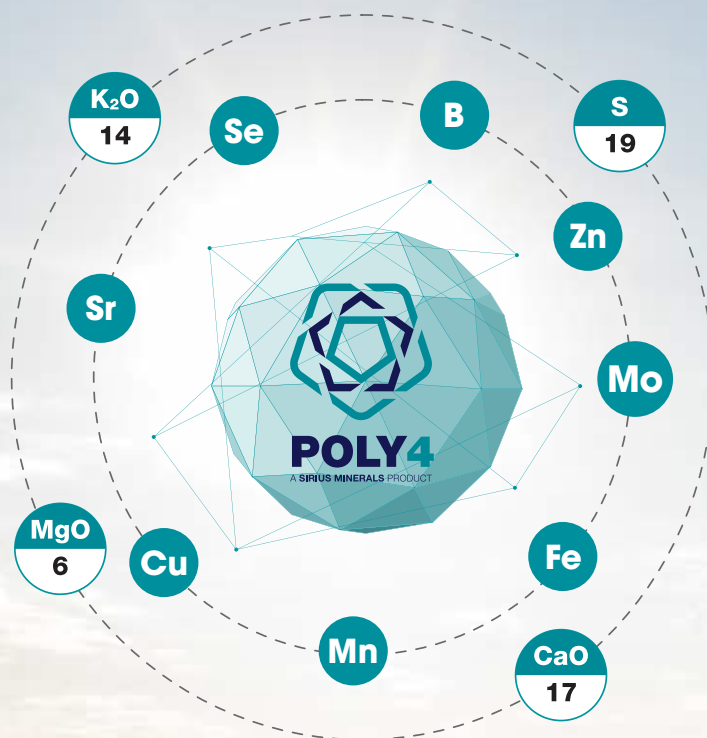


Growing **SOYBEANS** with POLY4



POLY4, polyhalite-based fertilizer, contains four nutrients essential for plant growth: potassium (K), sulphur (S), magnesium (Mg) and calcium (Ca) as well as a range of micro nutrients. The fertilizer analysis of POLY4 is 14% K_2O , 19% S, 6% MgO , and 17% CaO .

POLY4 is characterised by its multi-nutrient composition, pH neutrality and its sustained dissolution pattern. K, S, Mg and Ca each play a significant role in various metabolic activities of soybean growth and development.





SOYBEAN is one of the world's most important crops and is grown for oil and protein. Its uses include vegetable oil, animal feed, soy sauce, soy milk, tofu, and textured vegetable protein. Soybeans have a high protein and oil content and are a good source of dietary nutrients including fibre, iron, manganese, phosphorus and folate.

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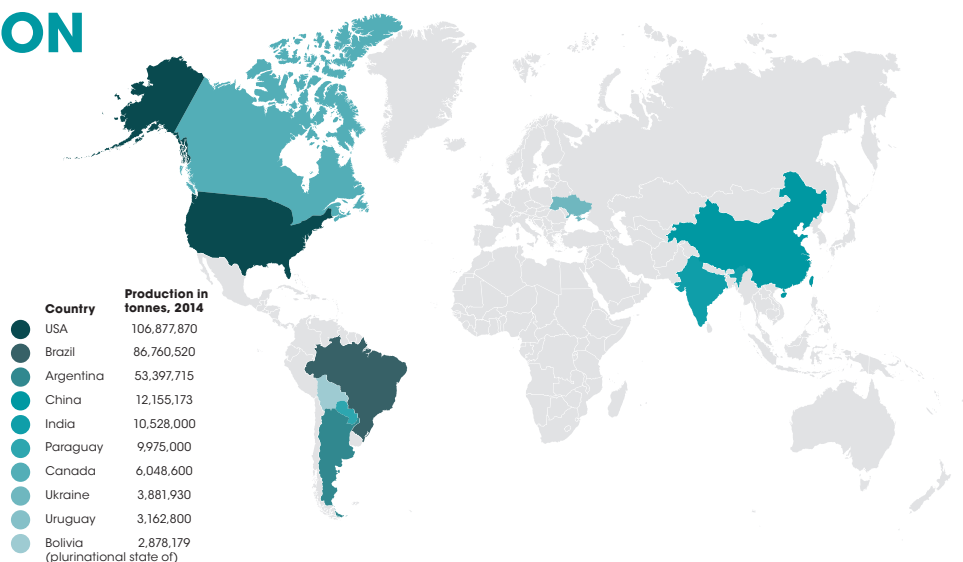
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WORLD PRODUCTION

Presently, three countries – Brazil, Argentina and the United States – produce approximately 82% of the world's soybeans (FAOSTAT, 2018).

The United States is the largest producer of soybean with 120 million metric tonnes (Mmt) grown in 2017. This was 35% of the global production. The next biggest producers are Brazil with 115 Mmt and Argentina with 55 Mmt. Brazil and the United States are also the highest yielding producers with average yields of 3.5 t ha⁻¹ in the United States and 3.4 t ha⁻¹ in Brazil.

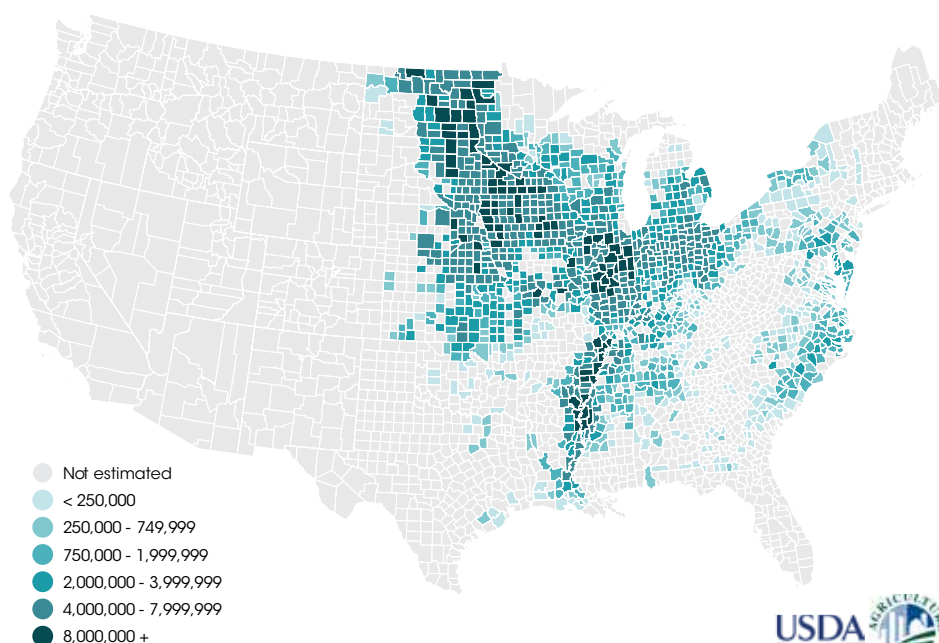


United States

Midwest

The main soybean producing states are in the north-central region of the Midwest and include Iowa, Illinois, Minnesota, South Dakota, eastern Nebraska, northern Missouri, eastern Kansas and southern Wisconsin.

Farmers in this region typically grow soybeans in rotation with corn, with one crop per year. In general, farmers will apply fertilizers for the corn crop and plant soybean without additional fertilization. Soils in the Midwest are deep, with a good release of nutrients from organic matter and potassium from soil reserves. Despite this, Iowa State University revised their recommendations for corn-soybean rotations in the early 2000s after noting increased frequency of potassium deficiency symptoms in corn and a high probability of yield responses for both corn and soybean in some soils with little to no K typically applied.¹



U.S. Department of Agriculture, National Agricultural Statistics Service



Fertilizer applications of nitrogen (N), phosphorus (P) and potassium (K) are generally made during the autumn season, if soil conditions allow. With a late autumn harvest due to late



planting, shortage of growing degree days (GDD) or excess autumn rainfall, fertilizer applications can be delayed until spring prior to planting of crops.

The method of application in both scenarios would be with spinner spreaders of 15 to 27 meter spreading widths or with large pneumatic spreaders as wide as 37 metres. Many farmers and fertilizer cooperatives still apply fertilizer with trailed spinning disc spreaders with widths from 15 to 27 metres. The fertilizer is then incorporated with tillage.

The response of soybean to K placement are small and inconsistent. However, for corn deep-banded K applications are more efficient than broadcast or planter-banded.¹

Sulphur use is becoming more prevalent across the corn and soybean areas of the Midwest as more and more farmers are seeing sulphur deficiencies in crops. Sulphur sales in Minnesota have tripled over the past ten years providing evidence of increased sulphur deficiencies being noted in crops.²

Florida and Texas^{3,4}

Soybeans have been grown in Florida and the Southeast for about 50 years. High yields are important in Florida due to the cost of production and price of land. Soybeans are normally planted into a small grain cover crop, or after small grain harvest. Many farmers also double crop with winter grazing. P and K are applied to the small grain crop on soils with clay subsoils within the top 15-20 cm. Soil is normally limed to a pH of 5.8 to 6.5.

In Texas the planting date ranges from mid-May to the end of June. In Florida the optimum planting time ranges from late

April until mid-June, but soybean may be planted through to early August with irrigation. Late planting of soybean is common with corn farmers to maintain soil cover for weed prevention. Farmers rarely put irrigation systems in for soybeans, but often do for crops such as corn, cotton and peanut. When planting in July, later maturing varieties are used as they are less influenced by shorter day length and therefore grow taller. Rows are also planted closer together to ensure canopy closure.

Brazil

In Brazil, soybean fertilization only occurs in regions with no winter crop, or further north where the annual succession is soybean to corn. In soybean-corn systems all P and K are applied before the soybean and corn receive complementary N fertilizer.

Cerrado

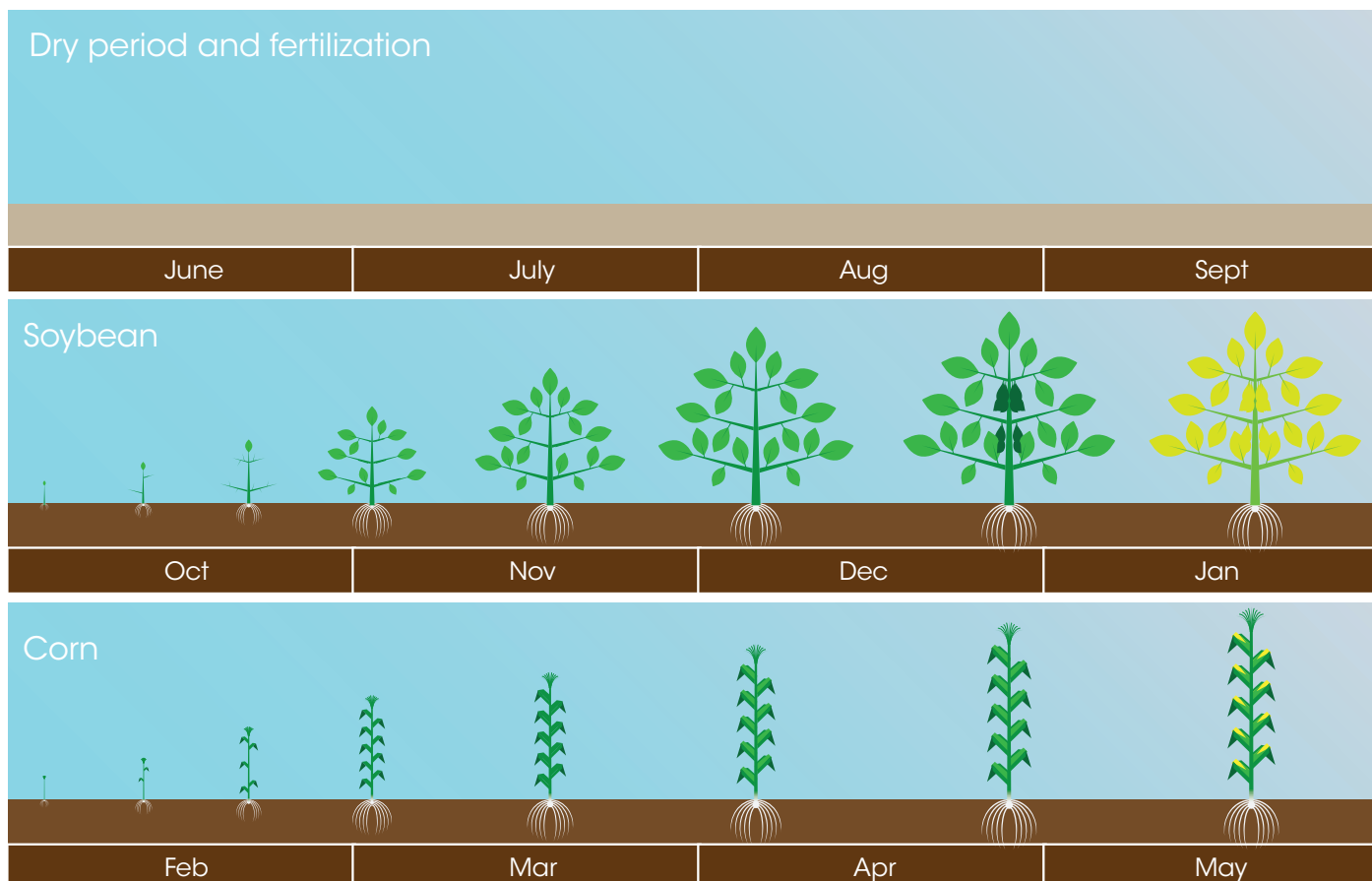
The Cerrado region (Brazilian Savanna) is the main area for soybean production. It is divided into eight states with most farms ranging from 1000 to 10,000 ha. This region uses an annual succession of soybean and corn thus P and K are applied before soybean, and only N is applied before corn.

Soils have high CEC (30-110 mmolc dm⁻³), with clay from 15-60%. pH is low and aluminium toxicity is common. K₂O and P₂O₅ are usually applied in a 0:20:20 blend to supply 70-80 kg of each nutrient. However, many farmers are changing from blends to straight applications of P₂O₅ from MAP at planting or SSP broadcast, and K₂O from MOP broadcast pre-planting. K₂O is sometimes applied two months before planting. Applying a 0:20:20 blend in the furrow is still common, but to make sowing faster broadcast applications are becoming more popular. For soils low in potassium a greater amount of K₂O is recommended.





Typical crop rotation system in the Cerrado

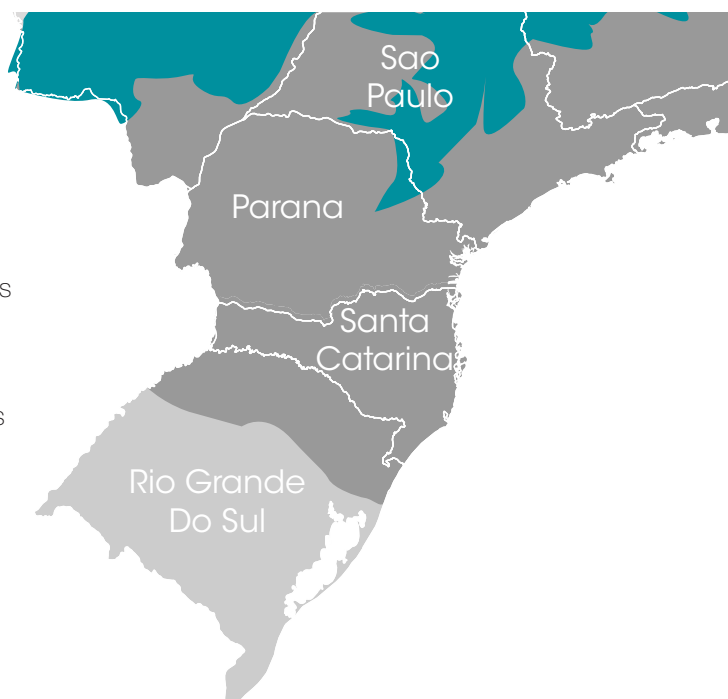


Southern states

In the southern states (Santa Catarina and Rio Grande do Sul), there is no winter crop and thus fertilizer is applied at planting for soybean, with K_2O and P_2O_5 each at a rate of 50 kg ha^{-1} in a 0:20:20 blend. Farms in this region are smaller (50 – 150 ha).

North of these states are Paraná and São Paulo. Most farms in this region are 100 – 500 ha. The timing of application is also at planting, but 70 kg ha^{-1} of both P_2O_5 and K_2O are applied in a 0:20:20 blend. The exception is southern Paraná which grows winter crops and therefore fertilizer is generally applied before the winter crop (wheat or barley) rather than before soybean.

Sulphur is also usually applied as either single superphosphate (SSP) or ammonium sulphate (AS).





CULTIVATION

Glyphosate-resistant soybeans have given farmers greater flexibility in timing of herbicide applications. This has made the use of conservation tillage more reliable and economical. Most soybean farmers in Brazil use no till, and many in the United States either use no till or some form of reduced

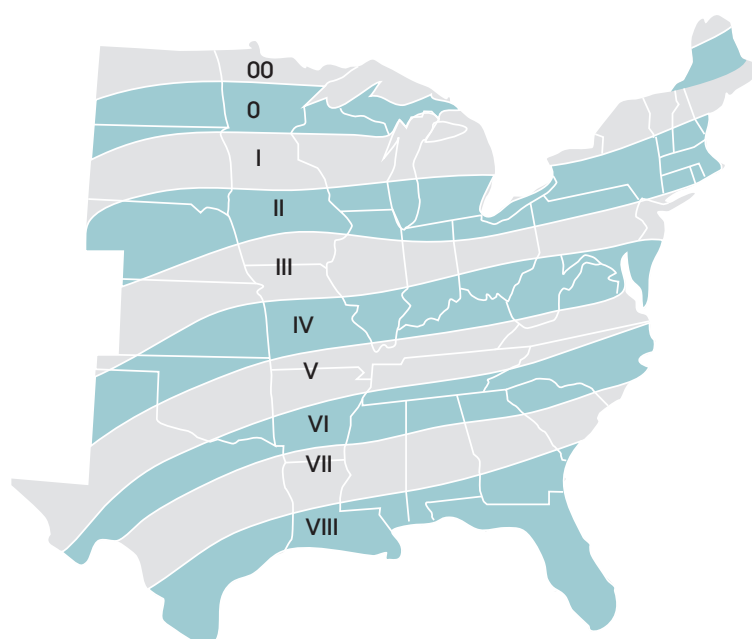
tillage. However, the frequency of weed resistance to glyphosate is increasing. Other herbicide programmes and traits are presently taking the place of, or used in addition to, glyphosate-resistant soybeans.

Maturity groups

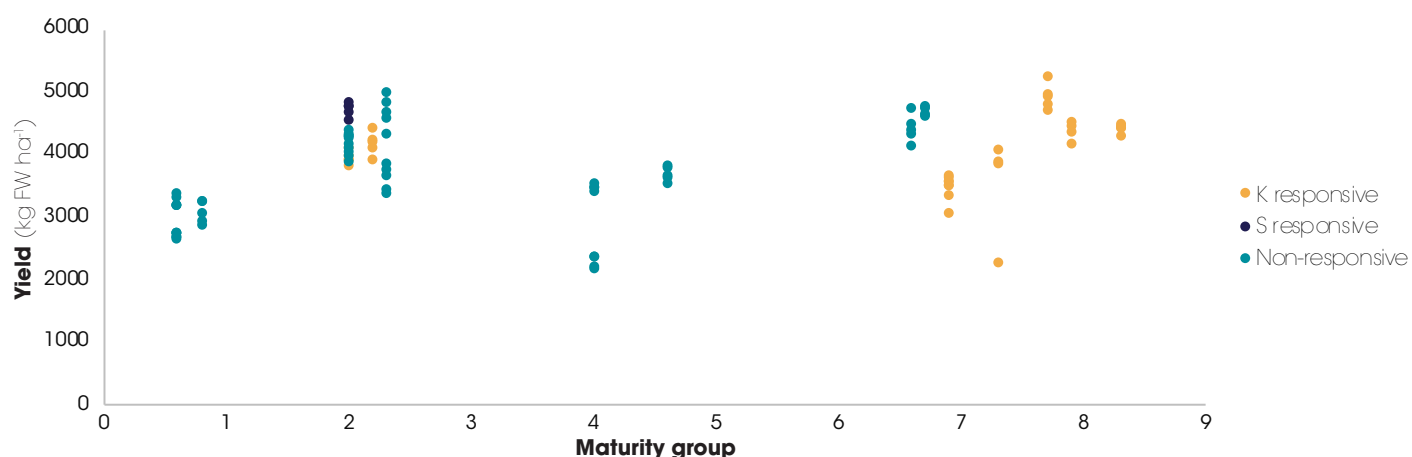
Soybean maturity group choice is primarily based on the days to average first frost and latitude. Groups 00 to IV are indeterminate with the plant flowering and producing pods while still growing vegetative parts. Groups V to VIII are determinate and will stop vegetative growth when they are reproductive.

In northern Minnesota and North Dakota farmers will plant earlier maturing varieties (group 00) to avoid frost or freeze damage and resulting yield losses. In Brazil and the southern areas of the United States such as Florida, Louisiana and Texas, it is common to plant later maturing soybeans. In Texas more than half are group IV though III and V are also used. In Florida groups V or VI do well when soybean is planted in late May or June without irrigation, while later maturity groups are recommended, in combination with irrigation, for July to early August planting.

Provided the correct maturity group is used for the latitude and region, the yield is maximised: high yields (4+ tonnes) are achievable at both low maturity groups in Minnesota (III) and high maturity groups in Brazil (VII+).



Trials with POLY4 tested yield responses of maturity groups to K and S.⁵ The maturity group does not appear to play a role in whether the plant was K or S responsive.





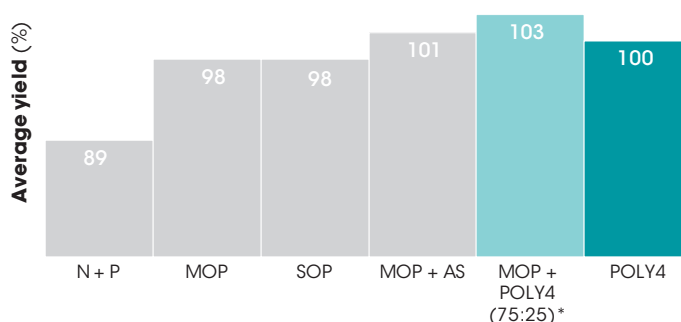
NUTRITIONAL BENEFITS OF POLY4 FOR SOYBEAN DEVELOPMENT

Soybean requires significant quantities of K, Ca, Mg and S contained in POLY4.

Across 35 field trials in the USA, Canada and Brazil, in 89% of trials application of POLY4 improved yield relative to the control. In 67% of all trials POLY4 outperformed MOP.⁶ Even greater yield performance was achieved with a 75:25 blend of MOP+POLY4 with an average yield 3% greater than with straight POLY4.

From 19 field trials in Brazil and the United States, where grain nutrients were analysed, the median soybean yield was 3.8 t ha⁻¹. Median N, P and K uptakes were 194, 15 and 57 kg ha⁻¹, and median S, Ca, and Mg uptakes were 9.3, 11 and 7.9 kg ha⁻¹, respectively. Other trials have found similar uptake values.

Average POLY4 performance against other K sources



Soybean nutrient uptake in grain in different US and Brazil states

Author	State	Soil texture	Yield (t ha ⁻¹)	Nutrient uptake (kg)			
				K	S	Ca	Mg
Sirius Minerals	United States and Brazil	Various	3.8	57	9.3	11	7.9
Bender et al. (2015) ⁷	IL	Silty clay loam	3.5	64	11	10	9
Gasper et al. (2017) ⁸	WI + MN	Silt loam	4.4		12.3	10	13
Bruns (2016) ⁹	MS	Sandy loam and clay soils	3.3	86	10	18	9

Potassium

Potassium (K) is one of the major nutrients considered essential for crop growth and yield. It is the most abundant cation in plants and associated with many of the physiological processes supporting plant growth and development. Insufficient leaf K levels lead to decreased photosynthesis as well as reduced leaf area and plant stature. This decreases light interception which ultimately leads to a reduction in crop yield.

Positive yield response to K fertilization is attributed to increased number of pods per plant, seed weight and photosynthetic capacity. The rate of response to potassium is governed by the soil K content and the content and type of soil clay mineral.

Potassium deficient soybean

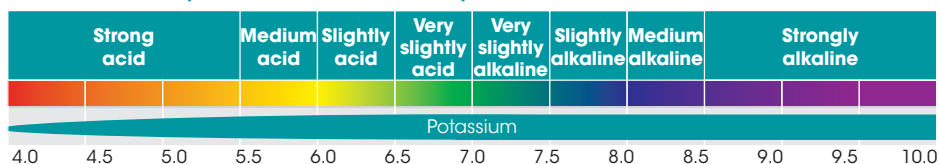




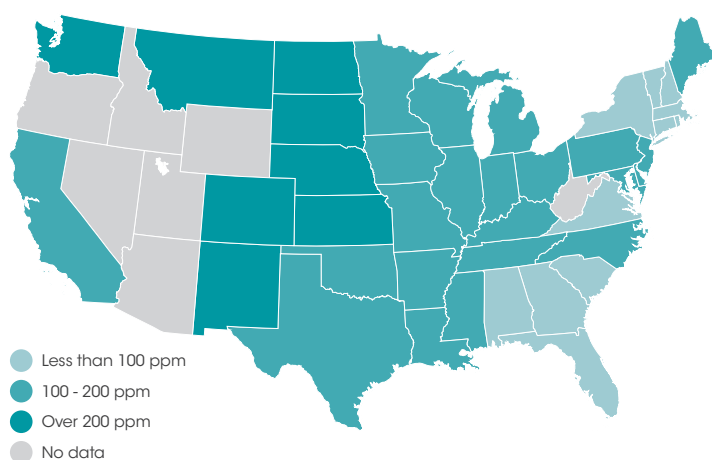
Soil

Potassium availability changes with soil pH. For maximum K availability soil should be maintained > pH 6.5.

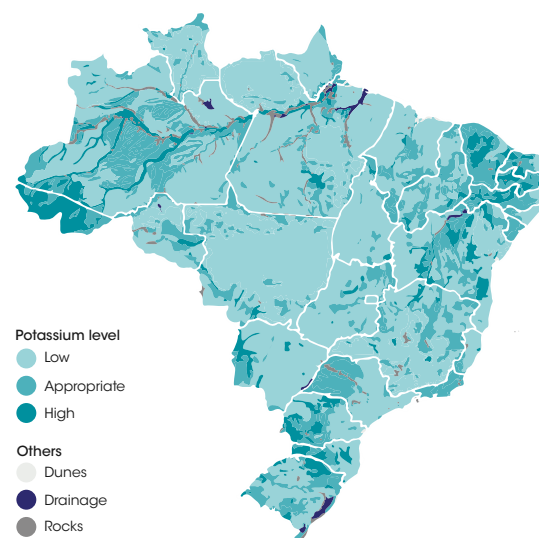
Soil effect on potassium availability



Soil potassium status in the United States¹⁰

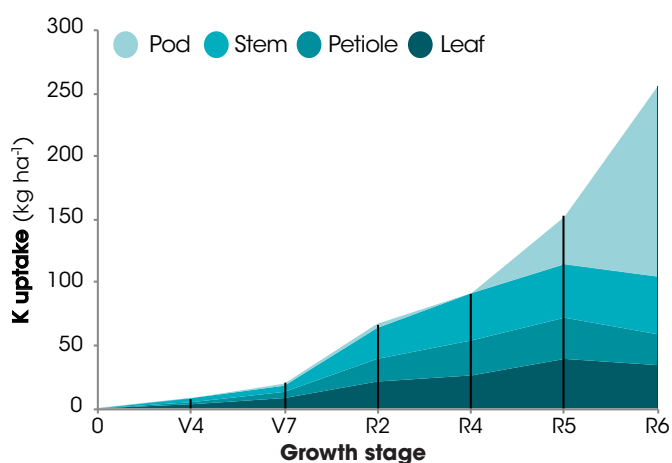


Soil potassium status in Brazil¹¹



K uptake

Soybean does not accumulate the majority of its K until after flowering (growth stage R2)¹², which means that the plant needs K fertilizer sources that can match the demands of the crop throughout its growing season.

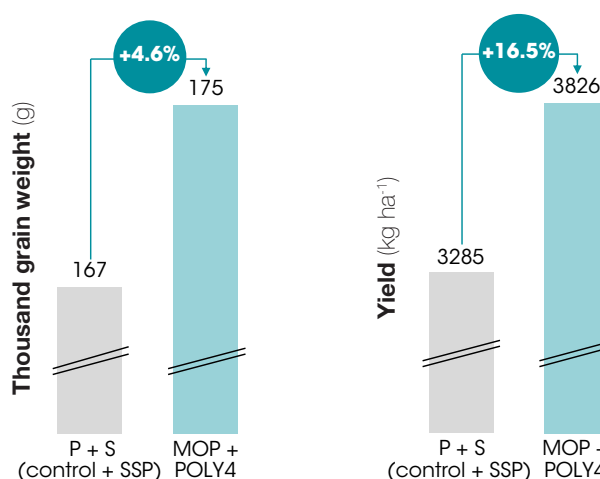


A case for POLY4

The value of potassium from POLY4 to soybean was demonstrated in three trials conducted in Itiquira (2014-2016) and one in Juscimeira (2014) by Fundação Mato

Grosso in Brazil.¹³⁻¹⁷ The response of yield and thousand grain weight (TGW) to K (35% sourced from POLY4 and the remainder from MOP) was compared with a non-K treatment that had S applied as SSP. In each trial the soybean crop responded to potassium application ($P < 0.05$).¹⁸ On average yield was improved by 16.5% and TGW by 4.6%.

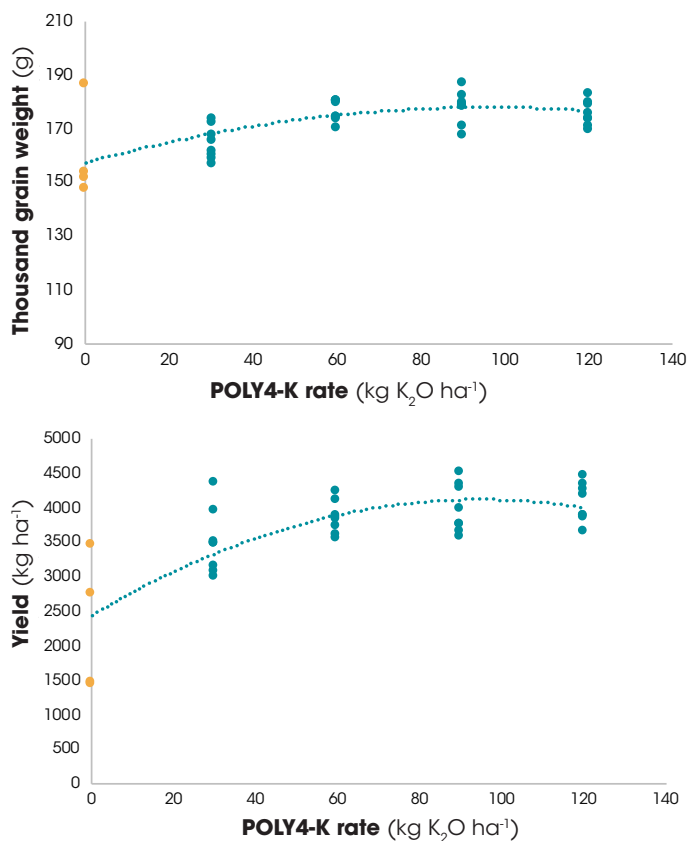
Mean thousand grain weight and grain yield with and without K*



* 2014, 2015 and 2016 in Itiquira, Brazil; 2014 in Juscimeira, Brazil.

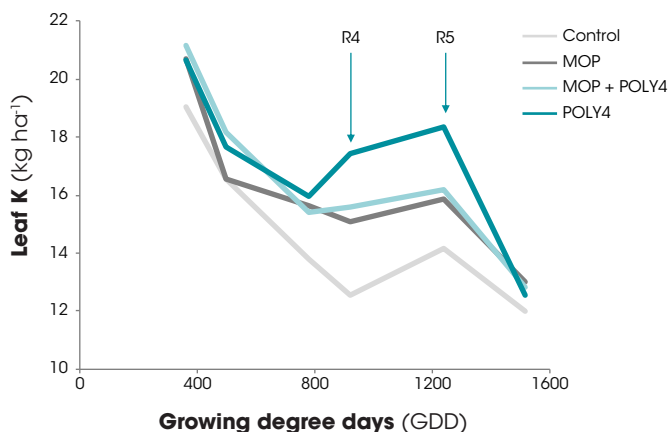


Thousand grain rate and yield versus K₂O application from POLY4*



* 2016 in Itaquira, Brazil.¹⁵ Control (0 K₂O) received S and Ca from SSP.

A trial^{12,19} by Louisiana State University in 2017 showed that during vegetative growth leaf K was similar from all sources, but POLY4 treatments had greater K concentration at the pod fill stages (R4-R5). R4 stage is when pods are filling at maximum rate.

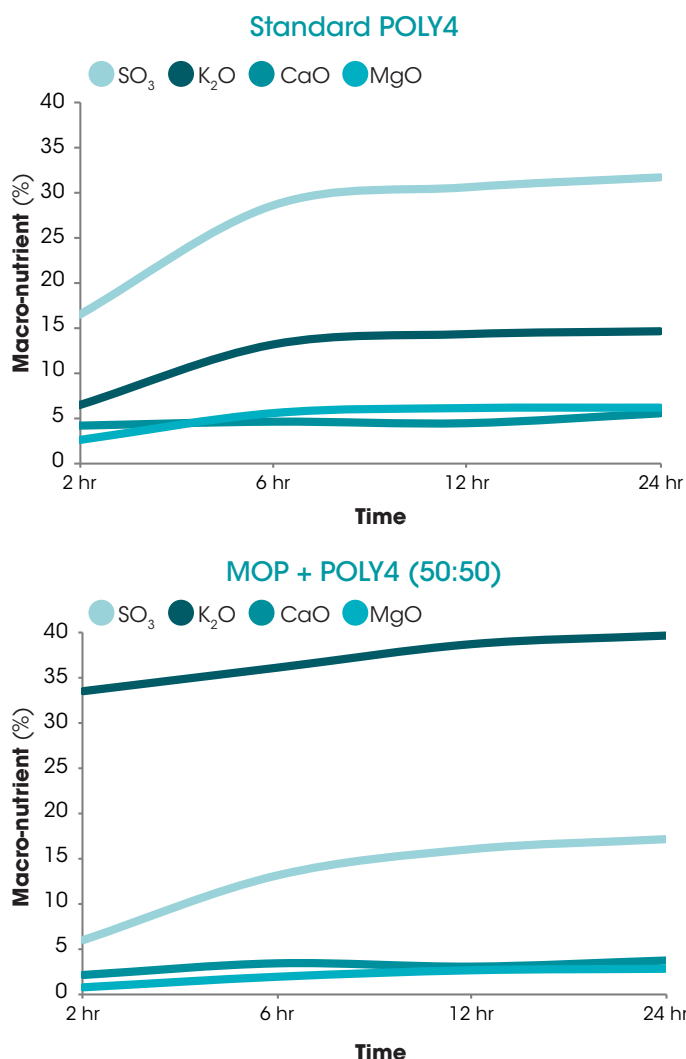


POLY4 is an ideal fertilizer for soybean production.

POLY4 releases nutrients at a rate which ensures nutrient availability throughout the growing season. This is especially important during late season reproductive growth stages when developing soybean grains have the highest nutrient requirements. K supply is therefore important as the plant mobilises reserves from its leaves, and if soil K is limited the plant will mobilise a greater proportion of the total leaf K, leaving the leaf susceptible to stresses, diseases and it hastens senescence.

By supplying K as a blend of MOP and POLY4, K is made available at early growth stages, and a sustained supply of K is made available throughout the growing season.

Nutrient release over time from standard POLY4 and a 50:50 blend of MOP + POLY4²⁰





Sulphur

Sulphur (S) supply is a major factor influencing protein quality and essential amino acid content. Amino acids containing S are important for the structure, conformation, and function of proteins and enzymes in vegetative plant tissue.²¹ They also provide soybean protection against stress and abiotic factors such as air pollution, drought, heavy metals, herbicides, low temperature, and UV-B radiation by decreasing toxic reactive oxygen species such as hydrogen peroxide.

S deficiency occurs everywhere: in tropical or temperate regions, dry or moist climates, fertile or highly leached soils. It first develops on light textured sections of a field. When plants are S deficient, leaves in higher positions turn yellow and have a marked decrease in their S concentration. The yellowing indicates a decrease in the leaf chlorophyll and protein levels due to reduced synthesis of S-containing amino acids. As a result, the soybean plant stops growing and brown spots appear on the edges of leaves and pods. Grains are small, not fully ripened, and in extreme cases germinated seedlings are stunted and wilted.

Sulphur deficient soybean

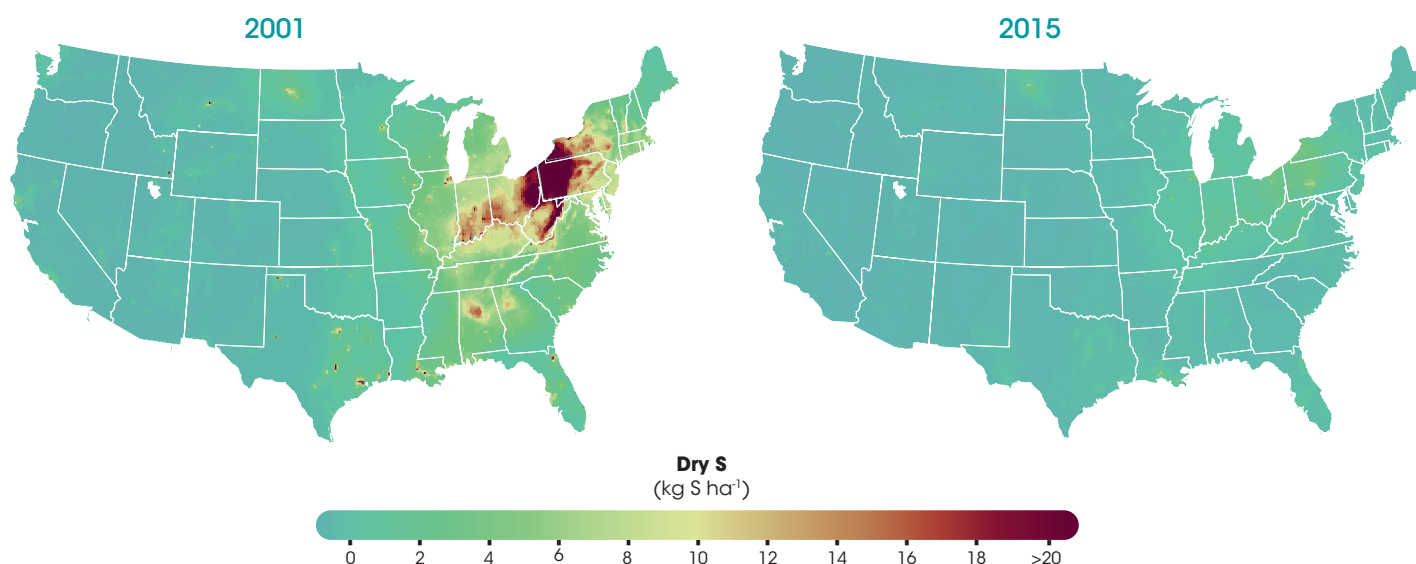


Sulphur recommendations and practice

Until recently S has not been recommended for soybean production. However, a decreasing trend in S deposited from the atmosphere²² as well as increased usage of purified chemical fertilizers (urea in place of AS; DAP in place of SSP;

MOP in place of SOP) are resulting in more frequent soybean seed yield responses to S fertilizer application. Almost 60% of soybean producing countries currently report S deficiencies.

Total deposition of sulphur in the United States

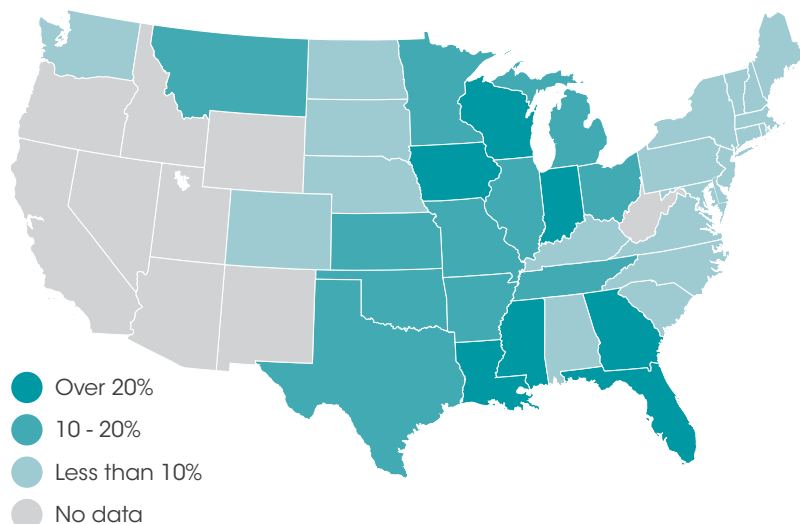




S requirements differ greatly depending on the crop and the location. Based on numerous field trials, application of about 20 to 40 kg S ha⁻¹ is necessary to achieve high yields in pulse crops (FAO Sulphur Network).

The Illinois soybean production guide (Illinois Soybean Association) now recommends a pre-plant application of sulphate for soybean, and more recently Purdue University is recommending a spring broadcast application based on field studies in Indiana. In Brazil, sulphur is recommended, and it is usually applied pre-planting as single super phosphate, or phosphogypsum when freight costs are low.

Low soil sulphur status in the United States¹⁰

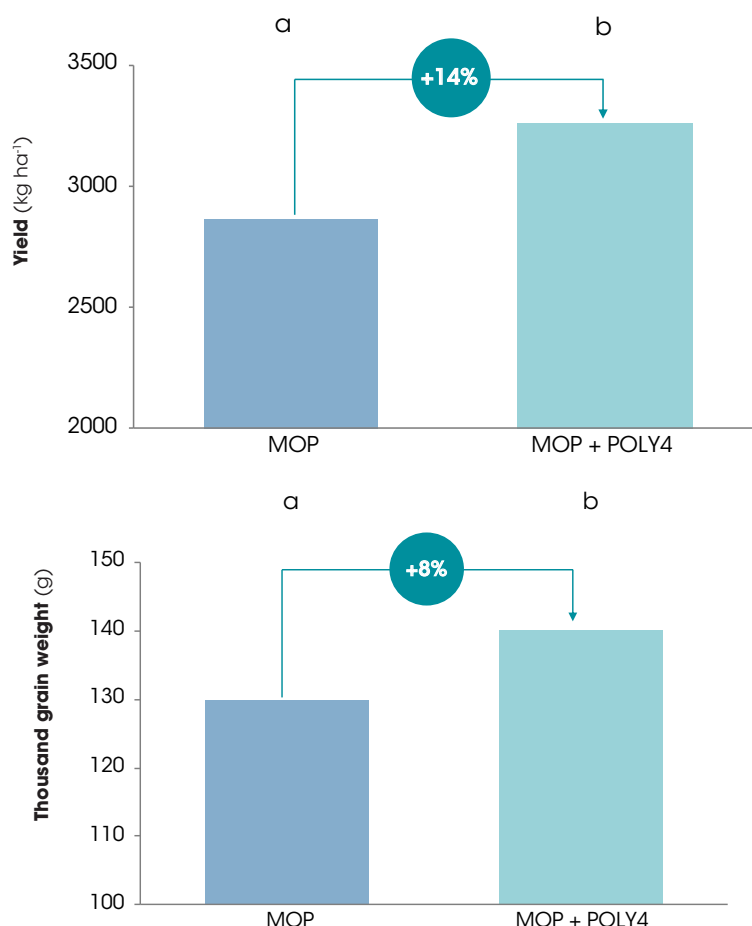


* Data based on states with over 2,000 samples; based on frequency of soil S being less than 3ppm in samples between 2005 – 2015

A case for POLY4

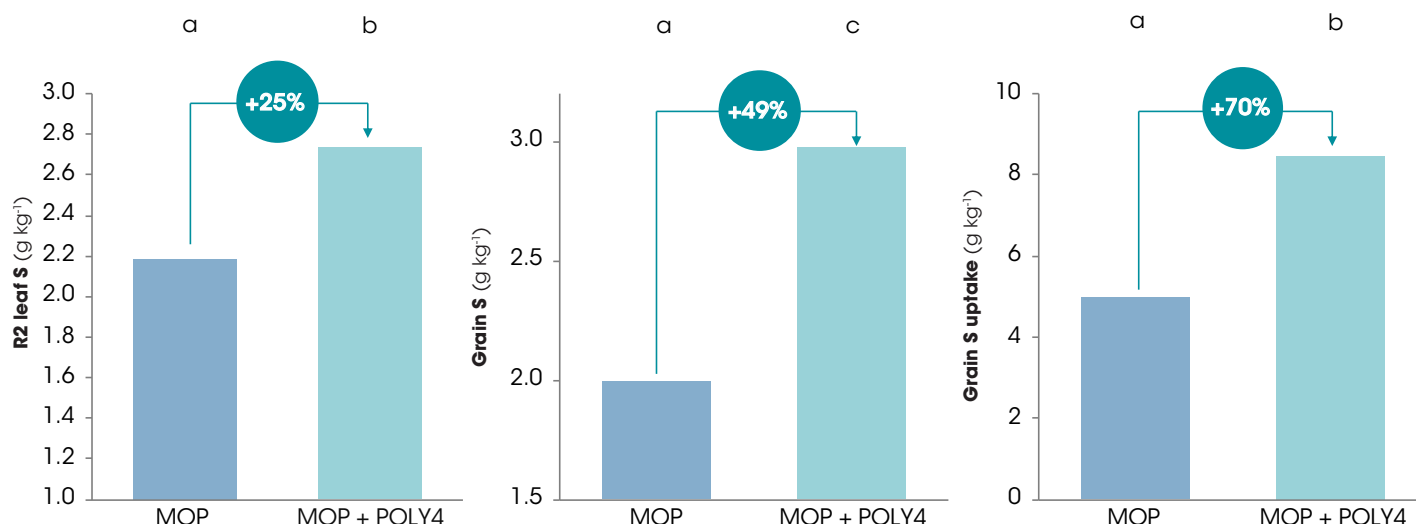
A study was conducted at Staples, MN in partnership with University of Minnesota.²³ Sulphur is not usually recommended in the Midwest, but there is growing recognition and occurrence of S deficiencies. The use of MOP + POLY4 was compared with the use of MOP with and without gypsum-S. In the MOP + POLY4 treatment 25% of K was supplied from POLY4.

At this site the yield was not K responsive ($P > 0.1$) but grain yield was increased ($P = 0.004$) in S treated plots. Thousand grain weight was also increased ($P < 0.001$) with S application. Leaf and grain S were both increased with fertilizers that contain S such as MOP + S and MOP + POLY4. The sufficiency range²⁴ in soybean leaves at growth stage R2 is 2.1 to 4.9 g kg⁻¹. Without S fertilizer the leaves were near the lower limit at 2.2 g kg⁻¹. This shows that application of S in the Midwest, and to soybeans in general, can be used to improve crop yield and nutritional health.





Sulphur



Magnesium

Magnesium (Mg) is a component of the chlorophyll molecule; a cofactor for enzymatic processes associated with phosphorylation, dephosphorylation, and protein synthesis; a structural stabilizer for various nucleotides; and, regulates membrane channels and receptor proteins.²⁵ Consequently, many critical physiological and biochemical processes in plants are adversely affected by Mg deficiency leading to reduced growth and yield.

Symptoms of Mg deficiency are often not visible and hard to diagnose but negatively affect crop yield. Magnesium is mobile in the phloem and translocated within the plant to actively growing parts. Consequently, magnesium deficiency symptoms typically appear on older plant leaves. Light intensity can affect the expression of Mg deficiency symptoms and cause reddish spots on the leaf blade. There is a higher requirement of Mg under intense light. This may be due to increased accumulation of reactive oxygen species (ROS) under high light and sub-optimal Mg which leads to plant damage.

Mg deficiency symptoms may be associated with an antagonistic relationship with other cations such as H⁺ (hydron), NH₄⁺ (ammonium ion), Ca²⁺ (calcium ion), K⁺ (potassium ion), Al³⁺ (aluminium ion) or Na⁺ (sodium ion). The competition of Mg²⁺ (magnesium ion) with other cations for uptake is as follows Ca²⁺ > Mg²⁺ > K⁺ = NH₄⁺ > Na⁺.²⁶

Magnesium deficient soybean



Within the plant there are also antagonistic relationships between Mg and other cations, particularly for various binding sites within cell membranes.



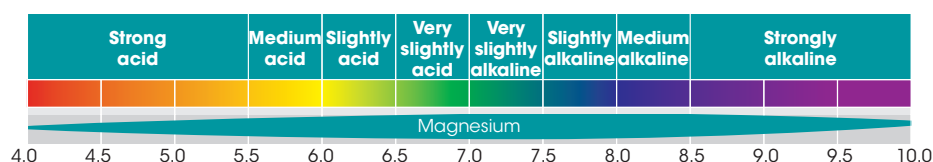
Soil

Mg deficiency symptoms are increased due to drought, poor drainage, excessive leaching, or cold temperatures. Low soil pH is also associated with limiting Mg supply.

Increased K fertilization or total availability will inhibit Mg absorption and accumulation, and vice versa. The degree depends on the ratio of K and Mg in fertilizer and soil availability. This has been noted in soybean.²⁷ High Ca contents in field soils sometimes limit Mg accumulation and may elicit Mg deficiency symptoms. Sandy soils typically have the lowest Mg content and clay soils the highest.

Soils that are not leached, or soils in depressions where leached nutrients may accumulate can have high contents.

Soil pH also influences magnesium availability. Availability reduces at low and high pH.



Magnesium practice

In general, Mg has not been a target nutrient for soybean farmers but has been applied through manure or as an impurity with other mineral fertilizers. In general, excessively leached sandy soils are associated with Mg deficiency.

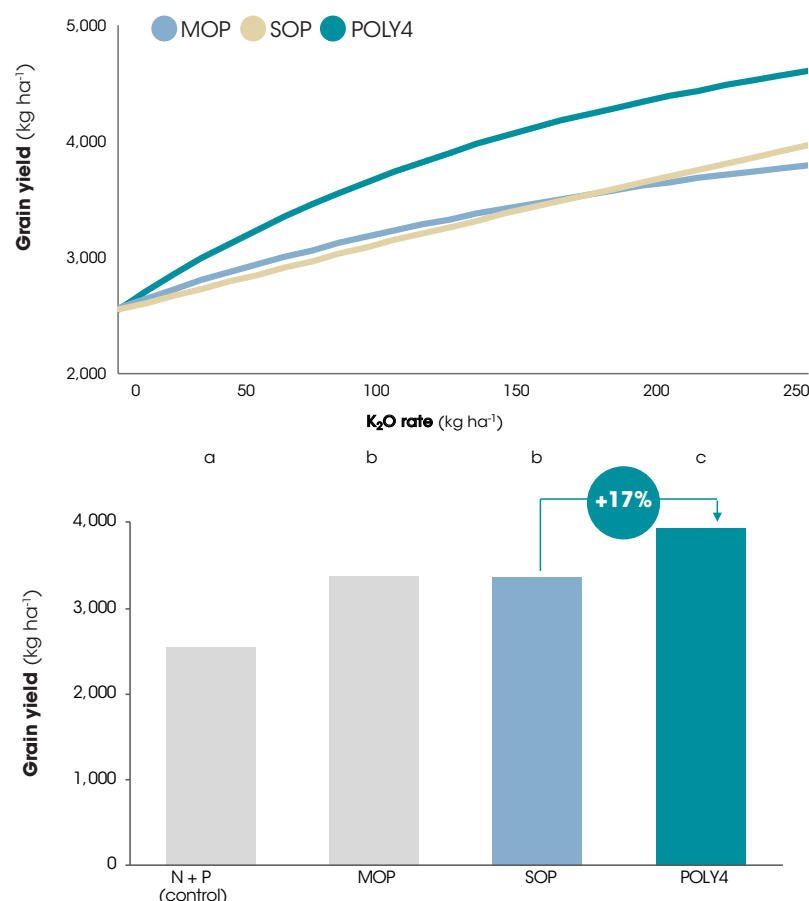
However, the current NPK-dominated fertilization practices often neglect Mg. This decrease in input together with considerable Mg offtake with harvested plant products means mining of soil Mg may occur frequently.

A case for POLY4

The use of POLY4 was compared with the use of MOP and SOP at various K_2O rates from 50 – 250 $kg\ ha^{-1}$ (average 138 $kg\ K_2O\ ha^{-1}$).^{28,29} Soils were predominately calcareous with a sandy clay loam texture. Soybean variety was Vernal 36.

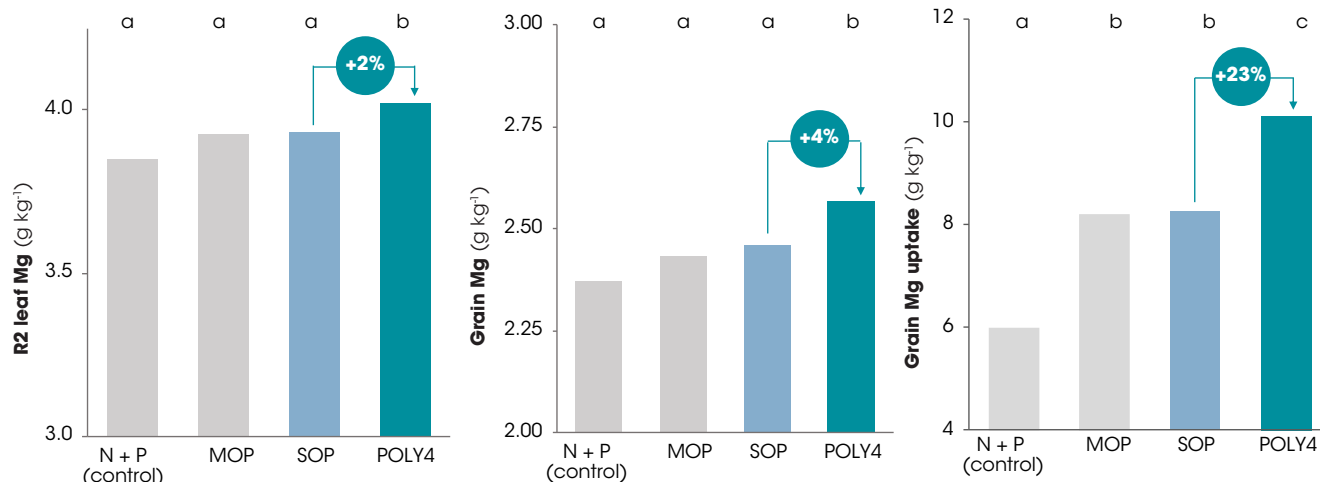
There was a significant ($P < 0.001$) response of grain yield to K fertilizer rate. All K sources increased yield. However, sources that supplied only K (MOP) or only K and S (SOP) had lower yield than the POLY4 treatment which supplied Mg. This shows the value of the multiple nutrients supplied by POLY4.

The value of magnesium can be seen in the tissue concentrations. POLY4 had greater R2 leaf and grain Mg than the other treatments, and due to this and their higher yields had greatest Mg uptake.





Magnesium



Calcium

Calcium (Ca) has several distinct functions within plants. It is important for cell wall structure and for cell membranes. Cell membranes lose selectivity of transported ions, and membranes also become leaky when plants are deficient in Ca. Ca is also essential for the growth of pollen tubes. Unlike K and Mg, Ca does not activate many enzymes and its concentration in the cytoplasm is kept low.

The entry of Ca into roots occurs initially into the cell walls and in the intercellular spaces of the roots. Ca is moved from the roots to the rest of the plant in the xylem via the transpiration stream. As Ca is not mobile in the phloem, existing plant Ca cannot be redistributed to young tissues. These rely on xylem transport but organs that do not have a high transpiration rate (e.g. fruits) can therefore be poorly supplied. Consequently, Ca deficiency symptoms (yellowish leaves) typically occur in new leaves while older leaves remain dark green. The restricted movement of Ca to the xylem causes most Ca deficiency disorders in plants. A period of hot sunny weather not only causes transpiration to pull Ca into leaves but gives rates of photosynthesis that

Calcium deficient soybean

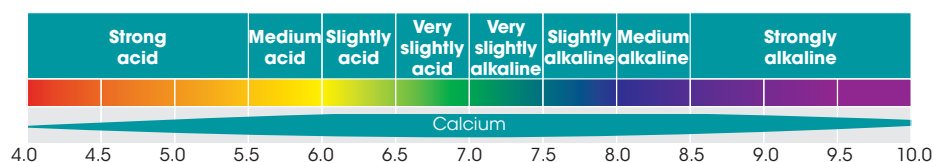


increase fruit growth. Under these conditions deficiencies of Ca can occur at the distal end of the fruit.

Soil

Given the abundance of Ca in soil, calcium deficiency is unusual in many crops. Despite this, plants can suffer from a range of Ca-deficiency disorders that affect tissues or organs that are naturally low in Ca, particularly in fruits and tubers. In these tissues Ca deficiency causes a general collapse of membrane and cell wall structure. With the general breakdown of cell walls and membranes, microbial infection is frequently a secondary effect. This affects factors such as fruit quality and storability.

Calcium availability is also soil pH dependant. Availability is best near neutral pH.



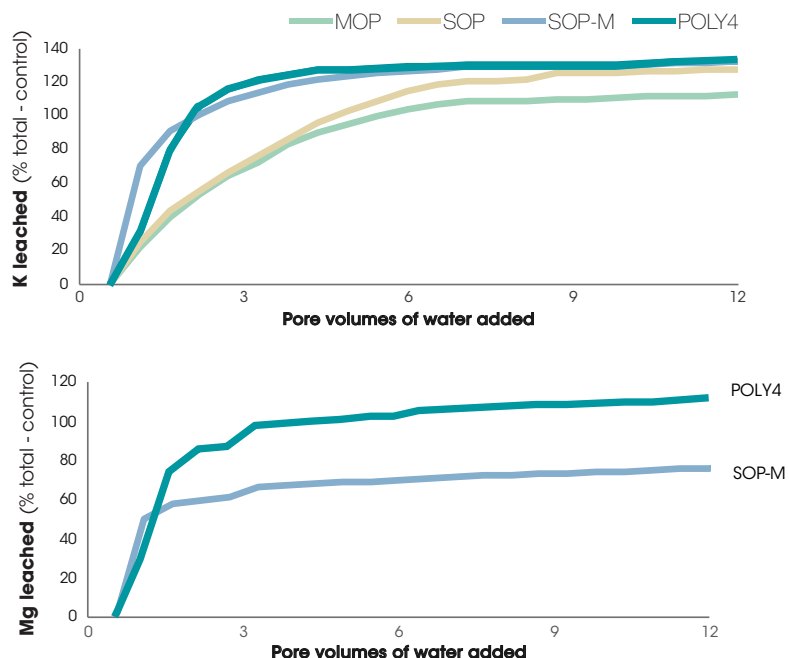


A case for POLY4

Calcium is important as a secondary nutrient for soybean growth and yield, but also for how it interacts with the soil exchange complex making nutrients such as potassium and magnesium more available for plant uptake.

POLY4 helps to mobilise potassium and magnesium release from soil. The total amount of K and Mg released after the POLY4 treatment exceeded the amount applied (130% for K and 115% for Mg).³⁰ It is expected the Ca cations displaced potassium cations held by the soil colloids and so increased the K in solution for crop uptake.

Calcium is also important for soil structure as it flocculates clay and organic matter. This allows air and water into the soil, improves drainage, and decreases susceptibility to soil erosion. The presence of calcium, magnesium, potassium and sulphur in POLY4 means that it provides a balanced fertilizer product with a nutrient profile that more closely meets plant requirements.



Soybean nutrient partitioning

Potassium (K) and sulphur (S) are taken up at the greatest rate between flowering and grain fill. This means that a fertilizer which can supply nutrients during this period is essential to maximise crop yield. POLY4's nutrient release pattern means that it can be applied pre-planting but have K and S available throughout the growing period when it is most required.

Calcium (Ca) uptake is also important during both vegetative growth and grain fill. It is pulled into leaves and other photosynthetic tissues by transpiration but is slow to move into non-photosynthetic tissues such as grain and is not translocated. This means that it is important for Ca to be easily available during this period.

YIELD RESPONSE

Yield response to soil K

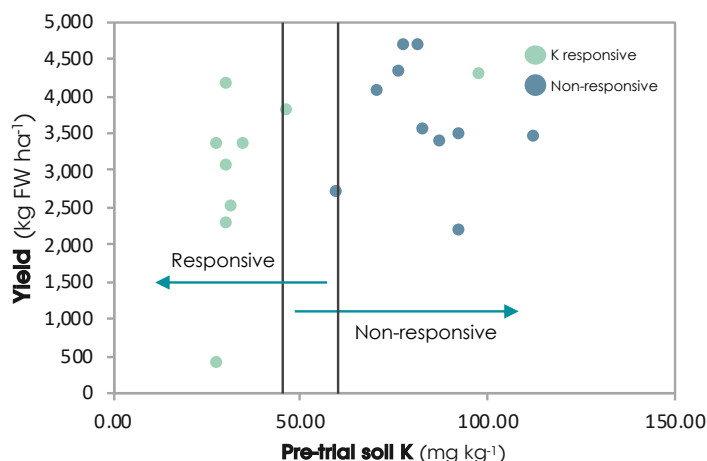
Critical level of soil K

The average yields of the controls at K responsive and non-K responsive sites were graphed against pre-trial soil potassium (K).⁵ In general, soils with K levels below 46 mg kg⁻¹ were K responsive ($P < 0.1$), while the sites with K above 60 mg kg⁻¹ were not, which defined the critical soil K level.

Exceptions occurred in trials in Texas, United States (soil K of 151 and 242 mg kg⁻¹)^{28, 31} and in Correntina, Brazil (soil K of 98 mg kg⁻¹)³² where the sites were K-responsive. For the soil in Texas most of the K was fixed by clay minerals and not readily available for plants. This soil clay mineralogy had an influence on plant response.

Potassium fertilizer policy should aim to elevate soil K to the critical level. Where soil is at that level, maintenance K applications should replace that removed by yield offtake.

Average yield of control treatment on K responsive and non-K responsive soils

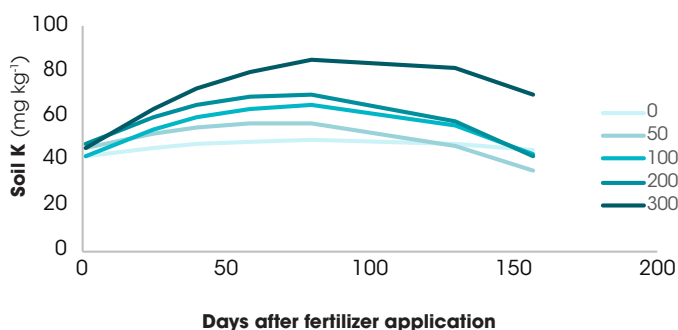


Application of K above the plant requirements increases post-harvest soil K. This is important for systems such as Brazil where a soybean-corn rotation is used but K is only applied prior to soybean.

A case for POLY4

A trial in Florida^{33, 34} tested soil K throughout the growing season of a soybean crop. The break-even application was 50-100 kg K₂O ha⁻¹ which reflects offtake replacement need. Fertilizer applications greater than crop need results in higher residual soil K status.

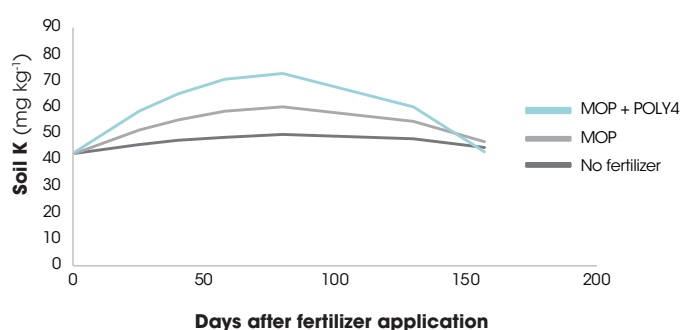
Soil K following different K application rates (kg K₂O ha⁻¹) *



* Values are means of K₂O type. The R² values of the quadratic equations are 24% for 50 kg K₂O, 22% for 100 kg, 7.2% for 200 kg and 12.6% for 300 kg.

Application of potassium as MOP + POLY4 or MOP^{33,34} resulted in increased soil K levels at the mid-season sample date 58 days after sowing. Evidence suggested that when POLY4 contributed to the potassium application, soil K was elevated higher than MOP ahead of peak crop demand.

Soil K after fertilizer applications *



* Values are means of K₂O application rates. The R² values of the quadratic equations are 5.4% for MOP and 14.4% for MOP + POLY4. Pre-trial soil K was 45 mg kg⁻¹.



Yield response to 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 46% 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.

60-90 $\text{kg K}_2\text{O}$ appear to support highest yield, while chloride application rates above 40-50 kg ha^{-1} may depress it.

A case for POLY4

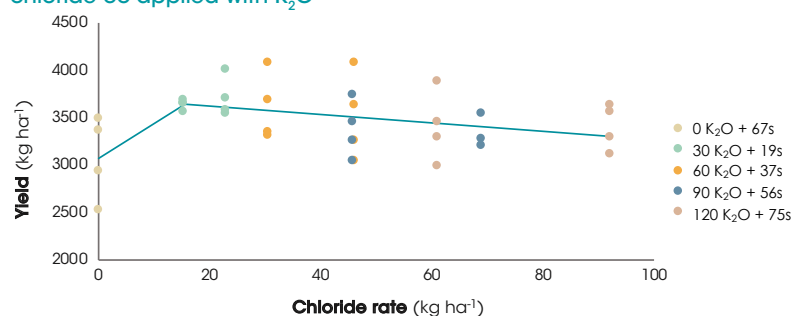
A trial in Mato Grosso, Brazil in 2015 examined the effect of the chloride co-applied with MOP and MOP + POLY4 on soybean yield.^{14,17} Treatments were tested at different K_2O rates with S applied at an 8:5 K_2O :S ratio. At each K_2O rate the MOP + POLY4 supplied less Cl^- than the MOP treatment: 46% of K_2O was supplied by POLY4 which has a low (<3%) Cl^- content compared with MOP (46% Cl^-).

The soil was K responsive ($P = 0.015$) with 30 $\text{kg K}_2\text{O}$ sufficient to increase yields by 550 kg ha^{-1} relative to the control S treatment. Further application of K_2O resulted in a decline in yield which could be attributed to the additional Cl^- supplied by the MOP. Overall, the relationship between yield and Cl^- content can be described by a split-line regression ($R^2 = 19.1\%$), with an initial increase in yield at low Cl^- rates due to the co-supply of K_2O followed by a decline in yield where the negative effects of Cl^- begin to outweigh any benefits gained from additional K_2O supply.

Yield was greatest when Cl^- was less than 30 kg ha^{-1} . This is equivalent to the amount co-applied with 40 $\text{kg MOP-K}_2\text{O}$ or > 140 $\text{kg straight POLY4-K}_2\text{O}$.

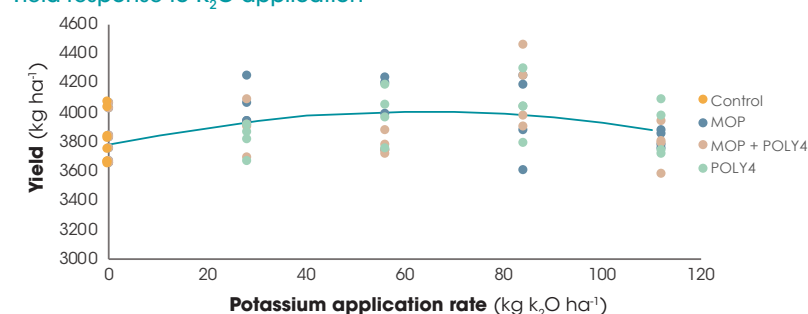
A trial at Becker, MN, United States in 2015 had a quadratic relationship ($P = 0.01$, $R^2 = 12.0$) between yield and K rate.^{35,36} The decline in yield at high K rates could have been due to chloride content of MOP. Yield was related to the chlorine content ($P = 0.019$, $R^2 = 9.9$) with a quadratic relationship, where K_2O applications with low chlorine co-application gave an increase in yield, but as chlorine content increased yield declined.

Soybean yield at Mato Grosso against rate of chloride co-applied with K_2O *



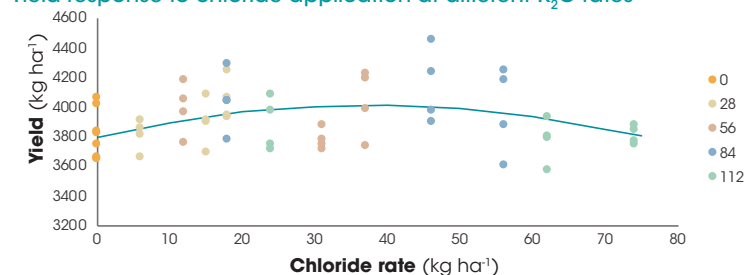
* Regression ($R^2 = 19.0$) is a split-line with Line 1 described by the equation $Y = 3076 + 36.8x$ and Line 2 described by the equation $Y = 3723.2 - 4.5x$.

Yield response to K_2O application*



* Yield response to K_2O application (kg ha⁻¹) at Becker, MN, US in 2015 for different K sources.^{35,36} Response is described by the equation $Y = 3778 + 7.34x - 0.058x^2$ ($P = 0.01$, $R^2 = 12.0$).

Yield response to chloride application at different K_2O rates*



* Yield response to chloride application at different K_2O rates applied at Becker, MN, US in 2015.^{35,36} Response is described by the equation $Y = 3804 + 11.2x - 0.15x^2$ ($P = 0.019$, $R^2 = 9.9$).



POTASSIUM RECOMMENDATIONS

United States

Soils in the Midwest are generally deep, with good release of nutrients from organic matter and potassium (K) from soil reserves. Farmers in the Midwest generally apply K for the prior corn crop rather than before the soybean crop. Iowa State University recommends that K application is based on soil tests. When soil K is in the optimum range, maintenance fertilizer based on estimates of nutrient removal is recommended.

Potassium recommendation table for Coastal Plain (east coast states including Florida and coastal Virginia) and Piedmont (inland east coast states including North Carolina, Georgia and inland Virginia) soils.³⁸ Most of the states with median soil K less than 100 mg kg⁻¹ are located in the Coastal Plain and Piedmont regions.

Iowa State University potassium recommendations for corn and soybean¹

Soil K category	Soil K (mg kg ⁻¹)	K ₂ O fertilizer rate (kg ha ⁻¹)		
		Corn	Soybean	Chance of soybean yield increase
Very low	0-90	146	134	80%
Low	91-130	101	101	65%
Optimum	131-170	50.4	84	25%
High	171-200	0	0	5%
Very high	201+	0	0	<1%

Minnesota University potassium recommendations for soybean³⁷

Soil K (mg kg ⁻¹)	K ₂ O fertilizer rate (kg ha ⁻¹)	
	3.4 – 4.0 t grain ha ⁻¹	>4.0 t grain ha ⁻¹
0-40	112	123
40-80	67	78
81-120	34	34
>121	0	0

University of Georgia potassium recommendations for soybean³⁸

Soil K category	Soil K (mg ha ⁻¹)		K ₂ O application rate (kg ha ⁻¹)
	Coastal plain	Piedmont	
Low	< 40	<69	<112
Medium	40-97	70 - 144	90
High	98-158	145-230	67
Very high	>159	>231	0



Brazil

Soybeans can use a large quantity of potassium, second only to nitrogen, and a significant proportion accumulates in the seed and will be exported. Approximately 18 kg K₂O (15

kg K) is exported in 1 ton of seed, meaning offtake of 72 kg K₂O ha⁻¹ in a 4 tons crop. In Brazil various authorities make potassium recommendations for local conditions.

Fundação MT potassium recommendation for soybean

Level	Soil K (mmolc dm ⁻³)	Soil K (mg L ⁻¹)	kg K ₂ O ha ⁻¹
Very low	< 0.5	< 20	130
Low	0.5 to 1	20 to 40	110
Medium	1 to 1.5	40 to 60	90
High	> 1.5	> 60	70

CPAC potassium recommendations for soybean (based on 3.6 t ha⁻¹ yield)

Potassium	Soil K (mmolc dm ⁻³)	Soil K (mg L ⁻¹)	kg K ₂ O ha ⁻¹
Low	<0.6	< 23	175
Medium	0.6 to 1.3	23-51	125
High	>1.3	>51	75

Foundation for Mato Grosso do Sul potassium recommendation for soybean (based on the K status of the soil and clay content)

Potassium	Clay (g kg ⁻¹)				
	> 600	450 to 600	300 to 450	160 to 300	< 150
Low	150.00	150.00	234.00	80.00	80.00
Medium	75.00	75.00	159.00	50.00	50.00
High	0.00	84.00	84.00	84.00	84.00



POLY4 RECOMMENDATIONS

Timing of application

Soybean systems in both the United States and Brazil have moved toward no-till. POLY4 should be applied prior to or at planting and can be incorporated by the drill at planting in no-till systems.

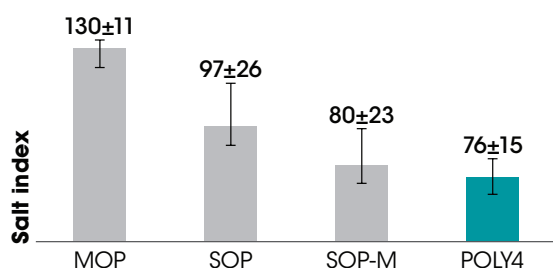
POLY4 builds a nutrient legacy in soil and therefore can also be applied with the previous crop in corn-soybean and small grain-soybean systems.

Salt index

High concentrations of fertilizer salts near a germinating seed or seedling can damage it. This occurs when the ion concentration in the soil is greater than in the plant cells. This causes water to move out of the plant and into soil resulting

in tissue desiccation. POLY4 has a lower salt index than MOP and SOP³⁹ which supports the plant's ability to absorb water and soil nutrients.

In Brazil it is recommended to apply no more than 50-70 kg MOP ha⁻¹ in the furrow at planting. For MOP this is equivalent to a salt index of 6500-9100 SI units. The equivalent furrow limit for POLY4 is 86-120 kg POLY4 ha⁻¹.



POLY4 application rate recommendations

In general, to match grain offtake, at least 72 kg K₂O ha⁻¹ should be applied for a 4 t ha⁻¹ yield. Up to 130 kg K₂O ha⁻¹ should be applied in very low soil K systems. S should be applied above offtake to replace sulphate leached from soil and support the plant demand.

Based on salt index of POLY4 and MOP, 65-90 kg of the

total blend volume can be applied in the furrow while the remainder should be applied pre-planting.

Fertilizer plans to include POLY4 should be constructed to deliver the sulphur need, contribute to K and reduce the chloride load.

MOP + POLY4 blends

For soybean it is recommended to use POLY4 in a blend with MOP. POLY4 provides benefits such as K availability, supply of S, Mg and Ca throughout the growing season and reduced chloride co-application.

Research in the United States and Brazil consistently showed the optimal inclusion of POLY4 to be 25 to 50% of K₂O. The exact inclusion is dependent on S recommendations and other secondary nutrient requirements.



To match offtake (72 kg K₂O ha⁻¹)

A1. With a 25% inclusion of POLY4, 72 kg K₂O ha⁻¹ will supply 18 kg ha⁻¹ of POLY4-K₂O giving 24 kg ha⁻¹ of POLY4-S. This amount of S is enough to both meet grain S offtake and provide additional S for the shoot partition. Importantly, the nutrient release characteristics of POLY4 mean there is K₂O available both upfront from MOP and from POLY4 at critical times such as grain fill when plant K uptake is high. The total blend quantity is 219 kg ha⁻¹. This scenario is typical of the United States.

B1. With a 38% POLY4 inclusion rate 72 kg K₂O ha⁻¹ will supply 27 kg of POLY4- K₂O, 37 kg of S, 11.7 kg MgO, and 33 kg CaO. This inclusion supplies the Mg and Ca offtake in addition to S. The total blend volume is 268 kg ha⁻¹ with a nutrient density of 75% and a chloride content of 38 kg ha⁻¹, compared to MOP alone which has 48 kg Cl⁻ ha⁻¹ and a nutrient density of 60%. This scenario is typically suitable for Brazil and WA, ND, SD, IA, KS, CO, TX states of the United states.

For low K soil

A2. & B2. With K₂O requirements of 130 kg K₂O ha⁻¹ an inclusion rate of 14-21% K₂O from POLY4 is recommended as this will both meet the nutritional requirements of the crop and provide a steady input of K throughout the growing season. A2 provides sufficient S while B2 meets Mg and Ca offtake.

For low Mg soil

C. Where soil Mg is critical, 258 kg POLY4 satisfies Mg offtake and improves soil Mg status.

Scenario	MOP	Low soil K		Sufficient soil K		Low soil Mg
		A1	B1	A2	B2	C
K ₂ O recommendation (kg ha ⁻¹)	72	72	72	130	130	130
POLY4 (% K inclusion)	0	25	38	14	21	28
POLY4 (kg ha ⁻¹)	0	128	195	128	195	258
MOP (kg ha ⁻¹)	120	90	74	186	172	156
S supply (kg ha ⁻¹)	0	24	37	24	37	49
MgO supply (kg ha ⁻¹)	0	8	12	8	12	16
CaO supply (kg ha ⁻¹)	0	22	33	22	33	44
Cl ⁻ (kg ha ⁻¹)	55	44	38	88	83	77
Maximum in furrow (kg fertilizer ha ⁻¹)	50-70	66-93	72-100	62-84	64-90	68-95



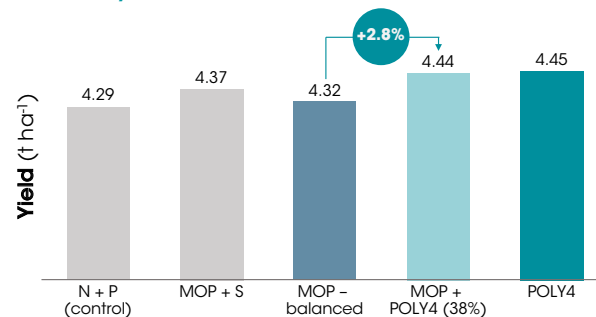
Yield improvement

At Becker, MN in the United States, a soybean trial^{40,41} conducted by University of Minnesota looked at various proportions of POLY4 at different K_2O rates. For the MOP + POLY4 treatment, POLY4 supplied 17 kg K_2O and 23 kg S. In total, 45 kg K_2O was applied. Supplying POLY4 as 38% of the K_2O application improved yield to the greatest extent.

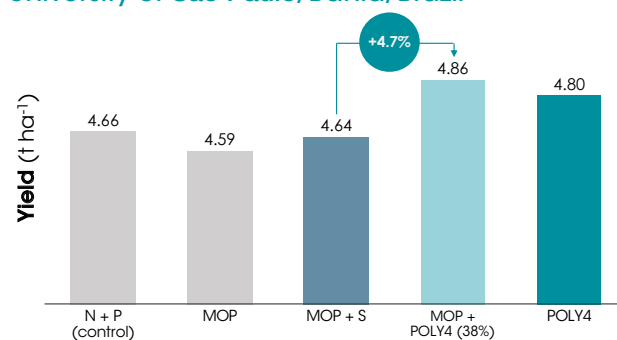
A trial by University of São Paulo at Correntina, Bahia in Brazil^{32, 40} tested soybean yield following application of MOP + S, MOP-balanced (for S, Mg and Ca), MOP + POLY4 (with 38% of K_2O from POLY4), and POLY4 supplying 100% of K_2O . Each K treatment received 45 kg K_2O ha⁻¹. The top performing treatments were MOP + POLY4 and POLY4, making 38% POLY4 the best treatment in this scenario.

University of São Paulo also run a trial in Jaboticabal, Brazil, where consistent yield improvements were seen over three years of trials from the MOP + POLY4 P-K 0:18:18 blend.⁴³⁻⁴⁵

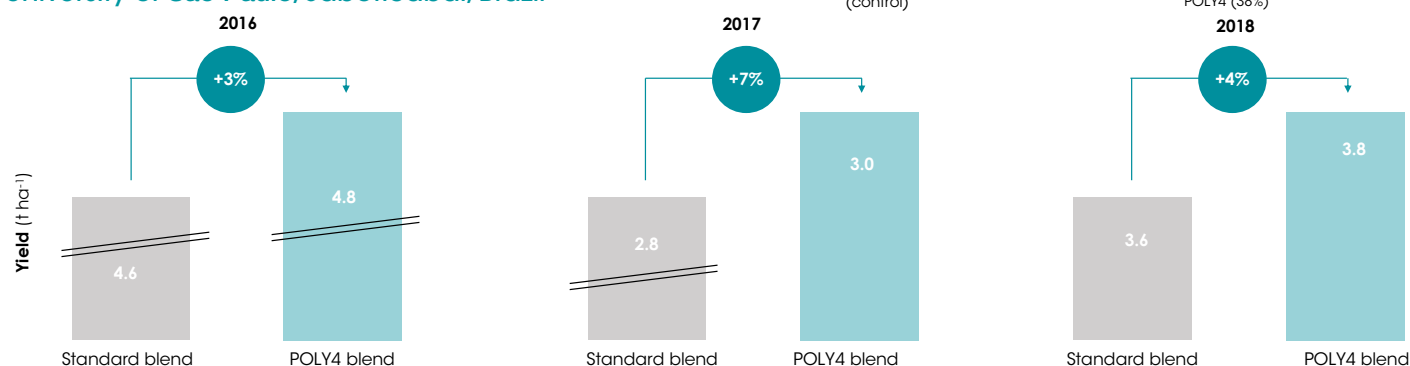
University of Minnesota, Becker, United States



University of São Paulo, Bahia, Brazil



University of São Paulo, Jaboticabal, Brazil

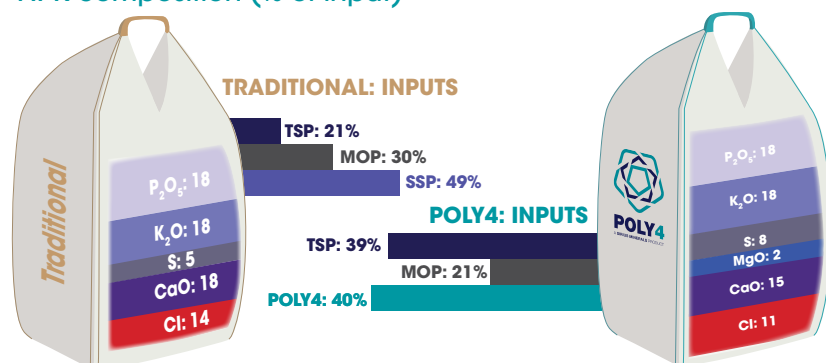


Incorporation of POLY4 in NPK blends

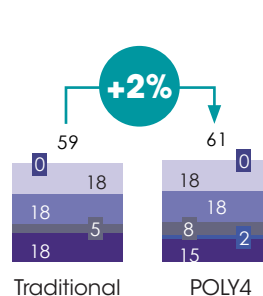
POLY4 can also be used to improve nutrient density compared to traditional blends. It was an effective component of a 0:18:18 blend in Brazil, giving yield increases across three study years from the same volume of product.⁴³⁻⁴⁵

POLY4 can also be used to replace SSP in 2:28:0:8 NPK + S blends, producing a 2:28:6:8 blend; a 4:30:10 blend which replaces TSP, SSP, and a portion of MOP with POLY4; or to replace a portion of MOP in a 12:12:12 blend to create a 12:12:12:9.

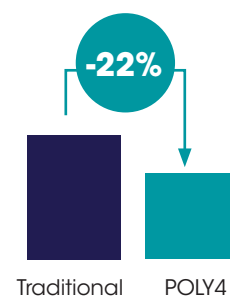
NPK composition (% of input)



Increase in nutrient content (%)



Decrease in chloride content (%)





Notes

- 1) Revised Iowa P and K recommendations: new soil-test K interpretations and support for a new soil P test, Antonio P. Mallarino, University of Iowa;
- 2) Dr. Dan Kaiser of the University of Minnesota;
- 3) Wright *et al.*, Soybean Production in Florida;
- 4) Bean & Miller, Quick Guide for Soybean Production in the Texas Panhandle and South Plains;
- 5) All soybean trials that compared treated crops with a control. Responsiveness is based on Genstat ANOVA analysis where $P < 0.01$;
- 6) Yields normalised relative to POLY4;
- 7) Bender *et al.*, 2015. Nutrient Uptake, Partitioning, and Remobilization in Modern Soybean Varieties;
- 8) Gasper *et al.*, 2017. Secondary and Micronutrient Uptake, Partitioning, and Removal across a Wide Range of Soybean Seed Yield Levels;
- 9) Bruns, 2016. Macro-Nutrient Concentration and Content of Irrigated Soybean Grown in the Early Production System of the Midsouth;
- 10) Adapted from IPNI (2018);
- 11) <https://waset.org/publications/11111/mapping-soil-fertility-at-different-scales-to-support-sustainable-brazilian-agriculture>;
- 12) 11000-LSU-11013-17;
- 13) Fundação MT, 5000-FMT-5011-14;
- 14) Fundação MT, 5000-FMT-5013-15;
- 15) Fundação MT, 5000-FMT-5014-16;
- 16) Pre-trial soil analysis of Juscimeira: pH (CaCl_2) 5.7, 39 mg P L^{-1} , 35 mg K L^{-1} , 601 mg Ca L^{-1} , 97 mg Mg L^{-1} , 10 mg S L^{-1} ;
- 17) Pre-trial soil analysis of Itiquira: pH (CaCl_2) 4.9, 9 mg P L^{-1} , 30 mg K L^{-1} , 501 mg Ca L^{-1} , 108 mg Mg L^{-1} , 7 mg S L^{-1} ;
- 18) Genstat ANOVA analysis;
- 19) Pre-trial soil analysis: 38 mg P kg^{-1} , 467 mg Ca kg^{-1} ; 2.5 mg S kg^{-1} , 148 mg Mg kg^{-1} , 111 mg K kg^{-1} in the control, 130 mg K kg^{-1} . K discrepancy is due to residual from same treatment structure in prior year;
- 20) 36000-NRM-36017-18;
- 21) Giovanelli, 1987. Methods in Enzymology: Sulfur amino acids of plants: An overview;
- 22) <http://nadp.slh.wisc.edu/committees/tdep/tdepmaps/preview.aspx>;



- 23) University of Minnesota, 4000-UMN-14018-17; Verndale sandy loam; pre-trial soil analysis: pH 7.5; 2.1% SOM; 21 mg P kg⁻¹; 237 mg K kg⁻¹; 5536 mg Ca kg⁻¹; 239 mg Mg kg⁻¹; 7 mg S kg⁻¹;
- 24) Lawson, 2012. Soybean Response to Sulfur Fertilization;
- 25) Guo, 2016. Magnesium deficiency in plants: An urgent problem;
- 26) Wild, 1993. Soils and the environment;
- 27) Leggett & Gilbert, 1967. Localization of the Ca-Mediated Apparent Ion Selectivity in the Cross-Sectional Volume of Soybean Roots;
- 28) Texas A&M, 0000-TAM-0027-14;
- 29) Initial soil analysis pH 7.4; 19 mg P kg⁻¹, 242 mg K kg⁻¹, 177 mg S kg⁻¹, 213 mg Mg kg⁻¹, 1029 mg Ca kg⁻¹;
- 30) 1000-UOF-1024-14;
- 31) 0000-TAM-0014-13;
- 32) 4000-USP-4014-14;
- 33) 1000-UOF-1010-13;
- 34) Initial soil analysis: pH 6.4, 45 mg K kg⁻¹, 112 mg Mg kg⁻¹, 351 mg Ca kg⁻¹;
- 35) 14000-UMN-14013-15;
- 36) pH 5.4, 1.1% SOM, 35 mg P kg⁻¹, 46 mg K kg⁻¹, 3 mg S kg⁻¹, 80 mg Mg kg⁻¹, 290 mg Ca kg⁻¹;
- 37) <https://extension.umn.edu/crop-specific-needs/soybean-fertilizer-recommendations#phosphate-and-potash-1078561>;
- 38) Fertilizer recommendations by crop- AESL;
- 39) Salt index (SI) for MOP, SOP, SOP-M and POLY4 using the Jackson (1958) method;
- 40) 14000-UMN-14015-16;
- 41) Loamy sand; initial soil analysis: pH 6.3, SOM 1.5% 34 mg P kg⁻¹, 82 mg K kg⁻¹, 1.8 mg S kg⁻¹, 94 mg Mg kg⁻¹, 502 mg Ca kg⁻¹;
- 42) Initial soil analysis: pH (CaCl₂) 5.5, 33 mg P L⁻¹, 98 mg K L⁻¹, 49 mg Mg L⁻¹, 341 mg Ca L⁻¹;
- 43) 4000-USP-4017-15: pH (CaCl₂) 6, 7 mg P L⁻¹, 56 mg K L⁻¹, 119 mg Mg L⁻¹, 502 mg Ca L⁻¹;
- 44) 4000-USP-4022-16: pH (CaCl₂) 4.6, 15 mg P kg⁻¹, 31 mg K kg⁻¹, 49 mg Mg kg⁻¹, 160 mg Ca kg⁻¹;
- 45) 4000-USP-4028-17: pH (CaCl₂) 5, 15 mg P L⁻¹, 27 mg K L⁻¹, 49 mg Mg L⁻¹, 300 mg Ca L⁻¹.



Efficient, effective, flexible and sustainable fertilizer

POLY4, as the source of macro and micro nutrients, is more efficient and effective for farmers and supports flexible and sustainable fertilizer practices. POLY4 is a low-chloride potassium and sulphate fertilizer that also contains magnesium and calcium – all in one product.

Sustained nutrient delivery

POLY4 provides continuous nutrition that is supportive of the crops' growth cycle. Nutrients are released efficiently and effectively closely matching the needs of the plant. POLY4's sustained dissolution rate generates a supply chain of nutrients that appear in soil solution simultaneously.

Rebalanced soil structure

POLY4 helps to rebalance and reconstruct the soil structure. Calcium in POLY4 helps to increase tensile strength, preventing soil movement, and improves resilience to compaction, thus preventing water runoff.

Improved efficiency and profitability

POLY4 delivers a better outcome to farmers – it improves crop health, increases yield and enhances quality of both broad-acre and high-value crops. POLY4 also offers additional value with the potential for increased economic margins.



Four nutrients in one product:
Potassium, sulphur, magnesium and calcium

Effective nutrient release



Fully soluble with sustained dissolution rate

Suitable crush strength



6.5 kgf

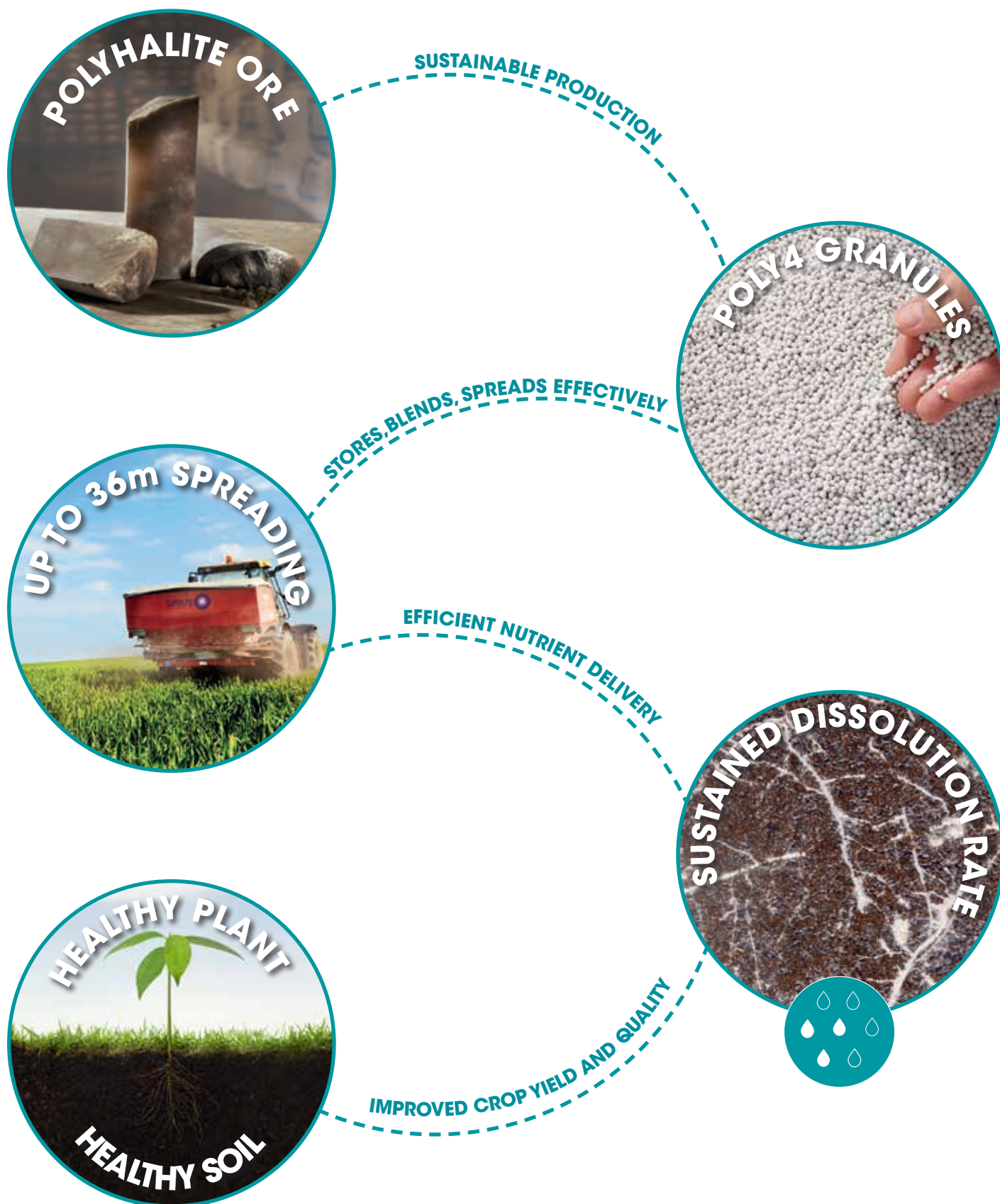


Successful as a component of blend formulations

Up to 36m effective spreading with uniform distribution pattern



36m





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