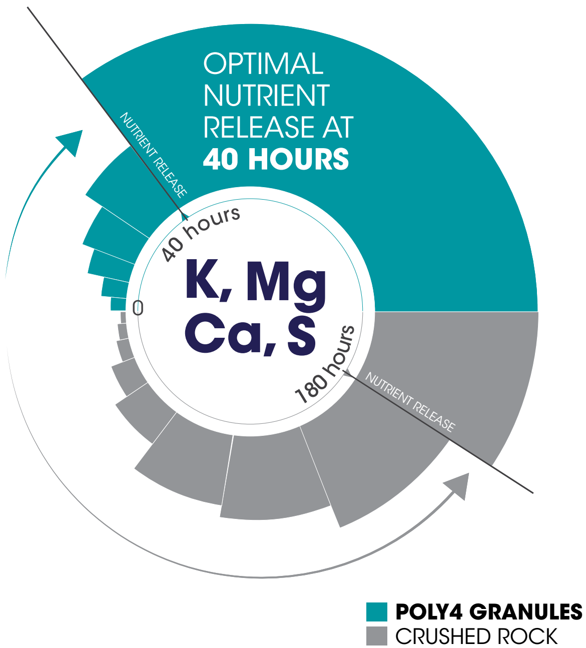
DISSOLUTION RATE

The availability of nutrients to plants is as important as the timing of fertilizer application. Dissolution is the rate of phase-change from solid into solution. Many factors control and influence this such as temperature and physical form. Fertilizer needs to effectively deliver its nutrients over a suitable timeframe allowing a plant to capture them when required. The fertilizer industry uses artificial barriers to control dissolution rate. POLY4's natural dissolution rate effectively regulates release of nutrients to crops without the need for artificial barriers.

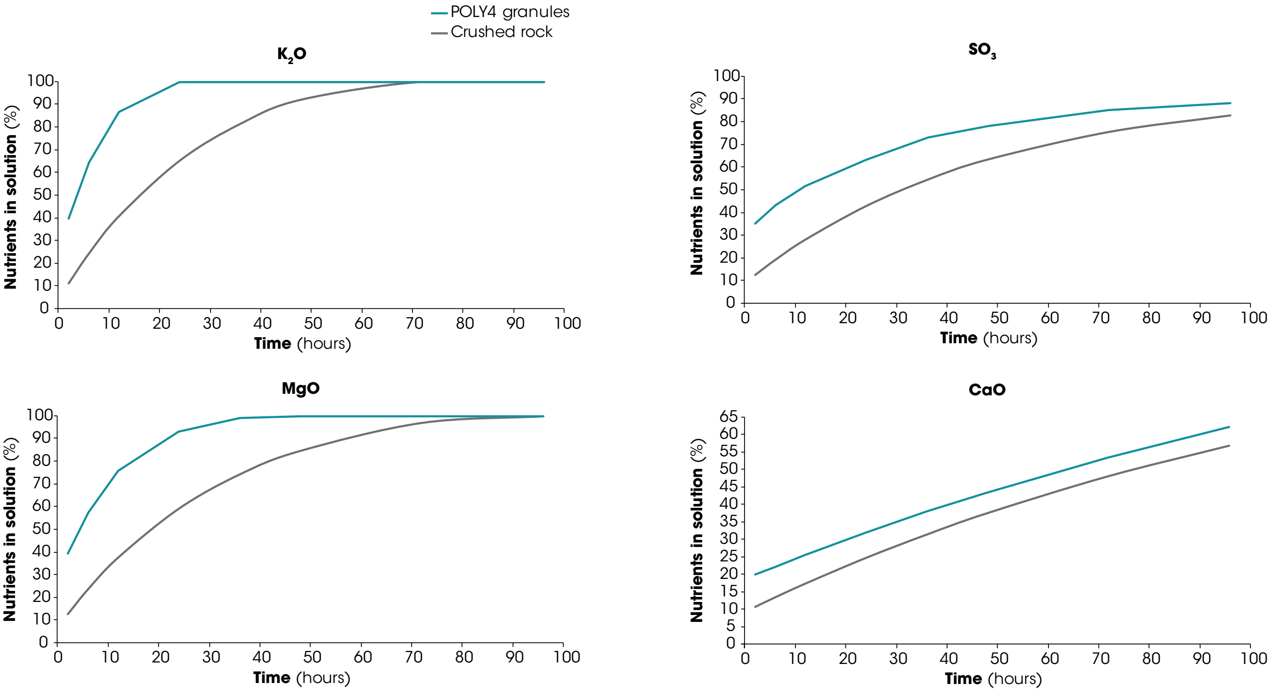
Dissolution rate of POLY4 granules and crushed polyhalite rock was tested in the laboratory.[89] Material was added to deionised water (0.5 g/500ml) to test for solublised potassium, sulphur, magnesium and calcium over time.

The percentage of nutrient recovery was quicker from POLY4 granules. Testing results showed that nutrients were released from the POLY4 granules in 40 hours, whereas it took up to 180 hours to recover nutrients from a similar size chip of crushed rock.

Nutrient recovery[89]



Nutrient recovery[89]



NUTRIENT DELIVERY PROFILE

A plant's nutrient requirements change as it develops so farmers must find a fertilizer option that aligns with those needs. POLY4 has a sustained nutrient delivery, which more closely meets the requirements of the plant.

Common fertilizer practice tends to apply nutrients such as nitrogen, potassium and sulphur at sowing. These nutrients can be lost through erosion, runoff or leaching, and so become unavailable towards the end of the plant's life cycle where nutrient uptake is at its highest. Sustained nutrient release is especially important for crops on sandy and other soils with limited capacity to retain and release nutrients.

In this laboratory study[90] soil columns (30 cm of sandy loam topsoil) were used to demonstrate nutrient release from POLY4 and other products. The test aimed to quantify the release of K, S and Mg to demonstrate the additional benefits of controlled nutrient release achieved from multi-nutrient POLY4.

The sulphate of potash magnesia (SOP-M) treatment quickly released K, with 70% of the added K removed from the topsoil in two pore volumes of simulated rainfall. The POLY4-fertilized soil also had a large peak of K mobilisation but expressed it over a longer period of time. This means it had both high K availability and sustained release of nutrients.

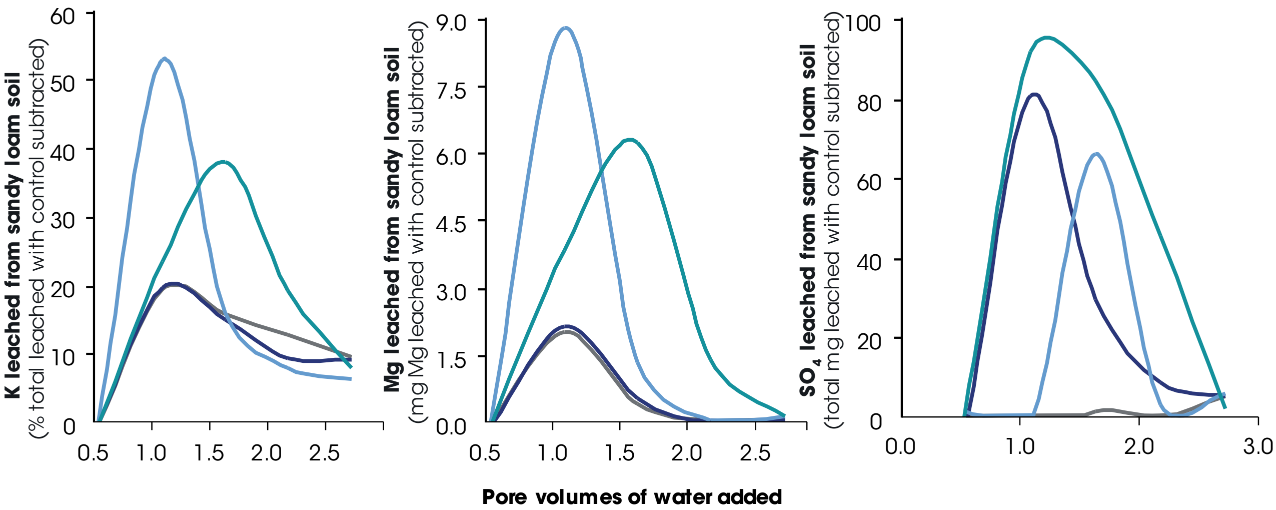
The trend was similar for Mg, with a quick, though short, release from SOP-M but a prolonged release from POLY4 that gave a broad peak of available Mg. When expressed as a percentage of the Mg applied by each of these treatments, the POLY4 quickly exceeded the Mg released from that of SOP-M. Less than 80% of the Mg added in SOP-M was mobilised.

The POLY4 treated soils also mobilised more sulphate (SO_4^{2-}) than soils treated with SOP or SOP-M. As with the K and Mg, adding POLY4 created a large and sustained peak of mobilised sulphate. The POLY4 added a little more sulphate than the SOP-M, but dramatically increased the available sulphate.

POLY4 provided a very strong and unique combination of prolonged K, S and Mg release with increased total availability of these nutrients: 115% K added (MOP = 64%) and 90% Mg added (SOP-M = 61%). The sustained release of nutrients allows plants to take advantage of this availability for a longer period of time, more closely matching the requirements of the plant.

Nutrient availability in soil[90]

POLY4 in 30 cm soil column

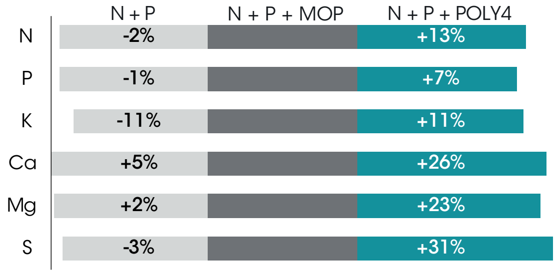


FERTILIZER USE EFFICIENCY

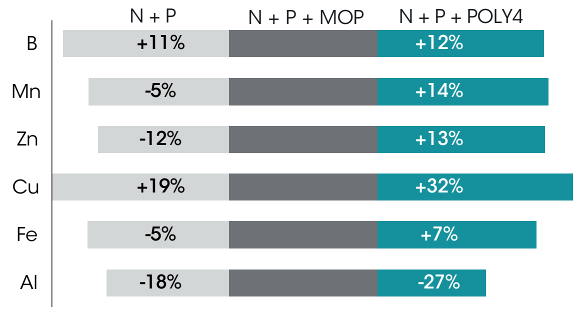
The demand for food will escalate in line with population growth. It is expected to double within 30 years equivalent to a 2.4% compound annual growth rate.[91] Nutrient use efficiency (NUE) is a critically important concept in the evaluation of crop production systems. It can be greatly impacted by fertilizer management as well as by soil- and plant-water management.[92]

The amount of nutrients taken up by plants relative to the amount applied in fertilizer can be used to measure NUE. We evaluated 32 trials globally including those conducted in Asia (China), Europe (UK & France), Latin America (Brazil) and North America (US) covering both high-value and broad-acre crops such as tea, tomato, soybean, wheat, potato and corn. Normalizing the nutrient uptakes to that delivered from MOP showed the value of POLY4 fertilizer plans to micro and macro-nutrient uptake.

Macro-nutrient uptake compared to MOP[93]



Micro-nutrient uptake compared to MOP[94]



Work from the trials showed that POLY4 supplied its nutrients over an extended delivery period. Our product promoted nutrient release, and enabled and supported a broad spectrum of macro and micro-nutrient uptake, creating a favourable nutritional support for crop production.

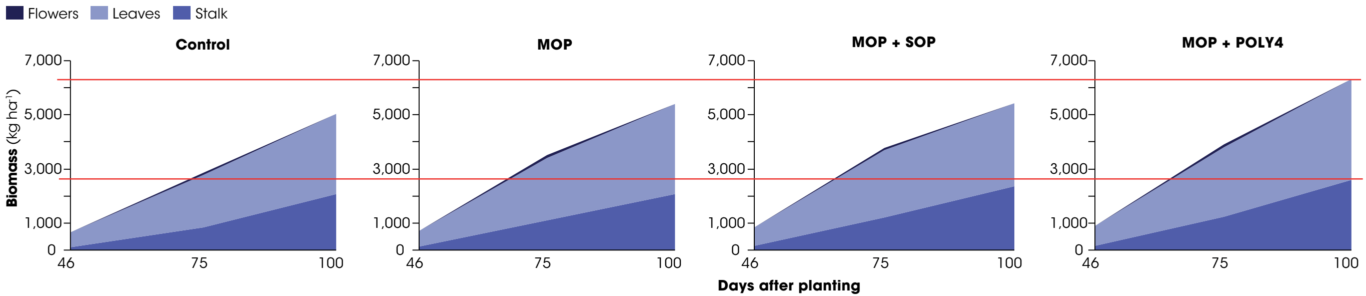
A nutrient-balanced field trial,[95] in partnership with the University of Kentucky, compared a POLY4-based fertilizer plan with a locally typical programme including one with a similar nutrient profile.

As part of the fertilizer plan, POLY4 elevated crop stalk and leaf biomass of the trialed Solanaceae crop. Nutrient uptake drove biomass generating 7% to 28% higher yields compared to MOP options.

Low-chloride POLY4 delivered nutrients such as K, S, Mg and Ca through to harvest influencing and improving the quality of crops.

Treatment	Nutrients applied in trial (kg ha^{-1})				
	K_2O	CaO	MgO	S	Cl^-
Control	0	0	0	0	0
MOP	180	0	0	0	138
MOP + SOP	180	0	0	58	56
MOP + POLY4	180	0	63	200	56

Biomass[96,97]



DISEASE REDUCTION

Good crop nutritional health supports several physiological and disease defense functions.[98] Reduction in tissue potassium leads to:

- Yield and quality penalties;
- Lodging risk;
- Inefficient nitrogen use;
- Drought and/or cold susceptibility.[99]

POLY4 supports plant disease resilience resulting in a healthier crop[100-102]

POLY4 reduced the severity of sheath blight on corn by 71% over MOP.

Tomato leaf spot incidence reduced by 48% over MOP.

Nitrogen is an essential building block in proteins, plant development and quality.

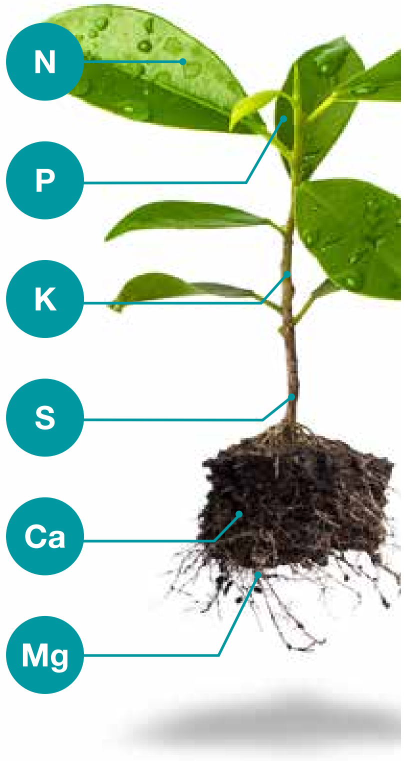
Phosphorus is essential for photosynthesis, respiration and energy transfer.

Potassium aids plant metabolism, water regulation/drought stress and improves disease resilience and plant health.

Sulphur is an essential component of proteins (e.g. enzymes). It drives yield and cereal protein content.

Calcium is important for cell's structure and integrity as well as root cell's wall nutrient transport.

Magnesium is a cofactor of many enzymes and key component of chlorophyll.



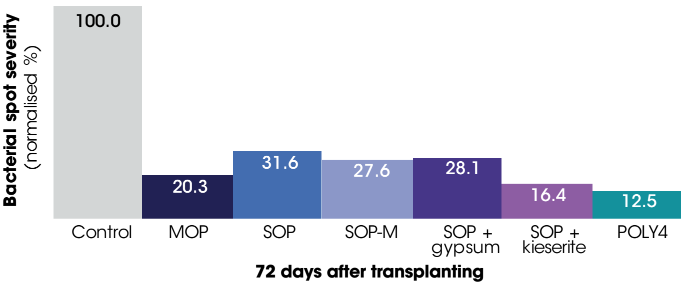
We assessed the effectiveness of POLY4 on tomato bacterial spot caused by Xanthomonas bacteria. This pathogen affects tomato yield and quality in many major tomato-producing countries.

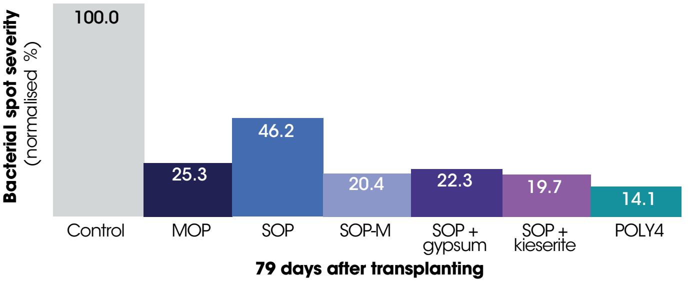
In this second year trial[103], in partnership with University of Florida, fertilizer treatments were incorporated into the soil at the start of the trial. Plants were inoculated with a bacterial spot suspension at 53 and 67 days after planting. Disease severity and plant height were assessed 64 and 98 days after transplanting. Various fertilizer sources were used to apply a range of K, S, Mg and/or Ca combinations.[104-106]

In this NPK-balanced trial we observed that:

- Supplying potassium significantly reduced the severity of bacterial spot;
- POLY4 supplied potassium, sulphur, magnesium and calcium ensuring the highest reduction of infection.

Bacterial spot severity



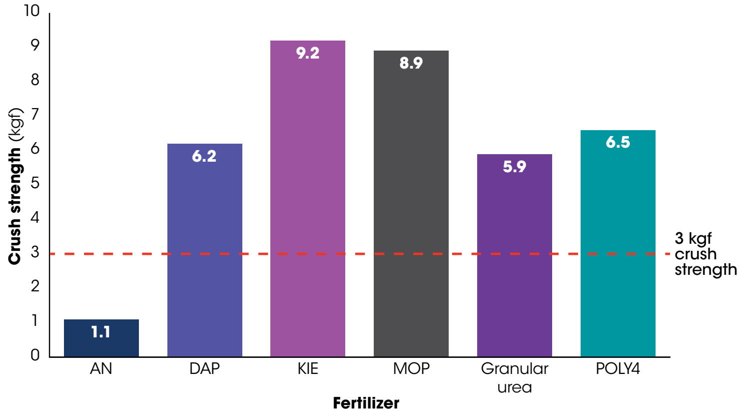


CRUSH STRENGTH

The crush strength of a fertilizer determines its suitability for spreading by agricultural machinery. A crush strength greater than 3 kgf is recommended[107] to ensure that the fertilizer will resist stress during transportation and spreading.

Testing showed that POLY4 had a crush strength of 6.5 kgf[108] which should be optimal for handling, distribution and field application. This strength means POLY4 is spreadable using a spinner at speeds of up to 900 rpm and also via boom spreaders.

Crush strength of POLY4 and other fertilizers



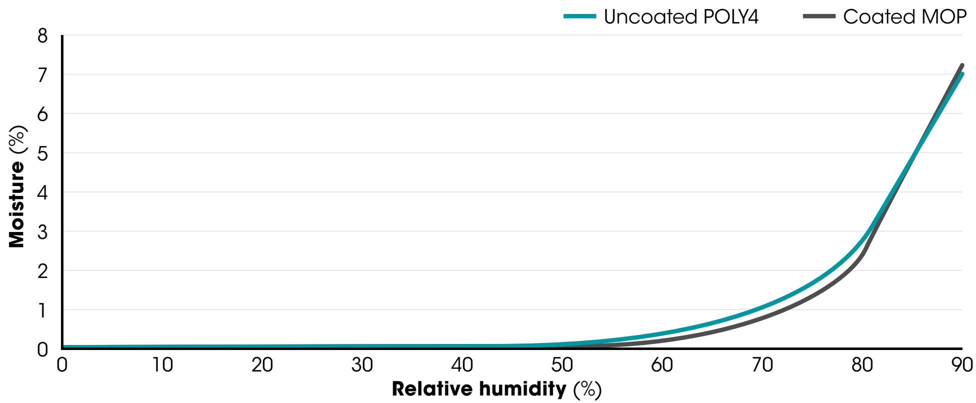
CRITICAL RELATIVE HUMIDITY (CRH)

The CRH of fertilizer is the value of relative humidity, above which a fertilizer will absorb moisture and below which it does not absorb moisture. Water absorption influences caking propensity which leads to difficulties in handling and spreading.

A typical curve from which CRH is determined compares uncoated POLY4 with coated MOP in the graph below. CRH values of 70% for MAP, DAP, MOP and urea, and lower values — near 55% — for blends have been reported.[109]

Uncoated POLY4 has a CRH of 70%. This is similar to other substitute products such as MOP (72%), giving blenders and growers confidence in the product's shelf life.

Plot of moisture content and relative humidity of uncoated POLY4 and coated MOP measured at 25°C[110]



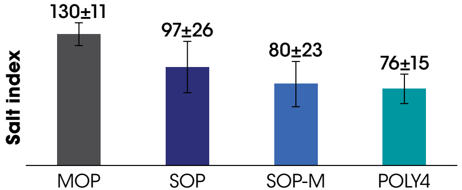
SALT INDEX

Most fertilizers are salts containing macro and micro nutrients which, when added to soil, cause an increase in the osmotic pressure of the soil solution. Fertilizers vary with regards to their osmotic effects and their potential for crop injury. They are measured in comparison to a standard reference material, sodium nitrate, giving a ratio referred to as the salt index.[111]

The Jackson (1958) method[112] is the current industry standard and was used to assess a range of potash fertilizers. Results from seven independent laboratories show a lower salt index for POLY4 than MOP, SOP and SOP-M.[113]

POLY4's relatively low salt index supports a plant's ability to absorb water and the nutrients contained within the soil solution.

Salt index (SI) +/- standard deviation for MOP, SOP, SOP-M and POLY4 using the Jackson (1958) method[113]



SPREADER TESTING

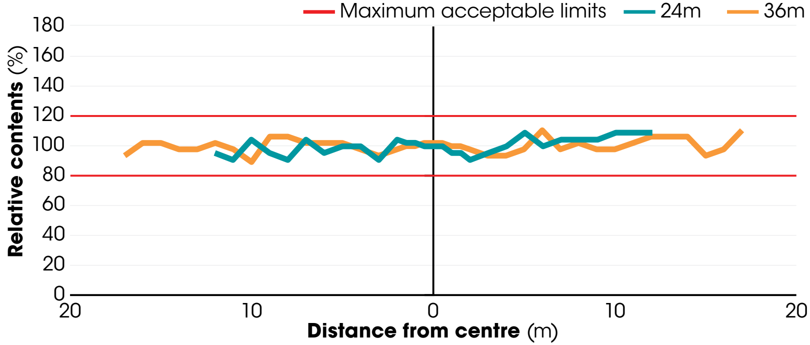
Fertilizer is often applied to fields using mechanical spreaders to ensure an even distribution of the required nutrients. Ineffective spreading leads to uneven fertilizer application, resulting in strips of nutrient-deficient crops and a subsequent loss of farmer income.

POLY4 granules were tested using spreading machinery[114] set to spreading widths of 24m and 36m, typical distances for fertilizer application. Uniformity of application is expressed as the coefficient of variation (CV). A CV of more than 20% generates stripes in the crop. Subsequently, uneven spreading increases the cost of crop production due to yield penalties and required corrective actions.

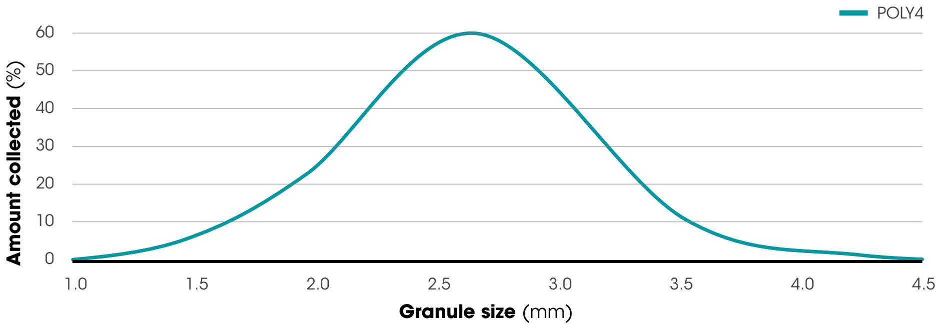
A lower CV means a more even distribution of fertilizer. The results of the POLY4 spreader testing were within the 20% tolerance limits with, for example, 3mm granules showing a CV of 5.52%. POLY4's quality spread pattern reduces the risk of additional expenditure.

Consistent particle size is also important for fertilizer practice use, for optimal spreading and for preventing segregation in bags and blends. A tighter grade pattern production of POLY4 granules allows them to be manufactured within 2mm to 4mm in diameter. This consistency in particle size is important for fertilizer spreading and for meeting customer specifications.

Spreading results of POLY4 granules at 24 and 36 metres[114]



Particle size distribution[115]

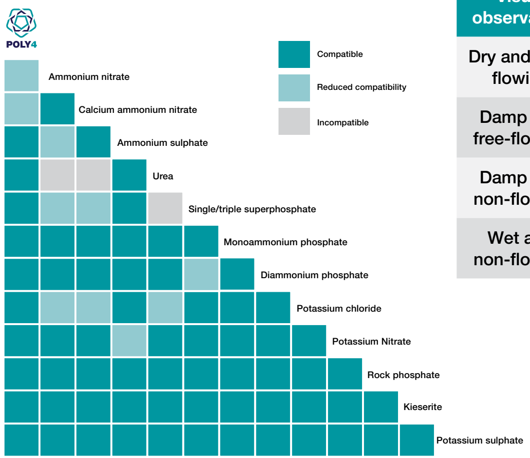


COMPATIBILITY IN BLENDS

The compatibility of POLY4 is essential since many fertilizers are sold as blends. Incompatible products often result in caking, which is affected by humidity, particle shape and size, composition, storage duration, temperature and pressure.

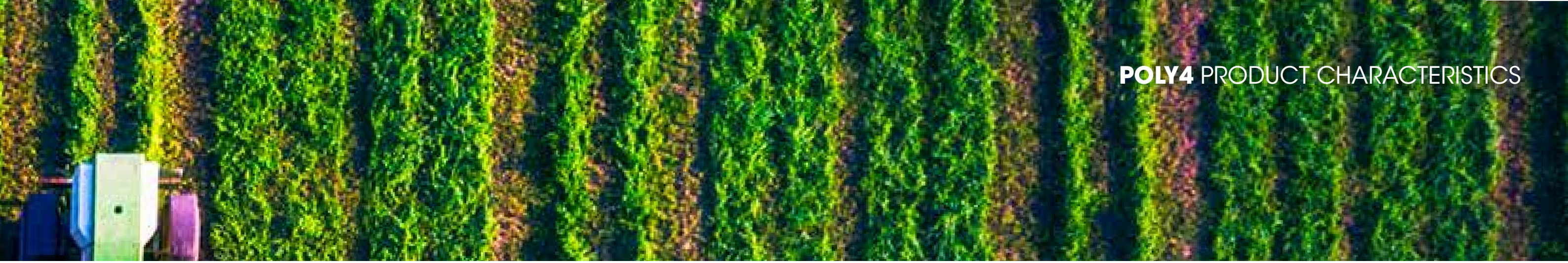
Blending fertilizers requires consideration of all components' compatibilities to prevent caking and ensure safety. International Fertilizer Development Center (IFDC) is an established industry specialist. Using a wide range of likely fertilizer combinations, IFDC carried out advanced testing on POLY4 to determine blend compatability.[116]

Testing took place over an extended period in order to mimic industrial conditions.[117] Materials were combined and blended such that the total sample (100 grams), occupied two-thirds of a 200 mL glass bottle. The samples were then tightly capped and placed in a convection oven at a temperature of 30°C for 30 days. The mixtures/bulk blends were inspected daily for signs of incompatibility. The chemical analyses of tested materials were performed according to the Association of Official Analytical Chemists (AOAC) methods.



Visual observation	Compatibility rating
Dry and free-flowing	Compatible
Damp and free-flowing	Compatible
Damp and non-flowing	Reduced compatibility
Wet and non-flowing	Incompatible

After testing,[118] all mixtures remained free-flowing through the duration of the test. The results showed that POLY4 is a compatible input for blending into NPK fertilizers.



USING POLY4 IN COMPOUNDS

The potential storage life of fertilizer blends can be estimated during the accelerated caking test.[119] Inclusion of POLY4 in steam-granulated NPK compounds reduced caking and improved caking resistance, which was tested using the small-bag technique.

Material tested[120]

Option 1: with urea-DAP-KCl$^-$-POLY4

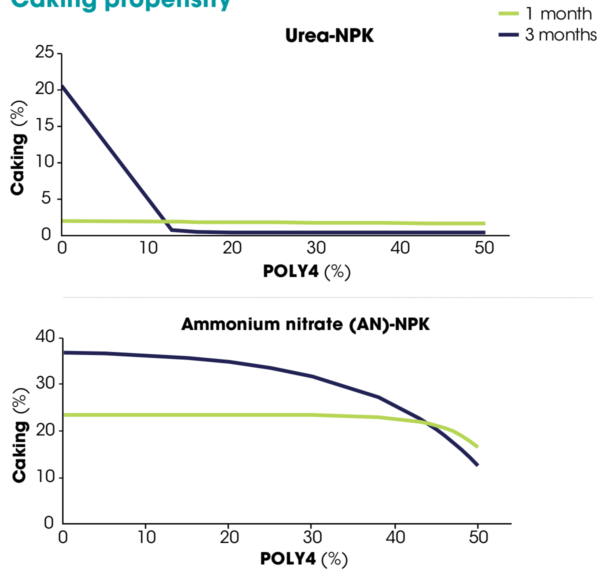
Nutrient ratio	Grade	Material (g)			
		Urea	DAP	KCl$^-$	POLY4
2:1:1	26.5-13.3-14.4	46.3	29.7	23.9	0.00
	24.2-11.9-12.0	42.6	26.4	16.7	14.2
	19.3-9.8-10.0	33.5	21.7	8.6	36.1
	16.5-8.2-8.3	28.8	18.2	2.4	50.7

Option 2: with AN-DAP-KCl$^-$-POLY4

Nutrient ratio	Grade	Material (g)			
		AN	DAP	K	POLY4
1:1:1	19.0-16.3-15.8	37.4	36.1	26.4	0.00
	17.0-16.0-17.5	31.8	35.6	28	4.8
	14.1-14.5-14.0	24.8	32.3	17.7	25.3
	10.5-9.8-10.8	19.8	21.8	6.3	52.1

The results showed that using POLY4 in compounds gave a longer storage life, which is desirable for blenders and growers.

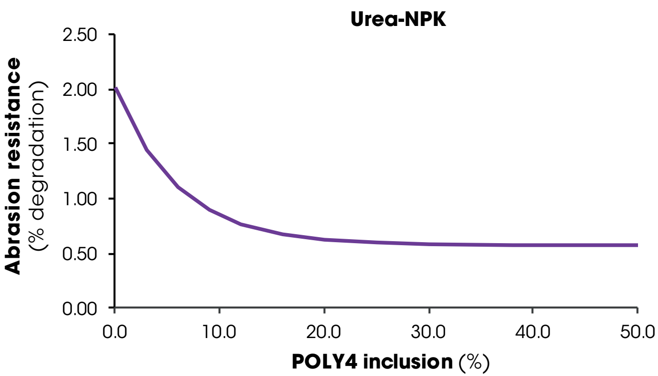
Caking propensity[121]

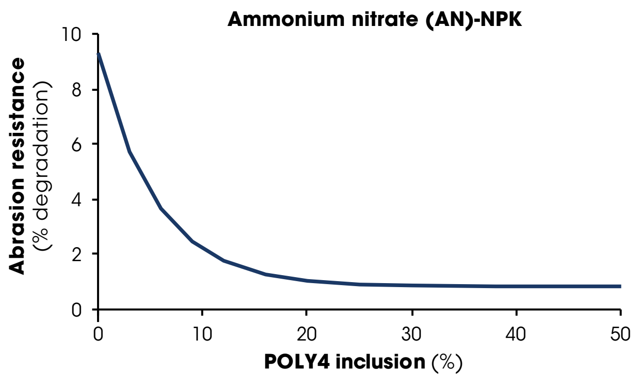


ABRASION RESISTANCE

Resilience to handling is important during transit and for on-farm use of product. Minimising degradation improves spreading patterns whilst supporting farm economics.

Inclusion of POLY4 in steam-granulated urea and AN-NPK compounds reduced degadation from abrasion to near zero.[122]



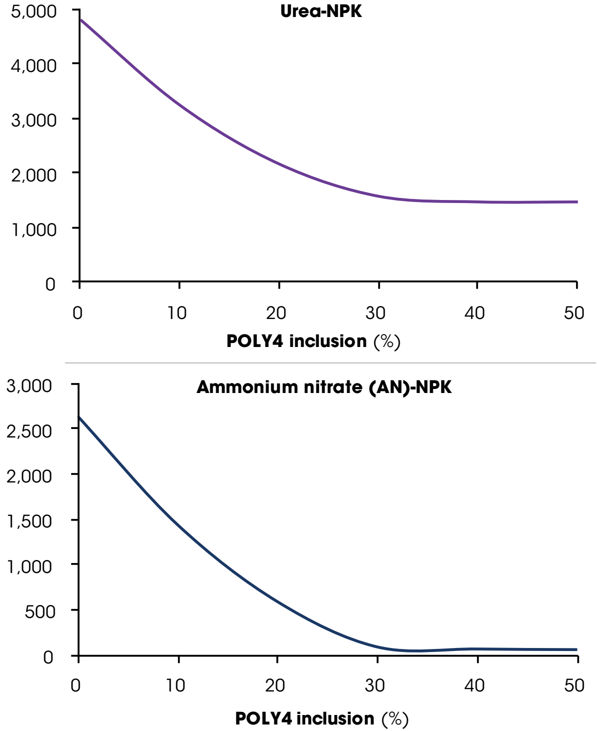


LOW DUST TENDENCY

Fertilizers that generate dust make fertilizer-handling difficult and are undesirable by manufactures, blenders and customers. Dust presents an inhalation safety hazard and makes fertilizer handling difficult. The higher surface area of dust particles can lead to a greater attraction of moisture, consequently increasing caking propensity and lowering shelf life.

POLY4 positively reduced dust in steam-water granulated NPK compounds. For steam-water granulated urea-NPK an inclusion of ~50% POLY4 reduced dust by 82%. For steam-water granulated AN-NPK product, POLY4 lowered dustiness by 24%.[123, 124]

Dustiness of product (mg kg^{-1})[123,124]



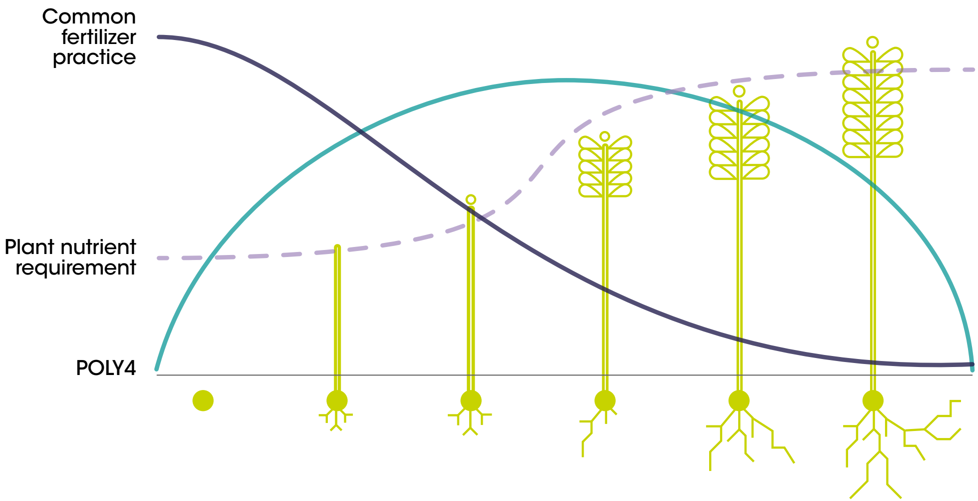
SUSTAINABILITY

NUTRIENT DELIVERY

Growing healthy plants and sustaining crop yield and quality begins with nutrient-rich soil. With four of the six macro nutrients (potassium, sulphur, magnesium, and calcium), fertilizer plans that include POLY4 deliver a better outcome – farmers see increased yield and improved crop quality as well as improved soil structure from this one simple product.

POLY4 is a naturally-occurring, low chloride, multi-nutrient fertilizer certified for organic use. Its nutrients become available over time, which more closely meets the nutrient uptake requirements of the plant. Our product is suitable for use and increases quality of both broad-acre and high-value crops.

Using POLY4 as a source of nutrients helps to improve crop quality, and is more efficient and effective for farmers whilst offering additional value with the potential for increased economic margins.

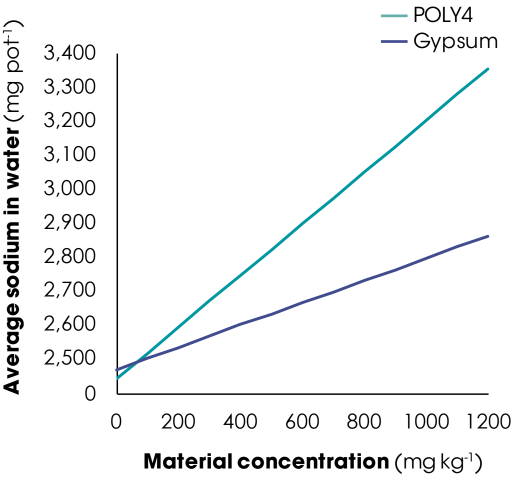


ROLE OF CALCIUM IN THE SOIL

Soils with high levels of exchangeable sodium (Na), which prevents plant growth, are called sodic soils. Classification of a soil as sodic is when the sodium absorption ratio (SAR) exceeds 15. This ratio is calculated by the amount of sodium cations relative to the combined magnesium and calcium cations. Under these conditions, soils have poor structure and drainage because clay particles are dispersed by sodium. Such soils may also then create a hard crust. In addition, plants struggle to extract water and access nutrients in this soil due to high salinity.

Calcium is commonly applied as lime or gypsum to restore sodic soils because calcium displaces sodium from soil exchange sites. Combined with sufficient input of water (rainfed or irrigated) to remove the sodium, sodic soils can be restored to functional agricultural land. In a greenhouse trial[125] in China, POLY4 mobilised soil sodium resulting in greater removal of sodium from the soil system compared to gypsum, applied on an equal weight basis.

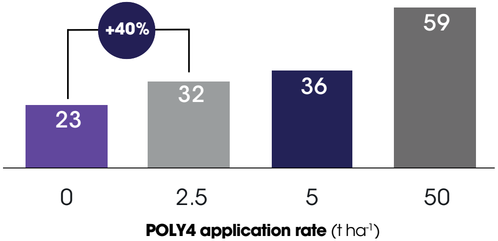
Soil sodium cumulative total



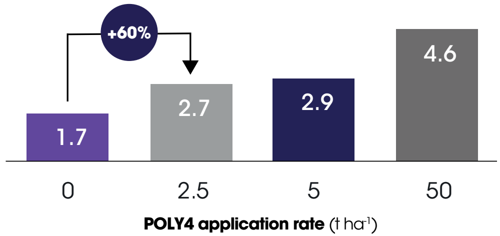
Soil erosion causes nutrient waste and leads to wider environmental pollution in waterways. In the EU, water-borne soil erosion affects 115 million ha of soil with a total loss of 970 Million metric tonnes (Mmt) per year. The most severe erosion affects 10.5% of total area costing €1.26 billion per year.[126]

Calcium in POLY4 helps to increase tensile strength and resilience to compaction.[127] Higher tensile strength prevents soil movement whilst resistance to compaction maintains a porous soil structure to allow water to drain into the soil rather than runoff.

Soil tensile strength (kPa)



Soil resilience to compaction (Young's Modulus MPa)[128]

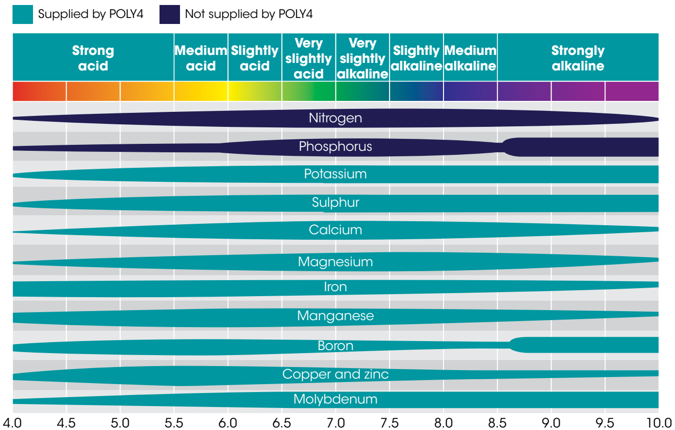


SOIL pH

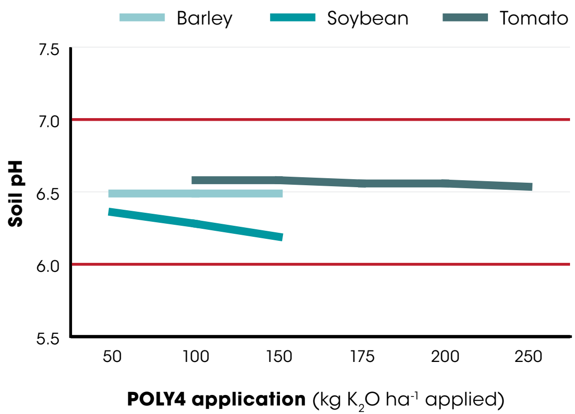
Maintenance of soil pH, within suitable limits, is important for optimum nutrient availability and therefore plant growth. POLY4 has no expected effect on soil pH levels unless there are reducing conditions, which can convert sulphates to elemental sulphur, or the soil has significant aluminium levels. Aluminium can exchange with cations and, upon release into the soil solution, enter into chemical reactions that affect pH.

Across a range of K_2O rates, POLY4 is shown to have no effect on soil pH; none of the soil pH values are significantly different from the unfertilized soil.

Soil effect on nutrient availability[129]



Soil pH in water post crop trial[130]

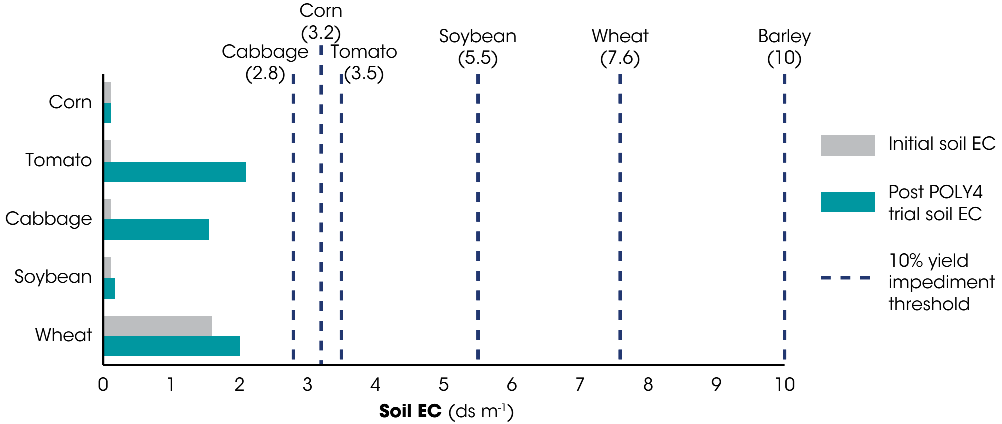


SOIL ELECTRICAL CONDUCTIVITY (EC)

Fertilizers are soluble salts and can increase soil water salinity thereby increasing soil EC. Studies showed that POLY4 and other fertilizers have increased soil EC (as measured after harvest at the higher application rates), but in no instances were the increases sufficient to cause crop damage.

The study[131,132] on a range of salt-sensitive crops to assess the effect of POLY4 application on soil EC has been carried out. The results showed that even at high K_2O application rates soil EC was well within the plant tolerance level for a range of sensitive crops.

Effect of POLY4 on soil EC



LOW CARBON FOOTPRINT

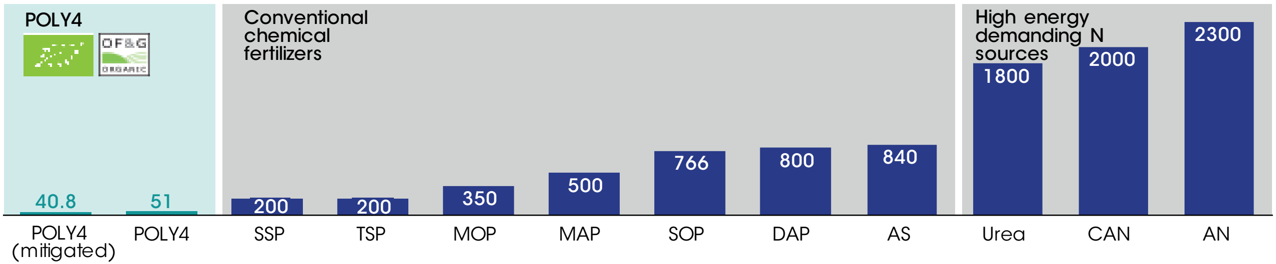
As the world's population grows, urbanises and industrialises, farmland per capita decreases and more food production is required from each acre, which in turn requires more plant nutrients. Fertilizers are one of the fundamental means to guarantee agricultural yields and address the forecasted future imbalance between food demand and supply.

However, the application of fertilizers is identified as a significant source of greenhouse gases (GHG). With amplified use, there becomes an ever-increasing need to improve the use efficiency of applied fertilizers and adoption of fertilizer species with lower GHG contributions.

POLY4 has a low CO_2 emission and is more environmentally-friendly than most fertilizer products and potassium fertilizer sources. This is due to the sustainable method of POLY4 production. POLY4 production generates only 7% CO_2 relative to SOP and 15% CO_2 relative to MOP.

For example, the three-year cotton trial[133], in partnership with Virginia Tech in the United States, showed that using POLY4 in a fertilizer plan increased yield by 18% (see page 23 of this handbook) and reduced CO_2 emission by about 51% compared to the MOP balanced option. The results showed that with POLY4 farmers can achieve both economic and environmental sustainability.

CO_2 emissions comparison of POLY4 to other fertilizers[134] (kg t^{-1} of fertilizer)



LOW CHLORIDE

Plants take up chloride as Cl^- ion from soil solution. It plays an important role in photosynthesis, osmotic adjustment and suppression of plant disease. Chloride is co-applied in the most commonly used potash fertilizer MOP with a 48% Cl^- content.

However, high concentrations of chloride can cause toxicity problems in crops and as a consequence reduce yields. Toxicity also causes leaf drop and death in chloride-sensitive crops.

Some crops require significant potassium fertilizer to economically maximise yield, but are negatively impacted by the co-applied chloride. Grape and citrus are sensitive to chloride toxicity – chloride accumulates in leaves, which can die and become more sensitive to falling during cold temperatures.

Studies[135] showed that POLY4, as a low-chloride polyhalite fertilizer, improved quality and increased yield of chloride-sensitive crops. For example, potato tuber dry matter (DM) content can be reduced by chloride application in MOP. Dry matter is an important measure of potato quality, particularly its fryability. When POLY4 partially or wholly replaced MOP as a K source, it increased dry matter content improving characteristics of potato quality.

Potato specific gravity (%DM)

Minnesota, USA trial (2016)[136]

Treatment	Dry matter (%)
MOP+gypsum	18
MOP+Ca+Mg+S	19
MOP+POLY4 (50:50)	19
POLY4	20

FREQUENTLY ASKED QUESTIONS

POLY4 – NUTRIENT CONTENT

Q: What is POLY4?

A: POLY4 is the commercial name for the Anglo American product, created from a natural mineral called polyhalite. It includes four of the six key macro nutrients that all plants need to grow: potassium, sulphur, magnesium and calcium. Its chemical formula is $K_2SO_4MgSO_42CaSO_42H_2O$.

Q: What is the specified nutrient content of POLY4?

A: POLY4's four macro nutrients are 14% K_2O, 17% CaO, 6% MgO and 19% S, which are based on a 90% polyhalite content of the ore body.

Q: Why doesn't the declared nutrient content of POLY4 add up to 100%?

A: The declared content is based on a 90% polyhalite content of the ore body. The remaining 10% is anhydrite, magnesite, kieserite, hexahydrite, szaibelyite, gypsum, halite, mica and syngenite.

The label-declared analysis of a fertilizer is the minimum content of its nutrients. It is most commonly expressed as a percentage by weight. Nutrient value is expressed in units to allow fair comparison of nutrient content between different fertilizers.

The elemental K, Ca, Mg, S, H and O composition of pure polyhalite is 12.9, 13.3, 4, 21.2, 0.7 and 47.8.

NUTRIENT CONTENT CONTINUED...

Q: What does the average polyhalite grade of 90% mean?

A: POLY4 is made from polyhalite, a natural mineral found underground. After extensive testing, we indicated that the typical composition of our product will be 90% polyhalite.

Q: Why is the potassium (K) contained in POLY4 good for plants?

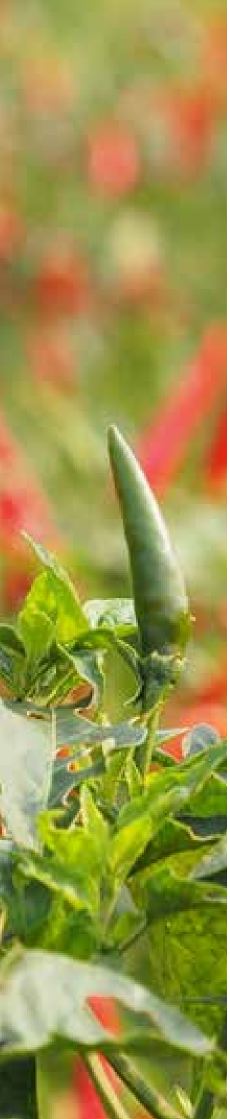
A: Potassium plays a critical role in: activation of different enzymes; maintenance of optimum cell pH; influencing photosynthesis, and transport of sugar, nutrients and water; synthesis of proteins and starch; and improving crop quality.

Q: Why is the magnesium (Mg) contained in POLY4 good for plants?

A: Magnesium enhances a broad spectrum nutrient uptake; it is constituent of chlorophyll and so affects photosynthesis; it is critical for energy transfer reactions influencing respiration.

Q: Why is the calcium (Ca) contained in POLY4 good for plants?

A: Calcium influences nitrogen metabolism and potassium uptake; cell elongation and division; the transport of carbohydrates and nutrients thus encouraging root growth and crop quality.



NUTRIENT CONTENT CONTINUED...

Q: Why is the sulphur (S) contained in POLY4 good for plants?

A: Sulphur is a constituent of three amino acids and coenzyme A thus it influences protein and fatty acid synthesis; it maintains an optimum N and S ratio and protein content; it also influences chlorophyll and ferredoxin content prompting nitrite and sulphate reduction and subsequently crop quality.

Q: Does POLY4 have too much sulphur?

A: POLY4 provides sulphur in sulphate form making it available to the plants. Our crop trials have shown that the sulphur supplied improves yield and quality. We have also seen a soil nutrient legacy from POLY4 making sulphur available for the next season's crops. Sulphate is a plant nutrient and has no toxic impact on the environment or other deleterious implications for soil or the plant itself.

Q: What are the benefits of the micro nutrients contained in POLY4?

A: POLY4 contains eight micro nutrients:

- Boron (B): cell division and regulation metabolism of carbohydrates;
- Copper (Cu): important for pollen tube production, cell wall structure and function as well as photosynthetic and respiratory pathways;
- Iron (Fe): an essential co-factor in a range of cellular redox reactions; important in energy transport metabolic pathways of the mitochondria and chloroplast;
- Manganese (Mn): essential for nitrate reduction and involved in the regulation photosynthetic enzymes;
- Molybdenum (Mo): essential cofactor of enzymes for the conversion of nitrate to amino acids and inorganic P to organic P;

NUTRIENT CONTENT CONTINUED...

- Selenium (Se): protects from variety of abiotic stresses such as cold, drought, desiccation, and metal stress;
- Strontium (Sr): supplements calcium uptake;
- Zinc (Zn): a component of enzymes involved in a photosynthesis, sugar and protein formation, DNA synthesis and gene regulation.

Q: How much sodium and how much chloride is present in POLY4?

A: Our specification offers a typical halite content of 3.07% with 1.2% of sodium content and 1.9% of the average content of Cl^-.

Q: What is the heavy metal content in POLY4?

A: POLY4 does not contain heavy metals. It is a natural material that contains beneficial elements such as boron, cobalt, selenium, strontium, copper, iron, manganese, molybdenum, zinc and sodium. Testing of POLY4 for the presence of aluminium, vanadium, thallium, beryllium and silver resulted in nil detections.

POLY4 – NUTRIENT DELIVERY

Q: What form are the macro nutrients delivered in POLY4?

A: The structure of polyhalite is crystalline, and, in solution, cations are K^+, Mg^{2+} and Ca^{2+} whilst the anion is SO_4^{2-}. Sulphur being the SO_4^{2-} anion is the form in which plants absorb it. All nutrients in POLY4 are available for immediate plant root uptake.

NUTRIENT DELIVERY CONTINUED...

Q: What is the nutrient release profile of POLY4?

A: To sustain crop yield and quality, a minimum level of nutrient status needs to be maintained in the soil. Our agronomic trials' data shows that POLY4's nutrients (potassium, sulphur, magnesium and calcium) become available over time, which more closely meets the nutrient uptake requirements of the plant.

Q: Is there a nutrient difference between various forms of POLY4?

A: All forms of POLY4 adhere to the same minimum nutrient content specification.

Q: Is there a risk that calcium sulphate (gypsum) is precipitated and nutrients become unavailable to a plant?

A: Both, POLY4 and gypsum, contain calcium and sulphate-sulphur, though only 27% of POLY4 components are the same as in gypsum.

Our trial results show the value of calcium (Ca) and sulphur (S) for soil structure and crop nutrition. Data also indicates that POLY4 typically delivers improved uptake of Ca and S.

POLY4 is approximately five times more soluble than gypsum. If POLY4 is applied at agronomically advisable rates and under normal soil conditions, precipitation will not occur.

Q: Since POLY4 delivers calcium into soil, is there a risk of making calcium phosphate and thus immobilising the crop nutrient phosphorus?

A: Repeated field testing indicates crops do not suffer a lack of phosphorus availability. On the contrary, our crop trial results show evidence for improved nutrient capture.

POLY4 – CHARACTERISTICS

Q: What is the crush strength of POLY4 granules?

A: POLY4 granules will have a minimum crush strength of 6.5 kgf.

Q: What is the critical relative humidity of POLY4?

A: Critical relative humidity (CRH) is the value of the relative humidity of the surrounding air above which a fertilizer will absorb moisture and below which it does not absorb moisture. This is important in preventing fertilizer from caking that makes it difficult to handle or use. Uncoated POLY4 has a CRH of 70%. This is similar to other products such as MOP (CRH of 72%).

Q: How soluble is POLY4?

A: POLY4 has a solubility of 27 g L^{-1} at 25°C. With this solubility, POLY4 effectively delivers K_2O, MgO, CaO and S at commercially-required rates.

Since POLY4 is a mineral, dissolution results in simultaneous nutrient release. Dissolution rate characterises the transition of a solid fertilizer into a solution. This rate is largely governed by physical parameters controlled during the patented granulation process. The result is a dissolution rate that favours provision of nutrients supporting plant growth throughout the growing season.

POLY4 – SUSTAINABILITY

Q: How is POLY4 different from other forms of potash?

A: Potash is a generic name for a range of potassium-bearing minerals and industrial products, which include muriate of potash (K_2O), potassium sulphate (K_2SO_4) and polyhalite ($K_2Ca_2Mg(SO_4)_4{\cdot}2(H_2O)$). POLY4 differs from most potash fertilizers because it is produced from a natural mineral with no chemical processing. This supports POLY4's organic registration and maintains its micro nutrient component. Further, the primary difference from muriate of potash (KCl) is the low chloride nature of POLY4.

Q: What is POLY4's salt index?

A: Results from seven independent laboratories using contemporary Jackson method show a POLY4 salt index of 76 compared to 130 for MOP, 97 for SOP and 80 for SOP-M.

Q: Does POLY4 affect the soil environment, particularly the high sulphate content?

A: Historical research has indicated that the nutrients such as calcium and magnesium can be beneficial particularly to the physical and chemical properties of the soil. The presence of these nutrients within POLY4 means that the soil environment can benefit in one season and over time.

POLY4 delivers sulphur in the sulphate form. This soluble cation does not accumulate in the soil, but moves out with water drainage. An independent review of the environmental risk concluded that POLY4 does not present a risk.

SUSTAINABILITY CONTINUED...

Q: Is a POLY4's neutral pH important?

A: POLY4 is a pH neutral fertilizer and does not affect soil pH regardless of the quantity applied. Using POLY4 as a component of fertilizer plans may result in reduction of acidifying effects from other nutrient sources such as ammonium sulphate.

Q: Can POLY4 be used in organic farming?

A: Yes. POLY4 is produced from a natural mineral and certified for use in organic systems according to the UK Soil Association and Organic Farmers & Growers. Farms certified by Soil Association or Organic Farmers & Growers do not need prior approval to use POLY4. However, use requires an on-farm justification, which is verifiable at audit.

POLY4 – HANDLING AND USE

Q: How does POLY4 handle?

A: Testing results demonstrate that POLY4 has a sufficient crush strength (6.5 kgf) throughout the manufacturing, handling and loading process. Our product is of premium quality, which means that it has a low caking tendency with a CRH of 70% and is compatible with other NPK fertilizers. A farmer, who gets the product at the end of the supply chain, will receive POLY4 granules with a long shelf life, durable and suitable for mechanical spreading up to 36m widths.

HANDLING AND USE CONTINUED...

Q: Is POLY4 flammable?

A: No. POLY4 is not made using chemical synthesised materials unlike nitrogen fertilizers that are chemically manufactured, eg, urea or ammonium nitrate. Since POLY4 is formed from natural materials, there is almost zero chance of it catching fire.

Q: Does POLY4 blend with other fertilizer inputs? Does it work in the majority of NPK plants?

A: Independent providers have ratified that POLY4 can be used as an ingredient in dry blends, compacted and steam granulated NPK alongside urea, DAP, rock phosphate, ammonium nitrate and MOP, being both physically and chemically compatible. Importantly, POLY4 blends can meet industry's shelf life expectations.

IFDC testing validates POLY4's compatibility across dry blend, complex, complex/compound NPK production. The high density of nutrients contained in POLY4, makes it an ideal feedstock to transform standard NPK blends into NPK+ blends supporting balanced fertilization globally.

Q: How abrasive will POLY4 be on our machinery?

A: The measure used in mineral processing is the abrasion index (AI). Polyhalite used for POLY4 production has measured an AI value of 0.002, which is two orders of magnitude lower than most common materials. This is because quartz or silica/silicates are essentially absent from polyhalite.

HANDLING AND USE CONTINUED...

Q: Do I have to apply four times as much POLY4 as MOP?

A: We recommend that farmers' fertilizer plans are provided by qualified advisors. The best agronomic and economic solutions maximise the value of each component of a fertilizer plan, whether supplied as a straight component, in blends or complex compounds.

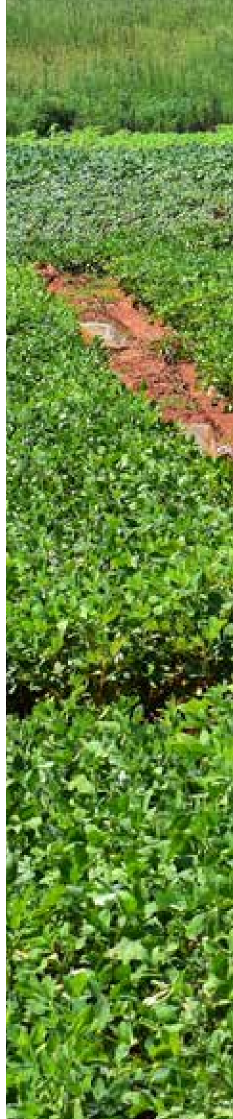
Potassium chloride or MOP is a single nutrient source rated at 60% K_2O, whilst POLY4 is a multi-nutrient source with rated nutrient contents of 14% K_2O, 6% MgO, 17% CaO and 19% S.

Through extensive testing, we have validated globally that, through the K rate response curve, using less K in POLY4 straight applications and in blends delivers better results. Crop fertilizer plans will be delivering not just potassium (K_2O) but also other macro nutrients such as magnesium and sulphur. Therefore, it is not an equitable comparison to compare MOP and POLY4. Under these circumstances there is little difference between the weight of fertilizer required for either plan.

Q: Can I spread POLY4 at 24m and 36m?

A: Uniformity of application is expressed as the coefficient of variation (CV). A lower CV means a more even distribution of a fertilizer. A CV of more than 20% generates stripes in the crop. Uneven spreading increases the cost of the crop production due to yield penalties and required corrective actions.

Spreader testing has demonstrated that POLY4 spreads at widths of both 24m and 36m. Test results ranged from a CV of 4.4 to 5.8%.



POLY4 – AGRONOMIC TRIALS

Q: Have any independent crop trial results been published in academic journals or papers to support POLY4results?

A: POLY4 sponsored agronomic research has been published in three science journals (International Scholars Journals, Powder Technology and HortScience) with one further agronomic paper expected to published in autumn 2018.

Much of the historic assessment of polyhalite as a fertilizer (Terelak, 1975, 1974; Panitkin, 1967; Marchesi Sociats, 1948; Lepeshkov and Shaposhnikova, 1958; Boratynski and Turyna, 1971; Fraps and Schmidt, 1932; Simrnova, 1965; Mercik, 1981) demonstrated that polyhalite could be used with equal or greater effect than other potassium fertilizers across a very broad range of important crops.

Granular polyhalite also proved an effective slow release potassium (K) fertilizer to usefully boost K uptake by ryegrass over a longer season (Mercik, 1981). Polyhalite also increased sulphur (S) uptake (Mercik, 1981), which is increasingly deficient for crops in Europe (EEA, 2012) and elsewhere. Furthermore, in deficient soils polyhalite was fully capable of providing magnesium to boost crop yields of potatoes, beets (Panitkin, 1967) and buckwheat (Boguszweski et al, 1968). Further assessments were made in the United States (Barbarick, 1989 and 1991) which confirmed equal or greater crop yields and nutrient uptake, compared to standard fertilizer. Consequently, polyhalite was accepted as a good fertilizer for K, Ca, Mg and S.

A large set of independent data demonstrates the exciting potential for POLY4. This work concentrates on the agricultural benefit to crops (Pavuluri et al, 2017; Sutradher et al, 2016; da Costa Mello et al, 2018) and the physical characteristics of POLY4 as a commercial fertilizer (Albadarin et al, 2017).

NB: Detailed references to publications are available on request.

AGRONOMIC TRIALS CONTINUED...

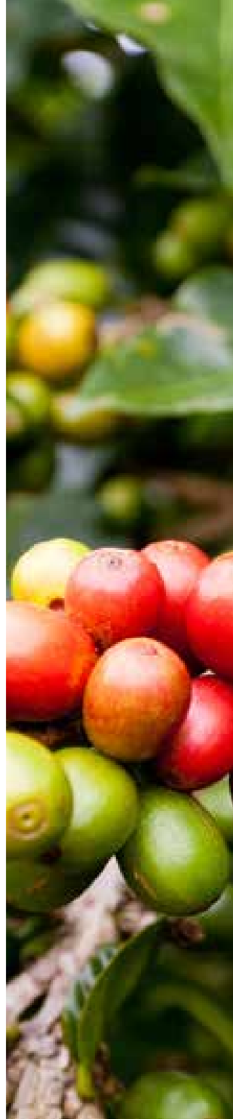
Q: How is the credibility of the POLY4 crop trial results assessed?

A: POLY4 trials are undertaken in partnership with independent research authorities that have their own in-house staff with a breadth of relevant experience. Currently we work with over one hundred leading agricultural universities, research institutions and commercial associates.

Q: Why would farmers want to use POLY4? Is it a low-nutrient content product?

A: POLY4 is a naturally occurring, low-chloride, multi-nutrient fertilizer certified for organic use. It contains four of the six nutrients that plants need to grow and a range of valuable micro nutrients. Our product's nutrient content (14% K_2O, 6% MgO, 17% CaO and 19% S) totals 56%, which compares favourably with 60% for MOP, 57% for potassium nitrate, 67% for SOP, 45% for kieserite or 55% for gypsum. It is an effective fertilizer that allows farmers to maximise their crop yield, increase quality and improve soil structure with one simple product.

NB: Detailed references to publications are available on request.



MARKET OPPORTUNITY CONTINUED...

POLY4 – MARKET OPPORTUNITY

Q: What is the market potential for POLY4?

A: POLY4 has a significant market opportunity. The size of the market options for POLY4 is framed in three key areas – as a substitute for existing products, to meet unmet market demand for high-value products and to provide premium performance.

Product substitution: POLY4's unique multi-nutrient content enables a wide range of opportunities for existing fertilizer products substitution. In addition, the demand for multi-nutrient fertilizers continues to grow at the farm gate.

Unmet market demand: There is a need for balanced fertilization and significant unmet demand for low-chloride potassium: 32% of total potassium consumption is used on chloride-sensitive crops while supply of low-chloride potassium is only 9%. The increasing demand for key attributes of POLY4, such as its suitability for use on chloride sensitive crops and its ability to address sulphur and magnesium soil deficiencies.

Product performance: POLY4 is a premium product: it increases yield on broad-acre and high-value crops, improves crop quality and health and soil structure, which is consistently evidenced by data collected through our R&D programme. Demand for multi-nutrient fertilizers continues to grow and as the performance of POLY4 becomes more widely validated, it is expected that so will its ability to attract a premium.

MARKET OPPORTUNITY CONTINUED...

Q: Have freight costs for POLY4 into markets have been accounted for?

A: Yes. The quoted prices for transportation of our product to the port of shipment, plus loading costs, are based on a variety of existing agreements and contracts in place on a CFR or FOB at Teesside port.

Q: Does it cost more if POLY4 is included in a fertilizer plan?

A: POLY4 has lower application cost on a nutrient basis. Many of our trials address the value of the nutrients within POLY4 compared to current options. For example, the results of our corn trial in partnership with University of Minnesota, that compared the use of MOP and MOP+POLY4 at a ratio of 75:25 K_2O as potassium and sulphur sources, showed that using MOP+POLY4 returns an extra US$247 per hectare compared to MOP while improving grain quality and increasing yield up to 15%. For some crops, such as tea, we show value and economic improvement when POLY4 application meets all potassium requirements. The data collected indicates that POLY4 value is in a fertilizer plan and these plans do not require more total weight of products.

MARKET OPPORTUNITY CONTINUED...

Q: Will blenders need to install new infrastructure to work with POLY4?

A: No. University of Greenwich's study of our product indicates that handling of POLY4 does not differ from other products, and there is no requirement to install new infrastructure by blenders for mechanical handling and facility requirements. POLY4 has been tested on dry blend, complex and complex/compound treatments, and covered aspects such as dumping into bins and passing around systems.

POLY4 has also been proven to handle and store effectively under similar conditions to other common fertilizer materials.

REFERENCES

***For full trial results and references, please visit poly4.com**

Page 11 1) Average initial soil analysis: 35 mg P kg^{-1}, 124 mg K kg^{-1}, 174 mg Mg kg^{-1}, 1807 mg Ca kg^{-1}, 25 mg S kg^{-1}, organic matter: 16 g kg^{-1}. The data consist of trials for both broad-acre and high-value crops such as: cotton, potato, tea, tomato, wheat, barley, oilseed rape (canola), carrots, onion, sorghum, grass, rice, corn and squash.

Page 12 2) FAOSTAT (2017); 3) Average initial soil analysis: 14 mg P kg^{-1}; 353 mg K kg^{-1}, 643 mg Mg kg^{-1}, 2350 mg Ca kg^{-1}, 40 mg S kg^{-1}, organic matter: 13.05 g kg^{-1}, pH (H_2O) 6.7; 4) POLY4 rice trials: 20000-CAS-20016-15; 61000-UARK-61010-17; 25000-SOH-25011-16 (4 sites); 19000-SAAS-19017-17; 20000-CAS-20010-14; 5) Nanjing Institute of Soil Science, Chinese Academy of Sciences (2015) 20000-CAS-20016-15.

Page 13 6) GENSTAT means; 7) All plots received 225 kg N ha^{-1} and 120 kg P_2O_5 ha^{-1} from urea and DAP. Initial soil analyses (0 – 20 cm) pH 6.7; 22 mg P kg^{-1}, 44 mg K kg^{-1}, 1096 mg Ca kg^{-1}, 214 mg Mg kg^{-1}, 119 mg S kg^{-1}, 0.08 mg B kg^{-1}, 0.92 mg Mo kg^{-1}, 0.64 mg Zn kg^{-1}, EC 1007 uS cm^{-1}.

Page 14 8) FAO (2016); 9) USDA (2018); 10) Average initial soil analysis: 24 mg P kg^{-1}; 115 mg K kg^{-1}, 216 mg Mg kg^{-1}, 1077 mg Ca kg^{-1}, 11 mg S kg^{-1}, organic matter 11.8 g kg^{-1}, pH (H_2O) 6.8; 11) POLY4 corn trials: 1000-UOF-1017-14 14000-UMN-14012-15; 14000-UMN-14012-15; 15000-NDS-15010-14; 15000-NDS-15012-15; 19000-SAAS-19012-14; 25000-SOH-25010-14; 27000-MLI-27011-15; 27000-MLI-27011-15; 48000-UGR-48010-16; 48000-UGR-48010-16; 8000-WCC-8015-16; 14000-UMN-14016-16; 14000-UMN-14016-16; 12) Fundação MT (2014, 2015, 2016) 5000-FMT-5010-14, 5000-FMT-5012-15 and 5000-FMT-5014-16; 13) USDA (2017); 14) Meredith Agrimedia (2017).

Page 15 15) Nutrient composition: urea: 46:0:0; TSP: 0:0:46 + 20CaO; SSP: 0:0:16 + 11S + 28CaO; MAP: 11:52:0; MOP: 0:0:60; POLY4: 0:0:14 + 19S + 6MgO + 17CaO; 16) Initial soil analysis based on average for 2014, 2015 and 2016 trials: pH 4.9; 1 mg P kg^{-1}, 66 mg K kg^{-1}, 184 mg Ca kg^{-1}, 325 mg Mg kg^{-1}, 4 mg available S kg^{-1}; 17) Results presented are based on data from GENSTAT regression analysis at average K_2O rate of 50 kg ha^{-1}; 18) Yield results are average estimates from 2014, 2015 and 2016 trials; 19) Fertilizer prices were obtained from CRU and are based on average fertilizer prices: MOP (US$302/t), POLY4 (US$200/t), SSP (Brazil Inland: US$229/t), TSP (US$354/t), urea (US$289/t) and MAP (US$437/t). Analysis accounts for fertilizer application or spreading cost of US$13.07/t; 20) Average corn price = US$162/t; 21) Net return = crop output minus (cost of fertilizer material plus cost of fertilizer application). The total cost calculation took into consideration the cost of additional 68 kg N ha^{-1} from urea as top dressing. Nutrient composition: urea: 46:0:0; TSP: 0:0:46 + 20CaO; SSP: 0:0:16 + 11S + 28CaO; MAP: 11:52:0; MOP: 0:0:60; POLY4: 0:0:14 + 19S + 6MgO + 17CaO.

Page 16 22) Average initial soil analysis: 31 mg P kg^{-1}; 95 mg K kg^{-1}, 156 mg Mg kg^{-1}, 949 mg Ca kg^{-1}, 27 mg S kg^{-1}, organic matter: 1.6 g kg^{-1}, pH (H_2O) 6.4; 23) POLY4 soybean trials: 1000-UOF-1018-14; 11000-LSU-11010-14; 14000-UMN-14013-15; 14000-UMN-14013-15; 48000-UGR-48010-16; 48000-UGR-48010-16; 0000-TAM-0027-14; 0000-TAM-0014-13; 14000-UMN-14015-16; 14000-UMN-14015-16; 11000-LSU-11011-16; 1000-UOF-1010-13; 11000-LSU-11013-17; 24) USDA (2017); BrazilGovNews (2017); 25) Fundação MT (2014, 2015, 2016) 5000-FMT-5011-14, 5000-FMT-5013-15 & 5000-FMT-5015-16.

Page 17 26) Nutrient composition: TSP: 0:0:46 + 20CaO; SSP: 0:0:16 + 11S + 28CaO; MAP: 11:52:0; MOP: 0:0:60; POLY4: 0:0:14 + 19S + 6MgO + 17CaO. Fertilizer prices are CRU prices based on average fertilizer prices for Brazil from 2014 to 2016: MOP (US$302/t), POLY4 (US$200/t), SSP (Brazil Inland: US$229/t) and TSP (US$354/t); 27) All treatments received 90 kg K_2O ha^{-1} from MOP and/or POLY4 and 90 kg P_2O_5 ha^{-1} from SSP and/or TSP respectively for the 0:14:14 and 0:18:18 trials. Initial soil analysis based on 2014 trial: pH 5.7; 28 mg P kg^{-1}, 67 mg K kg^{-1}, 760 mg Ca kg^{-1}, 324 mg Mg kg^{-1}, 6 mg available S kg^{-1}. 28) Results presented are based on data from GENSTAT regression analysis at 90 kg K_2O ha^{-1}. Yield results are average estimates from 2014, 2015 and 2016 trials; 29) Fertilizer prices are CRU prices based on average fertilizer prices for Brazil from 2014 to 2016: MOP (US$302/t), POLY4 (US$200/t), SSP (Brazil Inland: US$229/t) and TSP (US$354/t); 30) Analysis accounts for fertilizer application or spreading cost of US$13.07/t; 31) Margin = crop output minus (cost of fertilizer material + cost of fertilizer application).

Page 18 32) Average initial soil analysis: 118 mg P kg^{-1}; 118 mg K kg^{-1}, 141 mg Mg kg^{-1}, 2813 mg Ca kg^{-1}, 21 mg S kg^{-1}, organic matter: 21.3 g kg^{-1}, pH (H_2O) 6.4; 33) POLY4 wheat trials: 15000-NDS-15013-16; 17000-ASA-17010-14; 18000-SGS-18010-14; 20000-CAS-20010-14; 20000-CAS-20010-14; 49000-PUL-49010-16; 2000-CAS-20016-15; 2000-CAS-20018-15; 57000-HUT-57010-16; 57000-HUT-57010-16; 57000-HUT-57010-16; 49000-PUL-49010-16; 49000-PUL-49010-16; 49000-PUL-49010-16; 20000-CAS-20018-15; 20000-CAS-20016-15; 34) Average initial soil analysis: 32 mg P kg^{-1}; 128 mg K kg^{-1}, 206 mg Mg kg^{-1}, 1219 mg Ca kg^{-1}, 23 mg S kg^{-1}, organic matter: 15.9 g kg^{-1}, pH (H_2O) 6.5; 35) POLY4 barley trials: 8000-WCC-8010-14; 8000-WCC-8014-15; 65000-TEAG-65011-17; 65000-TEAG-65011-17; 8000-WCC-8016-16.

Page 19 36) FAOSTAT (2018); 37) Institute of Soil Science and Plant Cultivation, Pulawy (2016) 49000-PUL-49010-16; 38) Trial was conducted at four locations with the following initial soil analysis: Pulki I: pH (H_2O) 6.6, pH (KCl) 5.5, 116 mg P kg^{-1}, 180 mg K kg^{-1}, 29 mg Mg kg^{-1}, 4.6 mg S kg^{-1}; Pulki II: pH (H_2O) 6.8, pH (KCl) 5.9, 301 mg P kg^{-1}, 150 mg K kg^{-1}, 59 mg Mg kg^{-1}, 2.8 mg S kg^{-1}, Baborówko I: pH (H_2O) 6.3, pH (KCl) 6.1, 170 mg P kg^{-1}, 104 mg K kg^{-1}, 39 mg Mg kg^{-1}, 3.8 mg S kg^{-1}, Baborówko II: pH (H_2O) 6.0, pH (KCl) 4.7, 87 mg P kg^{-1}, 112 mg K kg^{-1}, 25 mg Mg kg^{-1}, 4.6 mg S kg^{-1}; 39) Results presented are based on data from GENSTAT ANOVA at K_2O rate of 75 kg ha^{-1}.

Page 20 40) Average initial soil analysis: 27 mg P kg^{-1}; 89 mg K kg^{-1}, 79 mg Mg kg^{-1}, 513 mg Ca kg^{-1}, 6 mg S kg^{-1}, organic matter: 16.3 g kg^{-1}, pH (H_2O) 5.8; 41) POLY4 potato trials: 13000-UWI-13010-14; 14000-UMN-14010-14; 14000-UMN-14011-15; 16000-SAC-16010-14; 16000-SAC-16011-15; 22000-MAC-22010-15; 16000-SAC-16012-16; 14000-UMN-14014-16; 0000-TAM-0010-12; 0000-TAM-0010-12; 1400-UMN-14017-17; 76000-SVPU-76010-17; 76000-SVPU-76010-17; 42) Statistics of Horticulture, Ministry of Agriculture and Farmer Welfare (India) 2016/17; 43) Sardar Vallabhbhai University of Agriculture & Technology (2018) 76000-SVPU-76010-17; 44) Results presented are based on data from GENSTAT. All data was quoted as means of K_2O rates; 45) Initial soil analysis: Meerut site: 139 mg N kg^{-1}, 19 mg P kg^{-1}, 225 mg K kg^{-1}, 19 mg S kg^{-1}, organic matter: 0.39%, soil pH (H_2O) 8.1.

Page 21 46) Data not presented; 47) Margin = output (yield times price) minus fertilizer cost and spreading cost. Prices are based on local prices supplied by regional agronomist: urea (US$85/t), DAP (US$315/t), MOP (US$194/t), bentonite (US$270/t), POLY4 (US$200/t), potato (US$75/t).

Page 22 48) Virginia Tech (2015) 23000-VIR-23010-15; 49) Average initial soil analysis: 22 mg P kg^{-1}; 88 mg K kg^{-1}, 124 mg Mg kg^{-1}, 956 mg Ca kg^{-1}, 13 mg S kg^{-1}, organic matter: 14.6 g kg^{-1}, pH (H_2O) 6.7; 50) POLY4 cotton trials: 12000-UGA-12011-14; 23000-VIR-23010-15; 23000-VIR-23014-16; 46000-HUB-46010-16; 46000-HUB-46010-16; 46000-HUB-46010-16; 51) USDA (US Department of Agriculture, 2017); 52) Virginia Tech (2015, 2016, 2017) 23000-VIR-23010-15; 23000-VIR-23014-16; 23000-VIR-23020-17.

Page 23 53) Virginia Tech (2016) 23000-VIR-23014-16; 54) Results presented are based on data from GENSTAT regression analysis. All treatments received 112 kg N ha^{-1}; 100 kg K_2O ha^{-1} from MOP and/or POLY4 and 1.12 kg B ha^{-1}. MOP + POLY4 was used in a ratio of 50:50 K_2O split. Initial soil analysis: 2015: pH 6.2; 35 mg P kg^{-1}, 73 mg K kg^{-1}, 211 mg Ca kg^{-1}, 33 mg Mg kg^{-1}; 2016: pH 5.9; 23 mg P kg^{-1}, 18 mg K kg^{-1}, 345 mg Ca kg^{-1}, 40 mg Mg kg^{-1}; 2017: pH 5.95; 38 mg P kg^{-1}, 56 mg K kg^{-1}, 267 mg Ca kg^{-1}, 49 mg Mg kg^{-1}; 55) MOP + = MOP + kieserite + gypsum. Margin = output (yield times price) minus fertilizer cost and spreading cost. Prices are average prices from 2015-2017: MOP (US$282/t); POLY4(US$200/t); gypsum (US$25/t) and kieserite (US$250/t). The cotton lint price obtained from FAOSTAT is the average US cotton lint from 2015 to 2016 (US$1480/t).

Page 24 56) Statista, Production of tea worldwide from 2006 to 2016 (2017); 57) Average initial soil analysis: 6 mg P kg^{-1}; 73 mg K kg^{-1}, 146 mg Mg kg^{-1}, 1600 mg Ca kg^{-1}, 126 mg S kg^{-1}, organic matter: 21.8 g kg^{-1}, pH (H_2O) 5; 58) POLY4 tea trials: two seasons of 19000-SAAS-19011-14; two seasons 21000-YAU-21014-15; two seasons 19000-SAAS-19014-15; two seasons 21000-YAU-21011-14; 59) Soil and Fertiliser Institute, Sichuan Academy of Agricultural Science (2015) 19000-SAAS-19011-14 and (2016) 19000-SAAS-19014-15 ; 60) FAOSTAT (2017); 61) Soil and Fertiliser Institute, Sichuan Academy of Agricultural Science (2016) 19000-SAAS-19014-15; 62) All plots received 240 kg N ha^{-1} and 120 kg P_2O_5 ha^{-1} from urea and DAP; 63) GENSTAT mean results. Initial soil analysis: pH 4.6, EC 1380 µS cm^{-1}, N 102 mg kg^{-1}, P 7 mg kg^{-1}, K 57 mg kg^{-1}, Ca 1602 mg kg^{-1}, Mg 88 mg kg^{-1}, S 127 mg kg^{-1}.

Page 26 64) FAOSTAT (2017); 65) Average initial soil analysis: 87mg P kg^{-1}; 68 mg K kg^{-1}, 85 mg Mg kg^{-1}, 4530 mg Ca kg^{-1} (limited data), 37 mg S kg^{-1}, organic matter: 1.1 g kg^{-1}, pH (H_2O) 6.2; 66) POLY4 tomato trials: 1000-UOF-1015-13; 3000-SAU-3012-13; 4000-USP-4011-14; 4000-USP-4016-15; 23000-VIR-23011-15; 27000-MLI-27010-15; 23000-VIR-23015-16; 67) POLY4 tomato trials: University of Florida (2015) 1000-UOF-1021-15; Virginia Tech (2015) 23000-VIR-23011-15; 68) All plants were supplied 194 kg N ha^{-1} as urea and 194 kg P_2O_5 ha^{-1} as TSP; 69) GENSTAT regression analysis; 70) Infection rates determined from amount of plant leaf canopy showing infection; 71) $p<0.001$; 72) 72 days after transplanting. Initial soil analysis: very gravelly loam, pH 7.3, 2.4% organic matter, 85 mg K kg^{-1}; 73) USDA (2016).

Page 27 74) Virginia Tech 23000-VIR-23015-16; 75) Nutrient content: urea: 0:0:46; DAP: 18:46:0; MOP: 0:0:0 + 48 Cl^-; ammonium sulphate: 21:0:0 + 24 S; gypsum: 0:0:0 + 22 S + 33 CaO; POLY4: 0:0:14 + 19 S + 6 MgO + 17 CaO +3 Cl^-; 76) Yield results presented are based on data from GENSTAT regression analysis at K_2O rate of 160 kg ha^{-1}; 77) MOP blends were made with urea, DAP and MOP; 78) MOP+ blends were made with AS, urea, DAP, MOP and gypsum; 79) POLY4 blends were made with urea, DAP, MOP and POLY4; 80) Fertilizer prices were obtained from CRU, based on US Mid-West (end of 2016) annual prices: urea (US$243/t), AS (US$248/t), DAP (US$346/t), MOP (US$239/t), POLY4 (US$200t), gypsum (US$25/t); 81) Net return = crop output minus (cost of fertilizer material + cost of fertilizer application). The price of tomato: US$904/t.

Page 29 82) SGS France Analysis (Nov 2014), 95% confidence interval for potassium, magnesium, calcium, sulphur and chloride.

Pages 30,31 83) SGS, France (2013); 84) Elam, M., S. Ben-Ari, and H. Megan (1995) The dissolution of different types of potassium fertilizers suitable for fertigation; 85) Sohnel, O., and Novotny, P. (1986) Densities of aqueous solutions of inorganic substances. Elsevier, Amsterdam; 86) IUPAC. (2014). IUPAC-NIST Solubility Database. Available online at http://srdata.nist.gov/solubility/index.aspx [Accessed on November 2015];
87) American Chemical Society (2006) Reagent chemicals: specifications and procedures: American Chemical Society specifications, official from January 1, 2006. Oxford University Press. p. 242. ISBN0- 8412-3945-2; 88) Gangolli, S. (1999) The Dictionary of Substances and Their Effects: C. Royal Society of Chemistry. p.71. ISBN 0-85404-813-8.

Page 32,33 89) NRM Laboratories (2014, 2015) 36000-NRM-36015-18.

Page 34,35 90) University of Florida 1000-UOF-1024-14. Amount of water is monthly equivalent to two years rainfall based on a five-year average rainfall of 1385 mm yr^{-1} in Florida.

Page 36 91) Glenn J.C., Gordon TJ, Florescu E. – Millennium Project: State of the Future. World Federation of UN Associations (2008); 92) Nutrient/fertilizer use efficiency: measurement, current situation and trends, Managing Water and Fertilizer for Sustainable Agricultural Intensification, Chapter: Chapter 2, Publisher: International Fertilizer Industry Association (IFA), International Water Management Institute (IWMI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI) (2015); 93) Initial soil analyses: 38 mg P kg^{-1}, 100 mg K kg^{-1}, 116 mg Mg kg^{-1}, 1311 mg Ca kg^{-1}, 20 mg S kg^{-1}, organic matter: 19 g kg^{-1}. 32 global trials (references available); 94) Initial soil analyses: 1.0 mg B kg^{-1}, 20 mg Mn kg^{-1}, 6.0 mg Zn kg^{-1}, 5.0 mg Cu kg^{-1}, 87 mg Fe kg^{-1}. 32 global trials (references available).

Page 37 95) Initial soil analyses: 88 mg P kg^{-1}, 96 mg K kg^{-1}, 148 mg Mg kg^{-1}, 1926 mg Ca kg^{-1}, 13 mg S kg^{-1}, soil pH 6.3. University of Kentucky (2017) 59000-UKY-59010-17; 96); GENSTAT means; 97) All treatments received 180 kg K_2O ha^{-1} from MOP, SOP, POLY4 or a combination except for control.

Page 38 98) POLY4 webcast (July 2014); 99) PDA (April 2018); 100) Rhizoctonia solani, Sichuan Academy of Agricultural Science (2014);
101) Alternaria spp. and Xanthomonas spp, University of Florida (2014); 102) GENSTAT mean results.

Page 39 103) University of Florida (2016) 1000-UOF-1021-15; 104); GENSTAT means; 105) All plants were supplied 194 kg N ha^{-1} as urea and 194 kg P_2O_5 ha^{-1} as TSP and 200 kg K_2O ha^{-1} of product; 106) Initial soil analysis: very gravelly loam, pH 7.3, 2.4% organic matter, 85 mg K kg^{-1}.

Page 40 107) UN Fertilizer Manual (1998); 108) In-house POLY4 testing (2018) and University of Limerick (2018) 32000-LIM-32013-18.

Page 41 109) Clayton, W.E. (1984) Humidity Factors Affecting Storage and Handling of Fertilizers. International Fertilizer Development Center; 110) University of Limerick (2015).

Page 42 111) The ratio of the increase in osmotic pressure produced by a fertilizer to that produced by the same weight of sodium nitrate multiplied by 100 to give whole numbers is called the "salt index" or SI (Rader, L.F., Jr., White, L.M., and Whittaker, C.W. (1943) The Salt Index – a measure of the effect of fertilizers on the concentration of the soil solution. Soil Science, V.55, No. 3, pp. 201–218; 112) Jackson W.L. (1958) Soil Chemical Analysis, Prentice Hall, Englewood Cliffs, NJ; 113) Salt index is average of results from in 2013 from Thornton Laboratories, Spectrum Analytic Inc., Southern Jesting, Midwest Laboratories, University of Florida, University of São Paulo and Shandong Agricultural University; 114) SCS Spreader & Sprayer Testing Ltd (2013).

Page 43 115) Results based on shaker plate sieve analysis. Novochem, Papiermolen 5, 3994 DJ Houten, Netherlands (2016).

Page 44 116) IFDC (2017) 66000-IFDC- 60010-17; 117) IFDC methodology ratifies methods of Walker et al (1998) and published findings of Albadarin et al (2017); 118) IFDC (2017) 66000-IFDC- 60010-17.

Page 45 119) Walker, G.M., Holland, C.R., Ahmad, M.N., Fox, J.N. and Kells, A.G. (1999). Granular Fertilizer Agglomeration in Accelerated Caking Tests. Ind. Eng. Chem. Res. 38. 4100–4103; 120) IFDC (2017) 66000-IFDC-60010-17, <1% of granulation plants use RP so here switched to DAP;
121) Determined according to the procedure (IFDC S-106) described in Manual for Determining Physical Properties of Fertilizer (IFDC—R-10). Source: IFDC (2017) 66000-IFDC-60010-17.

Page 46 122) Determined according to the procedure (IFDC S-122) described in Manual for Determining Physical Properties of Fertilizer (IFDC—R-10). Sources: IFDC (2017) 66000-IFDC-60010-17.

Page 47 123) Determined according to the procedure (IFDC S-122) described in Manual for Determining Physical Properties of Fertilizer (IFDC—R-10);
124) <200 is low, 200-500 is some dust generation, 500-100 is high, >2000 extreme. Source: IFDC (2017) 66000-IFDC-60010-17.

Page 50 125) Nanjing Institute of Soil Science (2016) 20000-CAS-20020-16.

Page 51 126) Panagos et al (2018). Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models. Land Degradation and Development, 29, pp 471-484; 127) University of Aberdeen (2015) 34000-UOA-34010-15;
128) Young's Modulus is a measurement of the elasticity of solid materials.

Page 52 129) Lucas, R.E. and Davis, J.F. (1961). Relationships between pH values of organic soils and availabilities of 12 plant nutrients. Soil Science. 92: 177–182; 130) University of Warwick (2014), University of Florida (2015).

Page 53 131) Corn 300 kg K_2O ha^{-1} Sichuan University (2014); tomato 175 kg K_2O ha^{-1} University of Florida (2014); cabbage 200 kg K_2O ha^{-1} University of Florida (2013); soybean 250 kg K_2O ha^{-1} University of Florida (2013); wheat 80 kg K_2O ha^{-1} SGS (2015); 132) FAO Irrigation & Drainage paper 61. (2002).

Page 54 133) Virginia Tech (2016) 23000-VIR-23014-16; 134) SSP – single super phosphate, TSP – triple super phosphate, MOP – muriate of potash, SOP – sulphate of potash, MAP – monoammonium phosphate, DAP – diammonium phosphate, AS – ammonium sulphate, CAN – calcified ammonium nitrate, AN – ammonium nitrate; 10% mitigation from renewable energy sources and 10% from tree planting offset; sources: POLY4 2015, Ricardo-AEA Ltd. 2014.

Page 55 135) Sources: 14000-UMN-14011-15; 14000-UMN-14014-16; 16000-SAC-16011-15; 22000-MAC-22010-15-SOW; 23000-VIR-23016-16; 26000-TOR-26010-14; 136) University of Minnesota (2016) 14000-UMN-14014-16; Initial soil analysis: pH 6.1, 58 mg K kg^{-1}, 123 mg Mg kg^{-1}, 2 mg S kg^{-}1, 2 mg S kg^{-1}; GENSTAT means.

* MOP + POLY4 K source supply ratio.

ACRONYMS

AN	Ammonium nitrate
AS	Ammonium sulphate
CAN	Calcium ammonium nitrate
CO_2	CO_2 emissions
DAP	Diammonium phosphate
kgf	kilogram force
MAP	Monoammonium phosphate
MOP	Muriate of potash
KIE	Kieserite
NOP	Potassium nitrate
SOP	Sulphate of potash
SOP-M	Sulphate of potash magnesium
SSP	Single superphosphate
TSP	Triple superphosphate

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