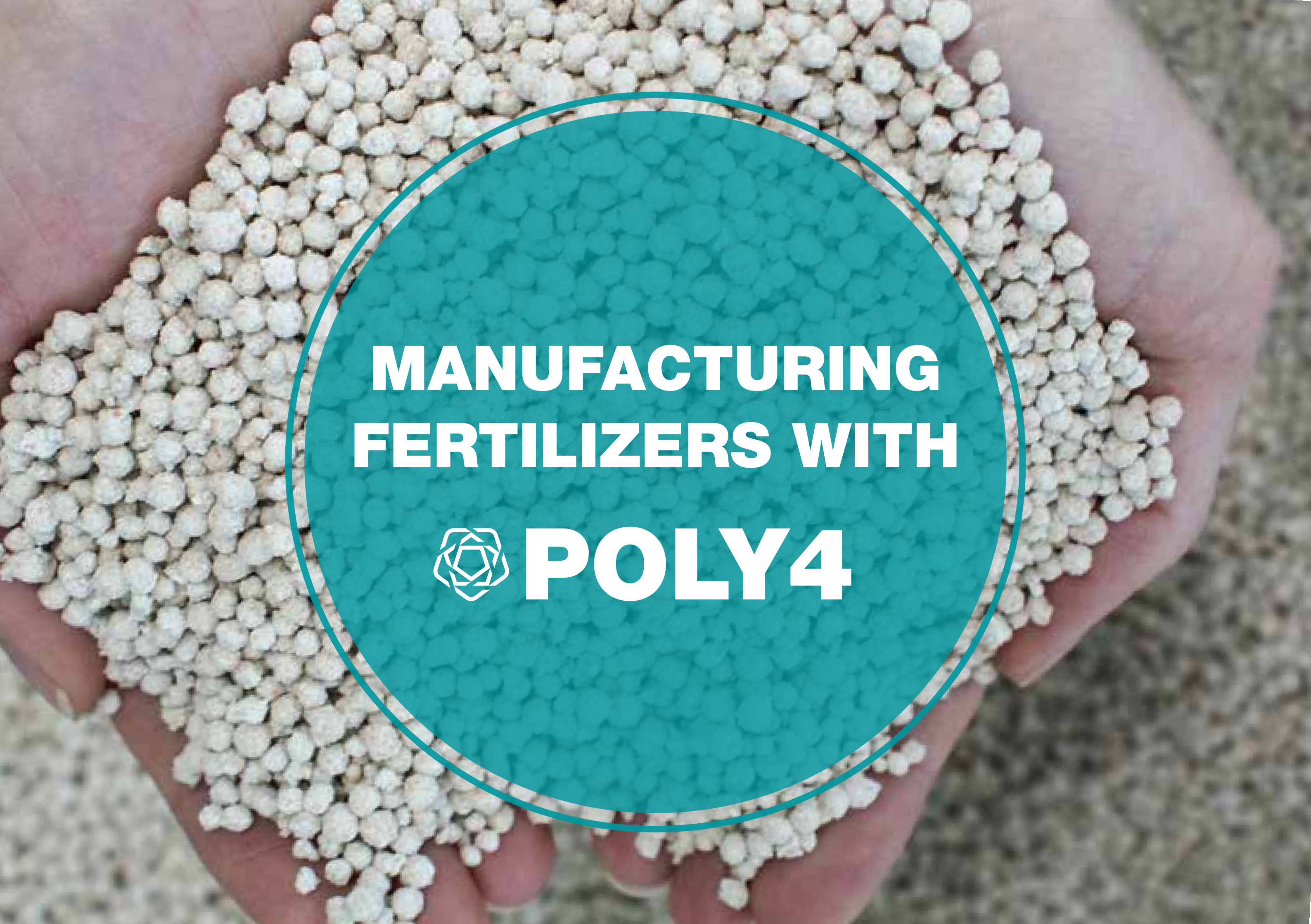
MANUFACTURING FERTILIZERS WITH POLY4



“Fertilizer is still one of the best investments a farmer can make. Reducing rates below optimum means less profit for the grower and also results in mining of soil nutrients. Maintaining soil fertility is easier and less costly than building it up.”

Dr. Terry Roberts, International Plant Nutrient Institute

Independent testing examined the impact of POLY4 on the characteristics of compacted, steam and chemically granulated NPK fertilizer products. This handbook gives a summary of the actual testing results using real data and displays physical and chemical properties of MOP, urea-based and AN-based NPK products.

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WHAT ARE FERTILIZERS?

Fertilizers are a natural or artificial substance which deliver nutrients to feed plants and support their growth.

Global food security continues to be a major concern in the world. In the first half of this century, the world's population is projected to grow to about 9.8 billion.[1] Associated with this population growth, global demand for food will nearly double. The Food and Agriculture Organization of the United Nations projected a worldwide annual increase in potash fertilizer demand, with an increase of 56% in Asia, 27% in the Americas, 1% in Europe, 6% in Africa and 0.4% in Oceania.[2]

Fertilizers are essential in today's farming practices. It is recognised that 50% of crop yield gap can be supported by fertilizer applications. Fertilizers are responsible for more than half of the world's food production, and, due to the increased food demand, additional fertilizer resources are needed. Agronomic advice is shifting, and fertilizer practice is seeking to apply a wider nutrient spectrum to achieve higher yields and better quality of crops. As a consequence, basic NPKs are superseded by NPK +S, NPKS +Mg or +micro nutrients, and so the value of multi-nutrient resources such as POLY4 is recognised.

Essential plant nutrients

Fertilizer practice is quite site specific, but in essence has one primary function and that is to replace nutrients exported in the harvested crop. Crops mine the soil for nutrients to build the plant biomass. Provided the soil continues to supply nutrients, crop productivity continues.

In order to grow, plants need 16 essential elements currently recognised by the agricultural sector.

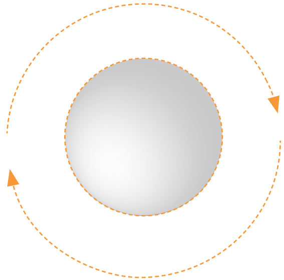
Fertilizers deliver nutrients in support of plant growth. Any substance that contains one or more of primary, secondary or micro nutrients in a form that is available to plants will act as a fertilizer.

Major elements	From the air and water	Carbon (C) Hydrogen (H) Oxygen (O)
	From the soil: primary nutrients	Nitrogen (N) Phosphorus (P) Potassium (K)
	From the soil: secondary nutrients	Calcium (Ca) Magnesium (Mg) Sulphur (S)
Minor elements	From the soil: micro nutrients	Boron (B) Chlorine (Cl) Copper (Cu) Iron (Fe) Manganese (Mn) Molybdenum (Mo) Zinc (Zn)

Forms of fertilizers

Various ways of manufacturing solid fertilizers lead to the production of different forms of end product.

Prills are smooth spherical particles formed by spraying liquefied chemicals down a tower with an upward current of cooling air. Prills solidify as they fall down the tower and are graded for size before packing. Superior quality prills are of a hard and solid consistency and have a low caking tendency. The normal size ranges from 1mm to 3mm with 75 per cent manufactured within 2.4mm to 2.8mm.



"90% of high quality **POLY4 granules** are manufactured in a **2mm to 4mm** size range."

Granules are made to make fertilizer handling and application easier. Granules are of a coarse texture and are made by passing a drying slurry through a rotating machinery to generate spherical particles. Products of a better quality are hard with a consistent bulk density, low caking potential and low abrasion index. Ninety per cent of high quality POLY4 granules are manufactured in a 2mm to 4mm size range.

A compacted fertilizer is more angular than granules and is made by pressing products between rollers to form a solid cake. Compacted material is then broken up and graded to achieve consistent size range of 2mm to 4mm. Compacted products may be referred to as granule or chips.

Fertilizer types

Farmers can choose to apply only one plant nutrient (a straight fertilizer) or a mixed nutrient product containing at least two of the primary nutrients (a compound fertilizer). Other types of fertilizers are described as complex, composite, mixed, blends or NPK fertilizers.

In the fertilizer industry, most products are distributed as mixed fertilizers in granular form, containing at least two (usually three) of the primary nutrients (N, P, K). Mixed fertilizers can be:

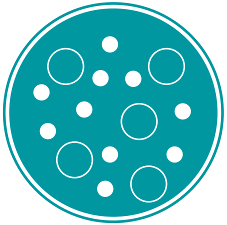
- Compound fertilizers – obtained by chemical processing and comprising granules of a similar composition;
- Blended fertilizers – obtained by dry mixing of granular fertilizer materials and comprising granules of a mixed composition.

It is now recognised that to grow healthy plants, that access the right nutrients at the right time, and to achieve higher yields, a wider nutrient spectrum is critical. As a consequence, basic NPKs are superseded by NPK +S, NPKS +Mg or +micro nutrients. POLY4 offers the value of multi-nutrient resources available in one product.

The quality of fertilizer characteristics

Compounds, compacted, steam and chemically granulated fertilizer products can be manufactured in several, different ways.

No matter the chosen route, the quality of fertilizer is determined by the same characteristics:

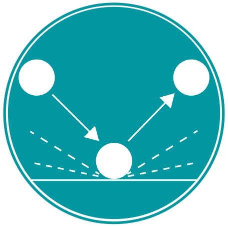


Particle size
of fertilizer products is defined as the range of particles size. Granulation technique affects particle size, which in turn influences agronomic performance, storage, handling, spreading and blending.

Crush strength
is the minimum force required to crush individual particles. It helps to estimate expected handling and storage, properties of granular materials, and to determine pressure limits during bag and bulk storage.

Abrasion resistance
is the resistance to the formation of dust and fines as a result of handling. It helps to assess material loss during handling, storage and application as well as, in some cases, helping to control pollution and hazard.

The quality of fertilizer characteristics... continued



Impact resistance
is the resistance of granules to breakage upon impact with a hard surface. It is a particularly important characteristic to users of fan-assisted spreaders and when the material is discharged from an overhead point into a bulk pile, eg, during ship loading.

Critical relative humidity (CRH)
is the value of humidity above which a material absorbs moisture. CRH determines the degree of protection a fertilizer product needs in storage, and during handling and distribution. Testing is undertaken in a controlled humidity chamber where moisture uptake is reflected in the product weight.

Hygroscopicity
is the tendency of a material to absorb water from the atmosphere. Fertilizer materials with the same CRH may behave differently due to the differing moisture-holding capacities. Fertilizers can be compared by being exposed to various periods of humidity. Assessments are made based on the moisture pick-up rate per unit of exposed surface area, the depth of the moisture penetration, the moisture holding capacity and the integrity of the wetted granules. This characteristic is important to fertilizer handling, storage and shelf life in differing climates.

COMPATIBILITY IN BLENDS

Chemical compatibility in blends is the ability for two or more materials to remain dry and free-flowing when blended together. Incompatibility causes wetting, caking, gas generation and/or particle disintegration. Compatibility is not only important in bulk-blending but also necessary for any NPK granulation system.

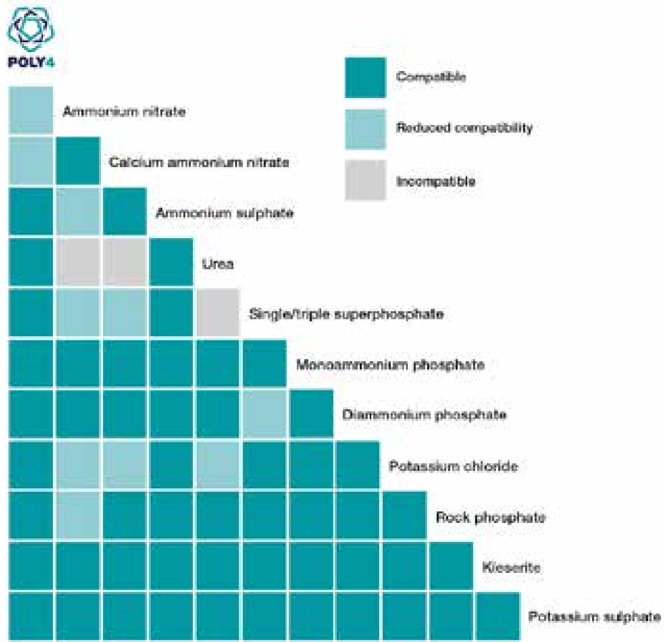
Blending fertilizers requires consideration of all components' compatibilities. Chemical compatibility testing can be broken into three sections: simple 50:50 mixtures, urea-based NPK bulk blends and ammonium nitrate (AN)-based NPK bulk blends. International Fertilizer Development Centre (IFDC), an established industry specialist, carried out advanced testing on POLY4 to determine its blend compatibility using a wide range of common fertilizer materials. IFDC tested two NPK series: urea-based and AN-based bulk blends.

Testing took place over an extended period in order to mimic industrial conditions.[3] To determine compatibility, mixtures with POLY4 were combined: a 100 grams sample was placed in a 200-millilitre glass bottle.[4] The bottles were tightly capped and placed in a convection oven at 30°C for 30 days. A 500 N load cell and a displacement transducer measured the time delay until 90 psi was reached indicating the time taken for a cake to form. The ejection pressure of the cake demonstrated the caking propensity.

Ammonium nitrate is recognised within the industry for its incompatibility with urea and its reduced compatibility with ammonium sulphate, triple super phosphate, single super phosphate, potassium chloride and rock phosphate. Ammonium nitrate exhibited a similar tendency with POLY4.

However, the results showed that POLY4 has a broad spectrum and good level of compatibility with other fertilizer products tested, namely urea, diammonium phosphate, rock phosphate and potassium chloride. The POLY4 compatibility triangle expands the European Fertilizer Manufacturers Association guidelines for fertilizer compatibility[5] with POLY4 test results showing that POLY4 is a compatible input for blending into NPK fertilizers.

POLY4 compatibility triangle[6,7]



MANUFACTURING NPKs WITH POLY4

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

POLY4-NPK products have excellent characteristics including improvements in crush strength, dust reduction and abrasion resistance. Moreover, CRH and moisture penetration characteristics of these products reduce caking tendency, thus improving fertilizer shelf life. All these qualities indicate that NPKs made using POLY4 as an input are eminently fit for purpose.

POLY4 compaction

Compacted fertilizers, made by pressing products between rollers to form a solid cake, are a simple and economical way to manufacture compound products. Certain materials are not so easily compacted together, whereas other ones are binders and act effectively as facilitators of the process.

During testing, the various raw materials required to produce each NPK grade were well mixed whilst in a powder form. The mixture was then fed to a compactor where the material was compressed by applying pressure. The compacted material was crushed before being screened to separate the fines, the oversize and the required product size. Undersized fines were recycled back to the compactor together with the fresh blend. The oversized material was sent back to the crusher, which discharged into the screening system thus completing the closed loop.

To determine physical properties of urea-based and AN-based NPK compounds including size analysis, granule crush strength, abrasion resistance, dustiness of product, CRH and moisture absorption penetration, IFDC undertook the compaction process using various NPK fertilizer grades from the urea and AN series (urea-DAP-KCl-POLY4 for urea-based and AN-phosphate rock-KCl-POLY4 for AN-based NPKs).

Urea-based NPK blend compaction process: testing results[8]

Targeted grade	27:14:14	24:12:12	20:10:10	16:8:8
Targeted POLY4 feedstock content (%)	0.0	13.8	35.8	50.9
Physical properties				
Size analysis (cumulative percentage retained on screen)				
4.00mm	0.1	0.4	1.1	1.2
3.35mm	2.6	5.9	16.0	22.9
2.80mm	19.3	30.3	42.2	55.5
2.36mm	42.9	61.3	68.6	85.8
2.00mm	61.9	82.7	84.6	98.3
1.70mm	72.3	91.6	91.5	99.4
Granule crushing strength (-2.80mm +2.36mm fraction)				
Average (kg/granule)	0.98	1.67	2.26	2.19
Range (kg/granule)	0.55-2.1	1.0-2.5	1.35-3.3	1.25-3.3
Abrasion resistance (% degradation)	10.45	3.86	2.54	1.44
Impact resistance (% shattered granules)	0.6	1.66	1.19	0.83

Urea-based NPK blend compaction process: testing results... continued[8]

Targeted grade	27:14:14	24:12:12	20:10:10	16:8:8
Targeted POLY4 feedstock content (%)	0.0	13.8	35.8	50.9
Physical properties				
Dustiness of product (mg kg^{-1} of product)	17,296	6,507	6,828	3,125
Critical relative humidity (CRH) (%)	55-60	55-60	55-60	55-60
Moisture absorption-penetration (72 hours @ 30°C, 80% RH)				
Moisture absorption (mg/cm^2)	486.1	505.9	478.7	492.6
Moisture penetration (cm)	9.2	7.0	6.5	6.3
Moisture holding capacity (mg/cm^3)	53.0	72.7	74.0	77.9
Moisture holding capacity (%)	6.8	9.4	8.4	8.6
Granule integrity (wet)	Poor	Poor	Fair	Fair
Caking 1 month	4.7	10.6	0.0	0.0
Caking 3 months	36.1	28.9	1.4	0.6
Caking 6 months	31.1	37.8	4.2	0.6

AN-based NPK blend compaction process: testing results[8]

Targeted grade	13:13:13	12:12:12	10:10:10	7:7:7
Targeted POLY4 feedstock content (%)	0.0	3.9	25.9	52.6
Physical properties				
Size analysis (cumulative percentage retained on screen)				
4.00mm	0.2	0.3	0.2	0.1
3.35mm	7.4	8.3	4.7	5.8
2.80mm	30.4	32.0	24.8	29.9
2.36mm	53.0	53.9	46.5	53.2
2.00mm	73.6	74.0	67.3	75.1
1.70mm	83.5	84.5	78.6	86.0
Granule crushing strength (-2.80mm +2.36mm fraction)				
Average (kg/granule)	0.95	0.94	0.78	1.02
Range (kg/granule)	0.45-1.75	0.40-1.8	0.35-1.3	0.40-1.7
Abrasion resistance (% degradation)	22.14	20.76	34.7	19.91
Impact resistance (% shattered granules)	11.07	15.61	13.26	20.15

AN-based NPK blend compaction process: testing results... continued[8]

Targeted grade	13:13:13	12:12:12	10:10:10	7:7:7
Targeted POLY4 feedstock content (%)	0.0	3.9	25.9	52.6
Physical properties				
Dustiness of product (mg kg^{-1} of product)	18,661	17,627	21,253	14,149
Critical relative humidity (CRH) (%)	60-65	60-65	60-65	60-65
Moisture absorption-penetration (72 hours @ 30°C, 80% RH)				
Moisture absorption (mg/cm^2)	385.4	374.8	411.4	405.1
Moisture penetration (cm)	6.6	7.9	8.0	7.1
Moisture holding capacity (mg/cm^3)	58.8	47.8	51.5	57.2
Moisture holding capacity (%)	6.4	4.8	5.1	5.0
Granule integrity (wet)	Poor	Poor	Poor	Poor
Caking 1 month	0.3	0.0	0.0	0.0
Caking 3 months	0.0	0.0	0.0	0.0
Caking 6 months	0.0	0.0	0.0	0.0

POLY4 COMPACTION: PHYSICAL PROPERTIES

Both compacted urea-based and AN-based products were manufactured with the tested grades without difficulty.

For urea-based NPKs, inclusion of 35% POLY4 maximised crush strength and abrasion resistance, and minimised dust occurrence. CRH was unaffected. POLY4's inclusion of 35% maximised fertilizer quality.

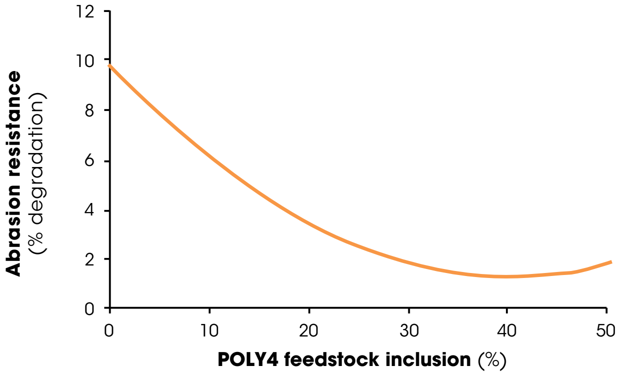
For AN-based NPKs, as expected, CRH was not influenced by inclusion of POLY4. Equally, abrasion resistance was unaffected and there was a minor impact on moisture holding-penetration characteristics. As with urea grades, there was evidence of an improvement in dust occurrence of the product.

Abrasion resistance

The actual testing results using real data showed that inclusion of 35% POLY4 maximised abrasion resistance in urea-based NPKs.

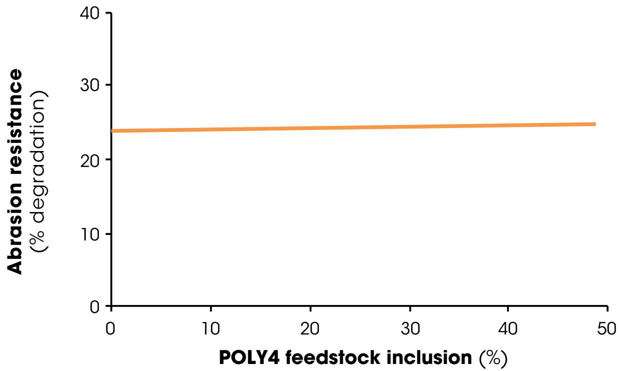
Abrasion resistance in AN-based NPKs was unaffected.

Urea-based blend*



* Genstat regression data

AN-based blend*

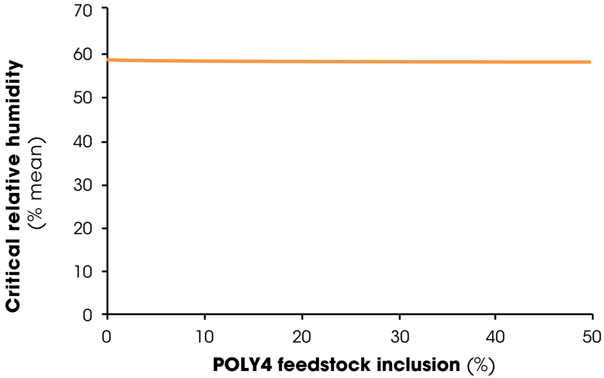


* Genstat regression data

Critical relative humidity

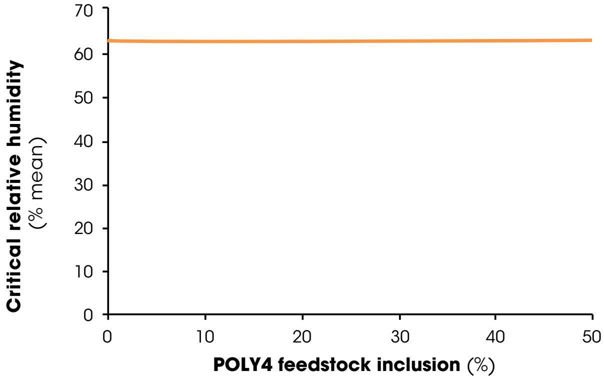
For both urea-based and AN-based NPKs, as expected, CRH was not influenced by inclusion of POLY4.

Urea-based blend*



* Genstat regression data

AN-based blend*



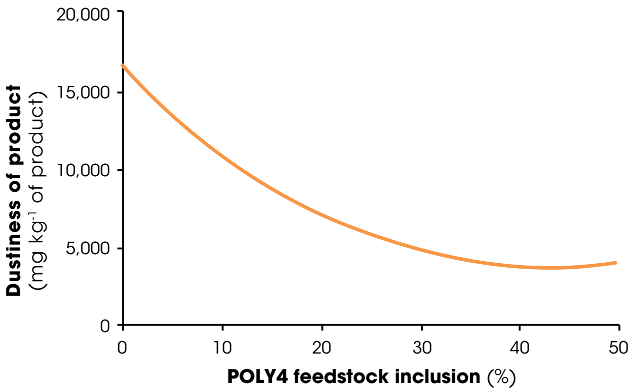
* Genstat regression data

Dust occurrence

The actual testing results using real data showed that inclusion of 35% POLY4 minimised dust occurrence in urea-based NPKs.

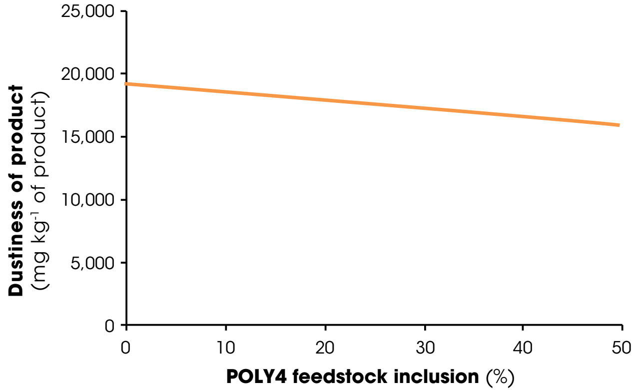
There also was evidence of an improvement in dust occurrence of AN-based NPKs.

Urea-based blend*



* Genstat regression data

AN-based blend*



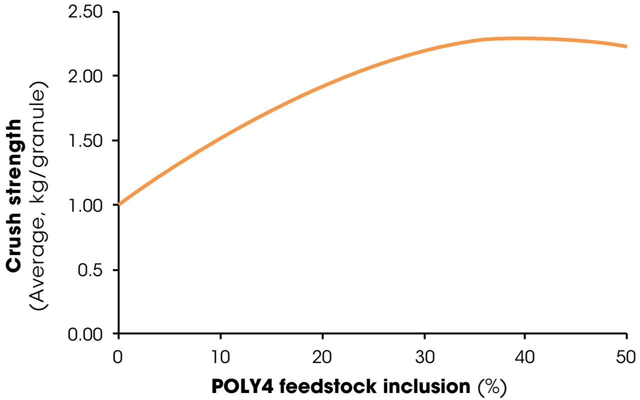
* Genstat regression data

Crush strength

The actual testing results using real data showed that inclusion of 35% POLY4 maximised crush strength in urea-based NPKs.

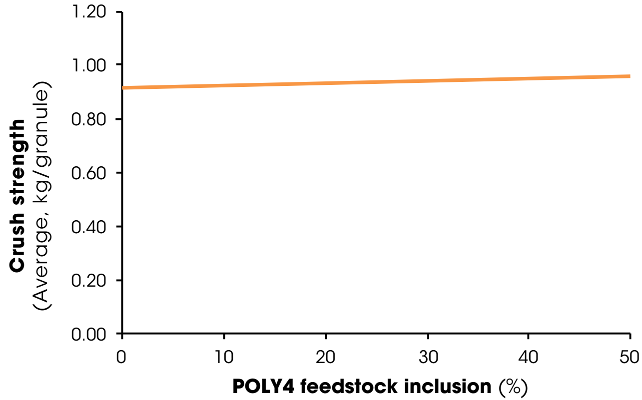
Crush strength in AN-based NPKs was unaffected.

Urea-based blend*



* Genstat regression data

AN-based blend*



* Genstat regression data

POLY4 STEAM GRANULATION

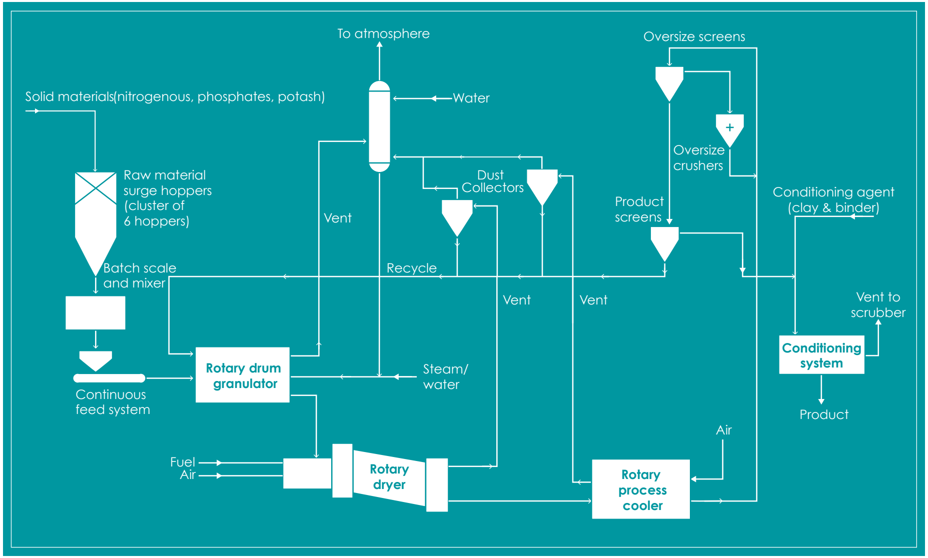
Complex fertilizers are manufactured by combining two or more nutrients. In a complex NPK, all the ingredients are mixed together before being formed into granules.

Steam granulation is one of the methods of manufacturing compound fertilizers. In this process granules are formed by agglomeration. Raw materials are weighed and premixed before being fed to a granulator (rotary drum or pug mill). Steam and/or water or scrubber liquor are added to provide sufficient liquid and plasticity to initiate agglomeration. In some cases, the pug mill is used to premix the solids and liquids prior to the granulation in a rotary drum unit. In other processes, a small amount of ammonia may also be added during granulation to react with superphosphates to promote granulation and improve fertilizer quality by decreasing the acidity and increasing CRH. Moist granules are dried, usually in a drum dryer, and screened to isolate the product size fraction. Final product is selected whilst the oversize and undersize material is crushed and recycled to the granulator.

To test POLY4 compatibility, IFDC configured a small-scale granulation pilot plant to simulate a commercial NPK granulation plant. The process involved the use of a rotary drum-type granulator, a rotary drum-type dryer and a rotary drum-type cooler. Nitrogenous material, either ammonium nitrate or urea, was introduced into the pug mill. This was followed by diammonium phosphate (DAP), potassium chloride and finally POLY4. All materials went to a granulator. From the granulator, the wet granular materials were at first discharged into a dryer and then went into a cooler. The dried product was transferred to the screening system to separate the final product from under and oversized material. The required size granules were passed through a product cooler, and finally, the cooled granulated product was collected. The diagram shows typical steam granulation process flow.

To determine physical properties of urea-based and AN-based NPK blends including size analysis, granule crush strength, abrasion resistance, dustiness of product, CRH and moisture absorption penetration, IFDC undertook the steam granulation process using two series of NPK fertilizer grades (urea-DAP-KCl-POLY4 for urea-based and AN-phosphate rock-KCl-POLY4 for AN-based NPKs).

Typical NPK fertilizer granulation plant using steam and/or water



Urea-based steam-granulated NPK compounds: testing results[9]

Targeted grade	27:14:14	24:12:12	20:10:10	16:8:8
Targeted POLY4 feedstock content (%)	0.0	13.8	35.8	50.9
Physical properties				
Size analysis (cumulative percentage retained on screen)				
4.00mm	0.1	0.0	0.0	0.0
3.35mm	13.6	2.0	2.3	15.2
2.80mm	55.7	24.7	21.3	60.1
2.36mm	87.5	77.8	71.9	90.1
2.00mm	98.2	97.7	97.7	98.5
1.70mm	98.9	98.9	99.5	99.0
Granule crushing strength (-2.80mm +2.36mm fraction)				
Average (kg/granule)	1.34	1.62	2.03	2.44
Range (kg/granule)	0.95-1.9	1.05-2.6	1.55-2.85	1.75-3.35
Abrasion resistance (% degradation)	2.02	0.71	0.57	2.41
Impact resistance (% shattered granules)	1.82	1.43	0.27	1.2

Urea-based steam-granulated NPK compounds: testing results... continued[9]

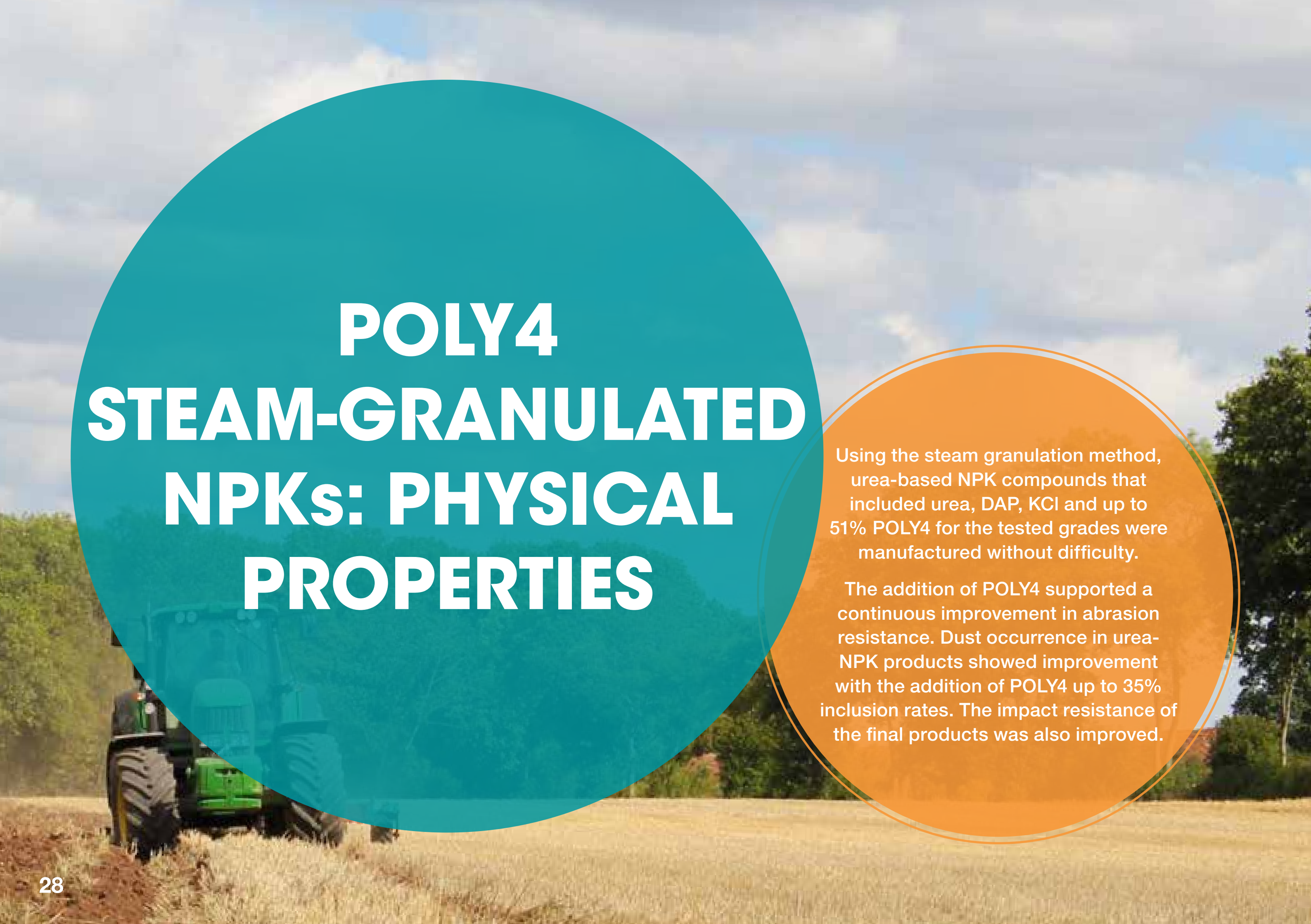
Targeted grade	27:14:14	24:12:12	20:10:10	16:8:8
Targeted POLY4 feedstock content (%)	0.0	13.8	35.8	50.9
Physical properties				
Dustiness of product (mg kg^{-1} of product)	4,742	2,935	1,295	1,975
Critical relative humidity (CRH) (%)	50-55	50-55	50-55	50-55
Moisture absorption-penetration (72 hours @ 30°C, 80% RH)				
Moisture absorption (mg/cm^2)	549.0	580.6	521.1	500.4
Moisture penetration (cm)	19.5	11.8	12.2	11.8
Moisture holding capacity (mg/cm^3)	28.2	50.5	42.6	43.6
Moisture holding capacity (%)	3.6	6.0	4.6	4.4
Granule integrity (wet)	Poor	Poor	Fair	Fair
Caking 1 month	2.0	0.6	4.2	0.1
Caking 3 months	20.6	0.6	2.8	0.6
Caking 6 months	7.2	1.7	4.2	4.4

AN-based steam-granulated NPK compounds: testing results[9]

Targeted grade	18:18:18	17:17:17	14:14:14	10:10:10
Targeted POLY4 feedstock content (%)	0.0	3.9	25.9	52.6
Physical properties				
Size analysis (cumulative percentage retained on screen)				
4.00mm	0.2	0.6	1.6	0.1
3.35mm	4.5	8.9	18.7	11.2
2.80mm	22.4	37.5	52.3	49.0
2.36mm	65.4	75.4	85.8	85.7
2.00mm	94.9	95.7	98.2	99.1
1.70mm	98.9	98.0	99.4	99.8
Granule crushing strength (-2.80mm +2.36mm fraction)				
Average (kg/granule)	1.27	1.02	1.27	1.20
Range (kg/granule)	0.5-3.35	0.9-3.0	0.5-2.75	0.55-1.95
Abrasion resistance (% degradation)	9.35	4.94	1.41	0.34
Impact resistance (% shattered granules)	10.05	3.53	1.16	0.68

AN-based steam-granulated NPK compounds: testing results... continued[9]

Targeted grade	18:18:18	17:17:17	14:14:14	10:10:10
Targeted POLY4 feedstock content (%)	0.0	3.9	25.9	52.6
Physical properties				
Dustiness of product (mg kg^{-1} of product)	3,244	1,362	456	195
Critical relative humidity (CRH) (%)	60-65	60-65	60-65	60-65
Moisture absorption-penetration (72 hours @ 30°C, 80% RH)				
Moisture absorption (mg/cm^2)	423.6	437.5	475.8	453.9
Moisture penetration (cm)	7.2	7.0	5.7	4.7
Moisture holding capacity (mg/cm^3)	58.7	62.7	83.4	96.4
Moisture holding capacity (%)	7.2	7.4	8.3	8.4
Granule integrity (wet)	Poor	Fair	Fair	Fair
Caking 1 month	21.1	25.6	23.3	12.2
Caking 3 months	36.1	36.7	33.3	7.8
Caking 6 months	69.4	47.9	55.6	28.6



POLY4 STEAM-GRANULATED NPKs: PHYSICAL PROPERTIES

Using the steam granulation method, urea-based NPK compounds that included urea, DAP, KCl and up to 51% POLY4 for the tested grades were manufactured without difficulty.

The addition of POLY4 supported a continuous improvement in abrasion resistance. Dust occurrence in urea-NPK products showed improvement with the addition of POLY4 up to 35% inclusion rates. The impact resistance of the final products was also improved.

POLY4 also had a positive impact on granule crush strength.

After one month, there was little difference in caking tendency amongst products. However, by three months the value of POLY4 was evident. At three months, the smallest inclusion of POLY4 supported a significant reduction in losses due to caking.
For the four urea-based NPK products, the percentage of caking after a six-month storage was:

- 7.2% caking for the product that did not contain POLY4;
- 1.7% caking for the product containing 13.8% POLY4;
- 4.2% caking for the product containing 35.8% POLY4;
- 4.4% caking for the product containing 50.9% POLY4.

Using the steam granulation method, AN-based NPK compounds from DAP, urea, KCl and up to 53% POLY4 for the tested grades were manufactured without difficulty.

The addition of POLY4 up to 35% inclusion rate into these AN-NPK products improved abrasion resistance and dust occurrence. There was a general trend in the improved impact resistance of the final product: the smallest inclusion of POLY4 promoted a 50% reduction in losses.

The substitution of POLY4 inclusion rates did not impact granule crush strength, and there seemed to be little impact on moisture holding-penetration characteristics.

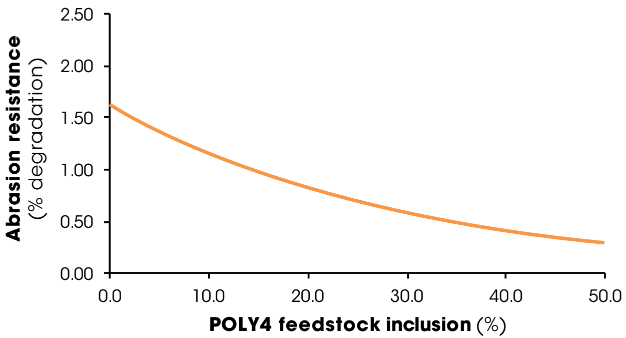
Caking tendency indicates fertilizer shelf life on a farm. For the four AN-based NPK products, the percentage of caking after a six-month storage was:

- 69.4% caking for the product that did not contain POLY4;
- 47.2% caking for the product containing 3.9% POLY4;
- 55.6% caking for the product containing 25.9% POLY4;
- 25.6% caking for the product containing 52.6% POLY4.

Abrasion resistance

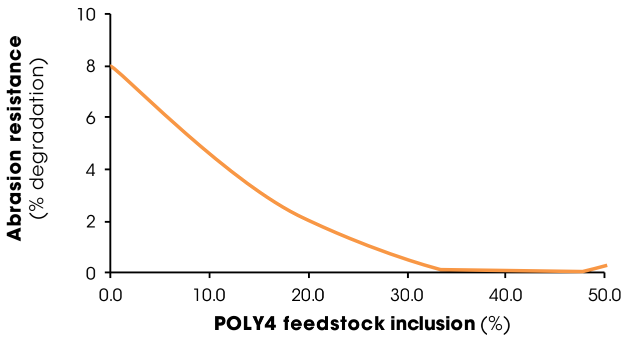
The actual testing results using real data showed that with an increase in POLY4 inclusion rates, abrasion resistance improved continuously in both urea-based and AN-based NPKs.

Urea-based steam-granulated compounds*



* Genstat regression data

AN-based steam-granulated compounds*

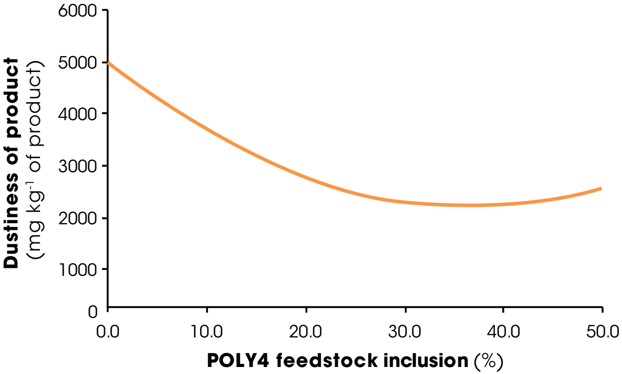


* Genstat regression data

Dust occurrence

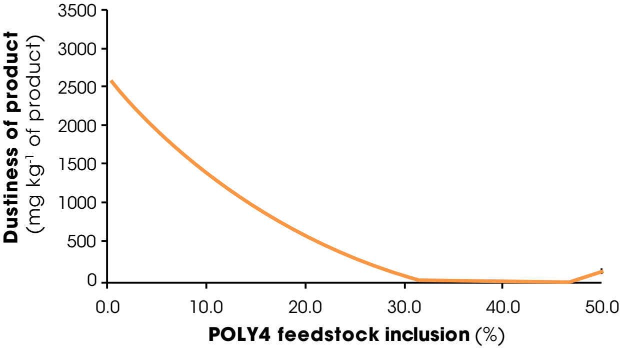
Dust occurrence improved with the addition of up to 35% POLY4 inclusion rates in both urea-based and AN-based products.

Urea-based steam-granulated compounds*



* Genstat regression data

AN-based steam-granulated compounds*



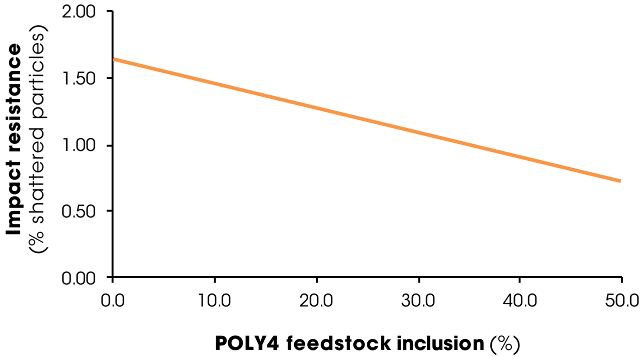
* Genstat regression data

Impact resistance

The actual testing results using real data showed that the impact resistance of the final products was improved.

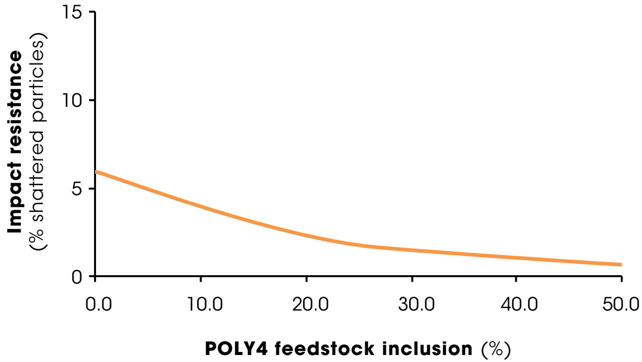
The smallest inclusion of POLY4 promoted a 50% reduction in losses in AN-based NPKs.

Urea-based steam-granulated compounds*



* Genstat regression data

AN-based steam-granulated compounds*



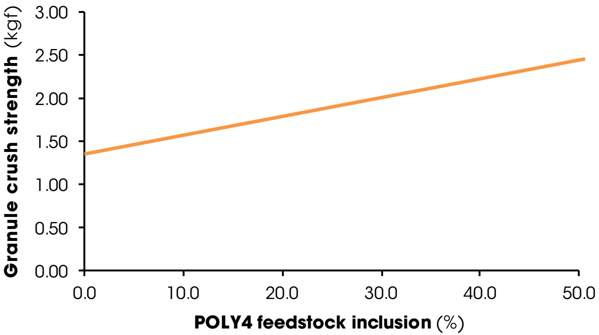
* Genstat regression data

Crush strength

POLY4 also had a positive impact on crush strength in urea-based NPKs.

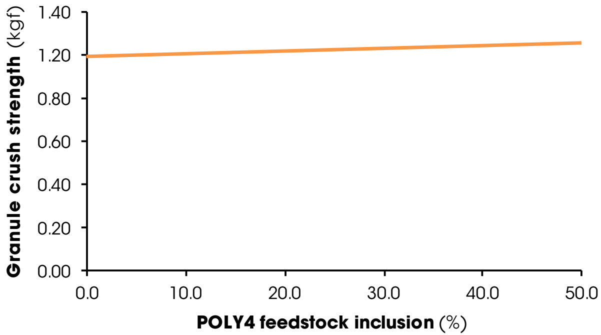
The substitution of POLY4 inclusion rates did not impact granule crush strength in AN-based NPKs.

Urea-based steam-granulated compounds*



* Genstat regression data

AN-based steam-granulated compounds*

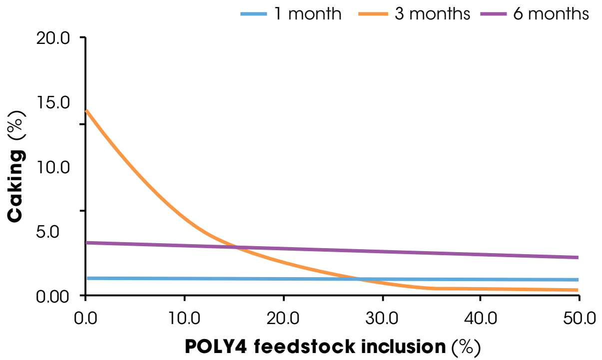


* Genstat regression data

Caking tendency

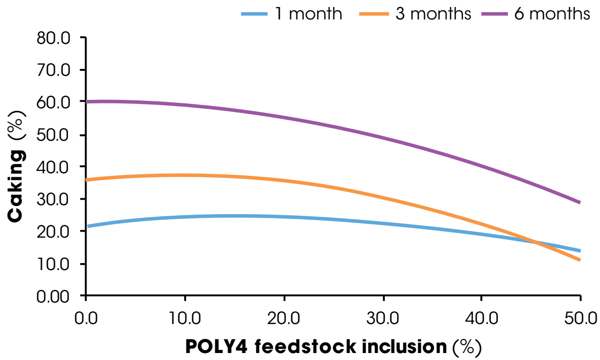
After one month, there was little difference in caking tendency amongst products. However, by three months the value of POLY4 was evident. After three months, the smallest inclusion of POLY4 supported a significant reduction in losses due to caking in both urea-based and AN-based NPKs.

Urea-based steam-granulated compounds*



* Genstat regression data

AN-based steam-granulated compounds*



* Genstat regression data

Phosphorus in POLY4 steam-granulated NPKs

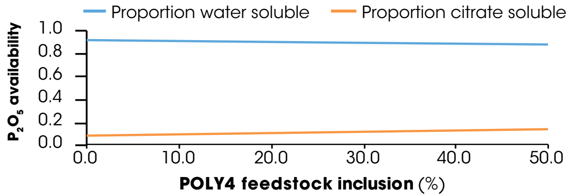
Reactive calcium (Ca) and phosphorus (P) can form dicalcium phosphate, which is known to have a low solubility.

A selection of a better grade phosphate rock is important to assure a desirable calcium to phosphorus ratio. Steam and chemical processes that use phosphate rock to make compounds must consider the Ca content.

IFDC analysed both urea-based and AN-based final products for water and citrate soluble phosphate (P_2O_5).[10] Inclusion of POLY4 showed only a small change from water soluble to citrate soluble forms of P_2O_5: 5% for the urea compound and 11% for the AN compound. Even at the highest POLY4 feedstock inclusion rate, 87% of P_2O_5 was available in a water-soluble form in urea-based and 86% in AN-based NPKs. Therefore, use of POLY4 successfully introduces calcium into NPKs without inhibiting P availability.

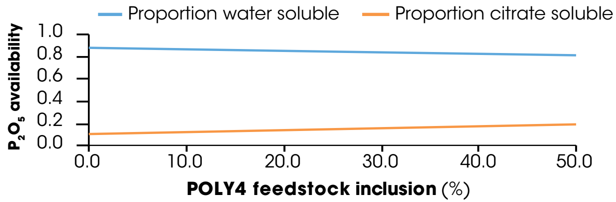
Plants access P in water-soluble form. Manufacturing NPKs with products that contain Ca could restrict water soluble phosphorous. Testing showed that inclusion of POLY4 in the granulation had a minimum impact on P_2O_5 availability: see water soluble trend lines in graphs. The citrate soluble trend line demonstrates that P has not been lost as part of the manufacturing process.

Steam-granulated urea-based compounds*



* Genstat regression data

Steam-granulated AN-based compounds*



* Genstat regression data

POLY4 CHEMICAL GRANULATION

Chemical granulation is the most complex method for preparing granular NPKs. Chemical granulation is similar to steam granulation, except that most of the liquid phase is generated by the reaction of ammonia with phosphoric, sulphuric and/or nitric acid. It is also possible to use a concentrated urea solution or ammonia nitrate. Some processes use a reaction between ammonia and single or triple superphosphate (SSP or TSP).

Much of the ammonia-acid reaction is performed outside the granulator in a pre-neutraliser or pipe reactor. Water, steam or scrubber liquor can be fed into the granulator to optimise the granulation process. In most NPK plants, a significant amount of solid raw materials is also used, and so granules are formed by agglomeration. Factors which determine the ratio of solid and liquid inputs are:

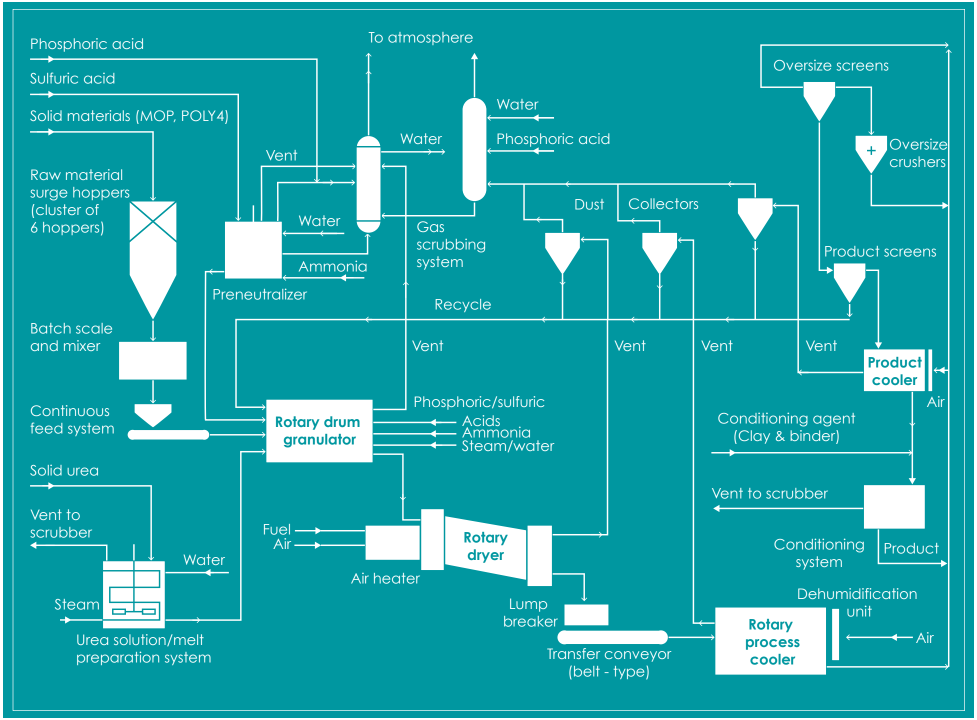
- NPK grade and nutrient solubility requirements;
- Liquid phase needs in granulation;
- Reaction to temperature and its limitations;
- Physical plant design, namely openings and apertures in the plant.

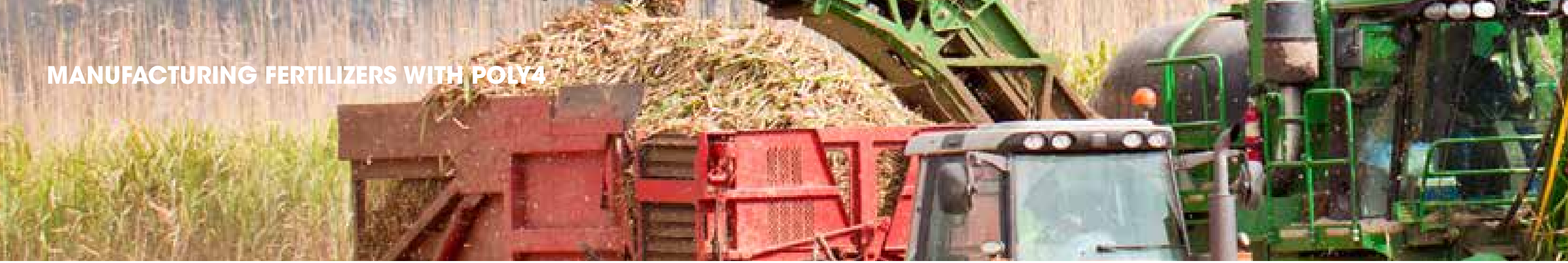
In some chemical granulations, the solid raw material such as MOP is partially dissolved in ammonium phosphate and/or ammonium nitrate slurry, which is then sprayed into a heated rotary drum. In such a process, granules are formed by the gradual accumulation of additional layers also known as accretion.

To test POLY4 compatibility, IFDC configured a small-scale granulation pilot plant to simulate a commercial process scenario. Merchant grade phosphoric acid and ammonia were fed to a pre- neutraliser to produce an ammonia phosphate slurry. The ammonium phosphate (NH_4:H_3PO_4) ratio was 1.5 to 1. The slurry was pumped to a drum granulator where more ammonia was introduced under the rolling bed of fertilizer material to elevate that NH_4:H_3PO_4 ratio to >1.8. In addition to the slurry and ammonia, urea or AN, MOP and POLY, water and recycled material were fed into the granulator. The discharge was then fed to a co-current rotary drier and cooled in a co-current rotary cooler before grading.

To determine physical properties of urea-based and AN-based NPK compounds including size analysis, granule crush strength, abrasion resistance, dustiness of product, CRH and moisture absorption penetration, IFDC undertook the chemical granulation process using two series of NPK fertilizer grades (urea-DAP-KCl-POLY4 for urea-based and AN-phosphate rock-KCl-POLY4 for AN-based NPKs).

Typical NPK fertilizer chemical granulation plant





Urea-based chemically-granulated NPK compounds: testing results[11]

Targeted grade	27:14:14	24:12:12	20:10:10	16:8:8
Targeted POLY4 feedstock content (%)	0.0	13.8	35.8	50.9
Physical properties				
Size analysis (cumulative percentage retained on screen)				
4.00mm	0.0	0.0	0.0	0.0
3.35mm	5.7	1.5	0.3	0.7
2.80mm	30.7	8.4	2.8	3.3
2.36mm	69.2	34.7	34.1	18.0
2.00mm	96.9	91.8	92.6	80.9
1.70mm	99.6	99.3	99.4	97.4
Granule crushing strength (-2.80mm +2.36mm fraction)				
Average (kg/granule)	1.62	1.19	1.77	1.96
Range (kg/granule)	0.95-2.45	0.85-1.6	1.1-2.85	1.2-3.65
Abrasion resistance (% degradation)	3.16	3.50	1.24	2.01
Impact resistance (% shattered granules)	1.99	1.29	2.73	1.61

Urea-based chemically-granulated NPK compounds: testing results... continued[11]

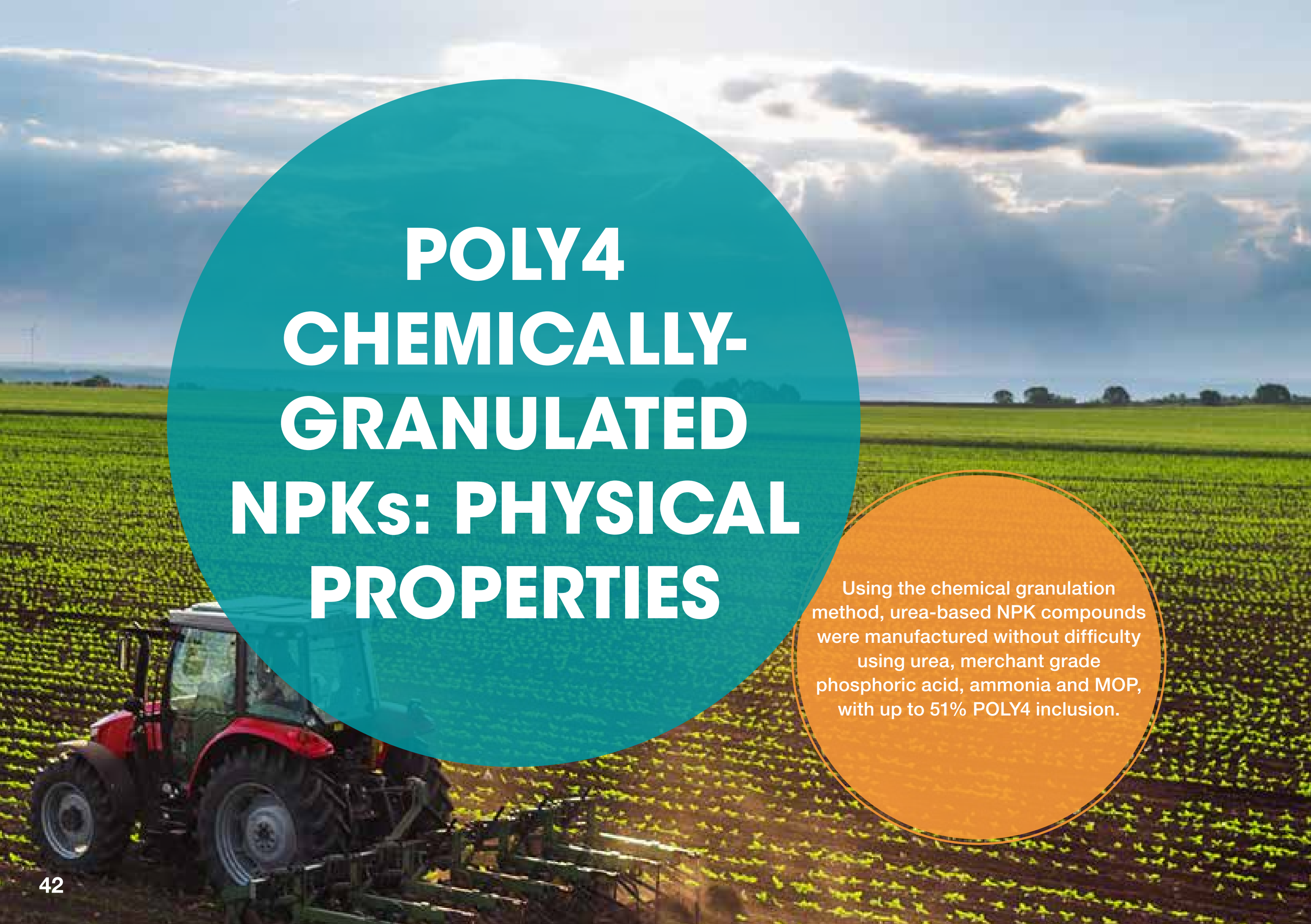
Targeted grade	27:14:14	24:12:12	20:10:10	16:8:8
Targeted POLY4 feedstock content (%)	0.0	13.8	35.8	50.9
Physical properties				
Dustiness of product (mg kg^{-1} of product)	1,370	1,611	865	1,201
Critical relative humidity (CRH) (%)	55-60	55-60	60-65	60-65
Moisture absorption-penetration (72 hours @ 30°C, 80% RH)				
Moisture absorption (mg/cm^2)	629.3	527.5	476.4	424.2
Moisture penetration (cm)	10.8	9.1	6.8	5.1
Moisture holding capacity (mg/cm^3)	58.4	59.1	70.1	87.6
Moisture holding capacity (%)	7.1	7.0	7.0	8.6
Granule integrity (wet)	poor	poor	fair	fair
Caking 1 month	0.3	0	0	0
Caking 3 months	0	0	0	0

AN-based chemically-granulated NPK compounds: testing results[11]

Targeted grade	18:18:18	17:17:17	14:14:14	10:10:10
Targeted POLY4 feedstock content (%)	0.0	3.9	25.9	52.6
Physical properties				
Size analysis (cumulative percentage retained on screen)				
4.00mm	0.1	0.3	0.2	0.1
3.35mm	12.8	11.8	15.2	8.6
2.80mm	50.6	48.3	57.7	43.4
2.36mm	80.6	80.8	88.5	82.1
2.00mm	97.3	94.9	98.9	98.7
1.70mm	99.4	96.8	99.7	99.8
Granule crushing strength (-2.80mm +2.36mm fraction)				
Average (kg/granule)	3.55	1.77	2.26	3.02
Range (kg/granule)	1.9-6.55	1-2.55	1.05-3.75	1.55-6.3
Abrasion resistance (% degradation)	2.42	5.96	1.15	0.38
Impact resistance (% shattered granules)	1.73	3.26	4.57	1.15

AN-based chemically-granulated NPK compounds: testing results... continued[11]

Targeted grade	18:18:18	17:17:17	14:14:14	10:10:10
Targeted POLY4 feedstock content (%)	0.0	3.9	25.9	52.6
Physical properties				
Dustiness of product (mg kg^{-1} of product)	1,982	6,318	1,747	354
Critical relative humidity (CRH) (%)	60-65	65-70	65-70	65-70
Moisture absorption-penetration (72 hours @ 30°C, 80% RH)				
Moisture absorption (mg/cm^2)	383.1	328.8	348.8	360.9
Moisture penetration (cm)	5.6	4.8	5.3	5.4
Moisture holding capacity (mg/cm^3)	67.7	68.1	66.6	67.6
Moisture holding capacity (%)	7.6	8.3	6.5	5.9
Granule integrity (wet)	poor	poor	fair	fair
Caking 1 month	0	0	0.3	0
Caking 3 months	0	0	0	0
Caking 6 months	26.1	28.3	17.8	5.6



POLY4 CHEMICALLY-GRANULATED NPKs: PHYSICAL PROPERTIES

Using the chemical granulation method, urea-based NPK compounds were manufactured without difficulty using urea, merchant grade phosphoric acid, ammonia and MOP, with up to 51% POLY4 inclusion.

There was a small but positive enhancement of abrasion resistance with the addition of higher POLY4 inclusion rates. There was also a positive improvement in granule crush strength and dust reduction with the addition of higher POLY4 inclusion rates. The impact resistance was not affected with the addition of POLY4. However, the moisture absorption and penetration characteristics improved with POLY4 – the greater the POLY4 content, the lower the amount of moisture that was absorbed per unit area.

By means of the chemical granulation method, AN-based NPK compounds were manufactured without difficulty using AN, merchant grade phosphoric acid, ammonia and MOP with up to 53% POLY4.

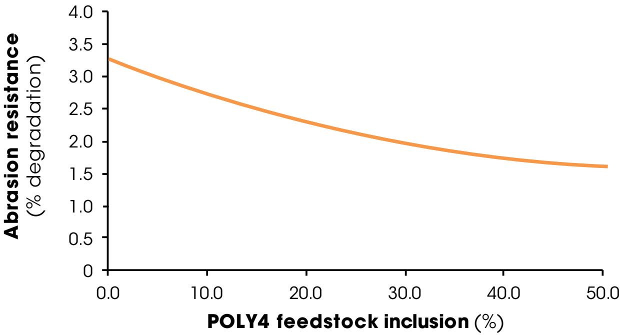
POLY4 inclusion did not affect granule crush strength and impact resistance characteristics, although a small positive trend was seen. Inclusion of POLY4 improved abrasion resistance. With an increase in POLY4 inclusion rates, a significant reduction of dust occurrence was present in AN-based chemically-granulated NPKs. The moisture absorption and penetration characteristics with the percentage of POLY4 were unaffected.

Caking was observed in both the urea-based and AN-based NPK products after a storage period of six months. Testing showed that increased POLY4 inclusion rates reduced the tendency for caking.

Abrasion resistance

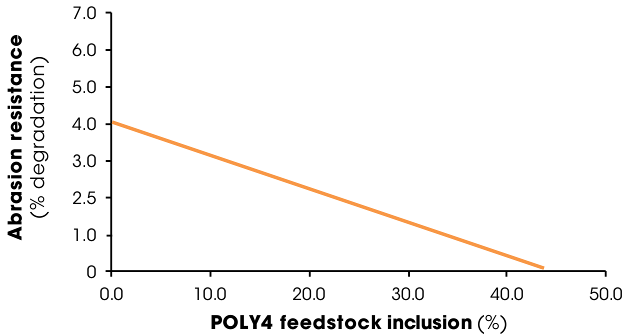
The actual testing results using real data showed that with an increase of POLY4 inclusion rates, the abrasion resistance of both urea-based and AN-based NPKs was significantly improved.

Urea-based chemically-granulated compounds*



* Genstat regression data

AN-based chemically-granulated compounds*

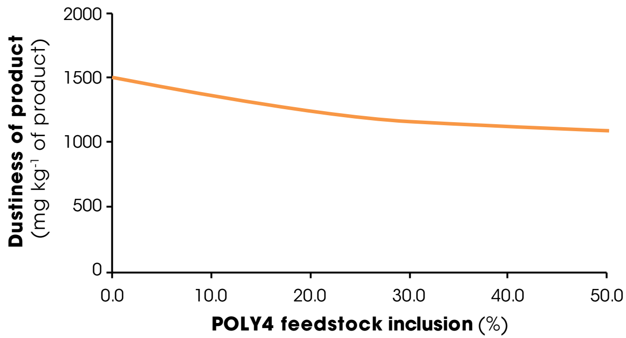


* Genstat regression data

Dust occurrence

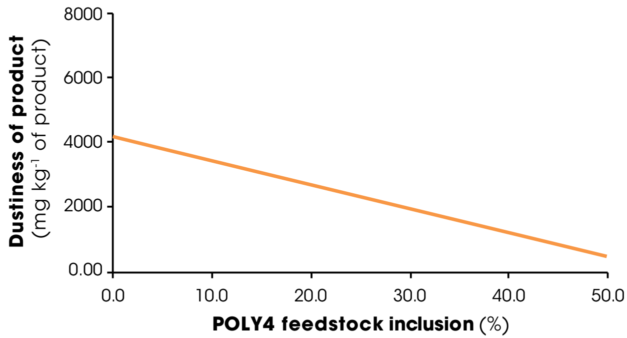
With the addition of higher POLY4 inclusion rates, there was a positive reduction in dust occurrence in both urea-based and AN-based chemically-granulated NPKs.

Urea-based chemically-granulated compounds*



* Genstat regression data

AN-based chemically-granulated compounds*

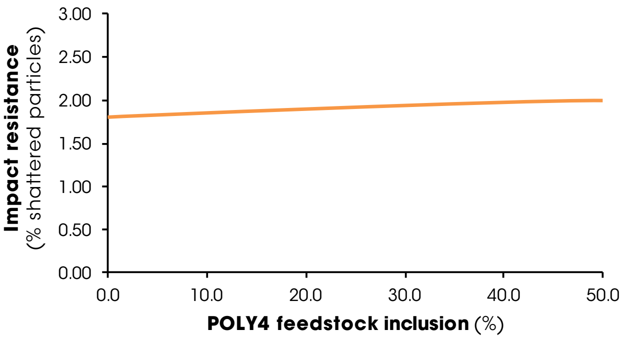


* Genstat regression data

Impact resistance

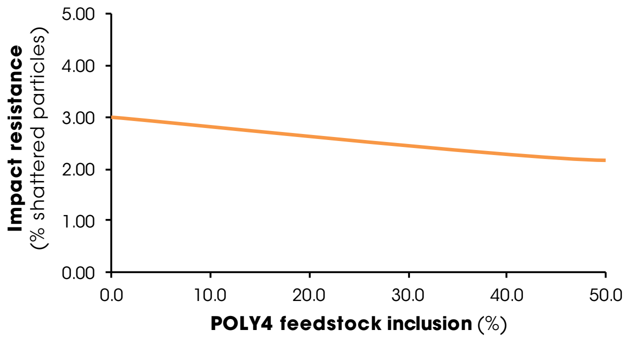
The actual testing results using real data showed that the impact resistance was not affected with the addition of POLY4 in both urea-based and AN-based NPKs, although a small positive trend was present in AN-based NPKs.

Urea-based chemically-granulated compounds*

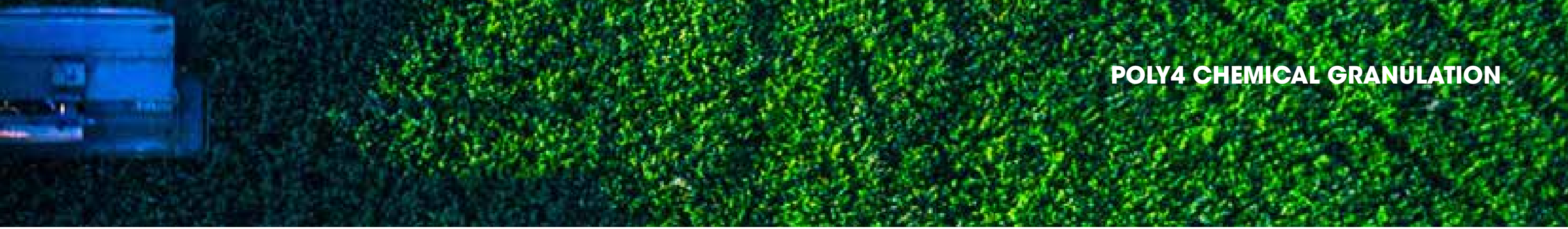


* Genstat regression data

AN-based chemically-granulated compounds*



* Genstat regression data

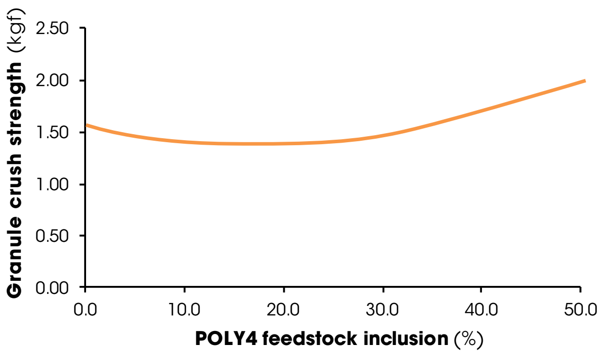


Crush strength

The actual testing results using real data showed that there was a positive improvement in granule crush strength of urea-based NPKs with the addition of higher POLY4 inclusion rates.

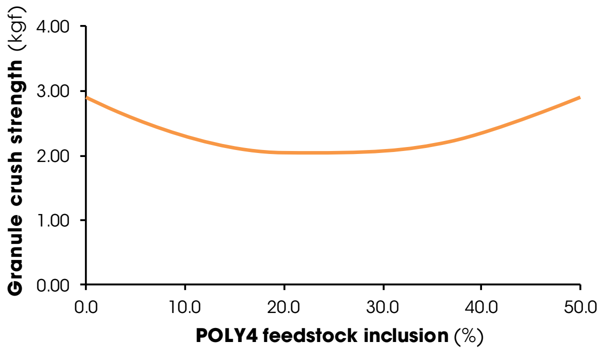
POLY4 inclusion did not affect granule crush strength of AN-based NPKs, although showed a small positive trend.

Urea-based chemically-granulated compounds*



* Genstat regression data

AN-based chemically-granulated compounds*



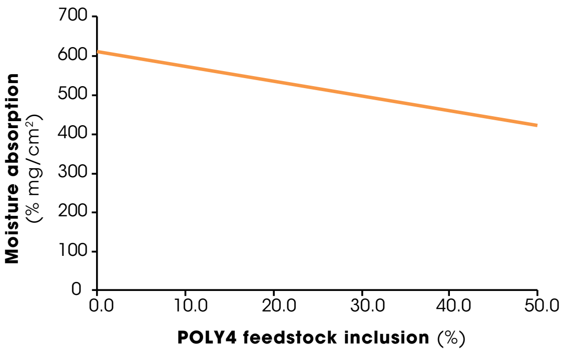
* Genstat regression data

Moisture absorption

The moisture absorption characteristic improved with addition of POLY4 in urea-based NPKs – the greater the POLY4 content, the lower the amount of moisture that was absorbed per unit area.

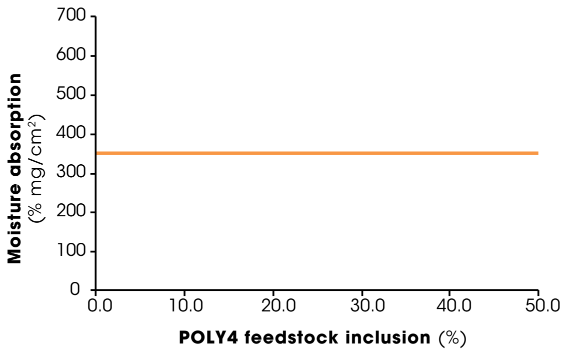
The moisture absorption of AN-based NPKs with the percentage of POLY4 was unaffected.

Urea-based chemically-granulated compounds*



* Genstat regression data

AN-based chemically-granulated compounds*

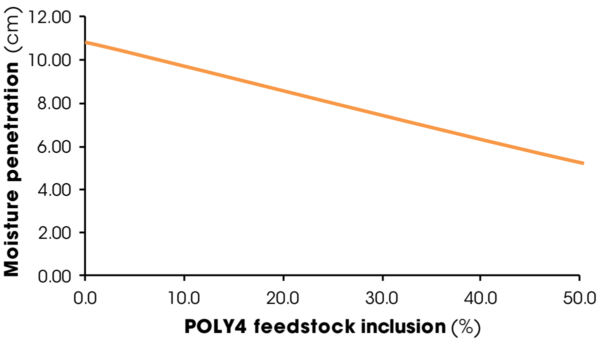


* Genstat regression data

Moisture penetration

The moisture penetration improved with addition of POLY4 in urea-based NPKs – the greater the POLY4 content, the lower the amount of moisture that was absorbed per unit area.

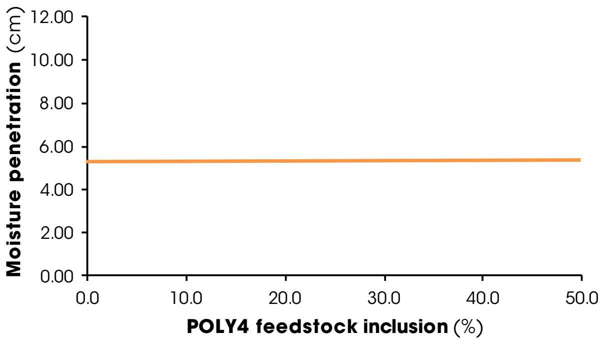
Urea-based chemically-granulated compounds*



* Genstat regression data

The moisture penetration of AN-based NPKs with the percentage of POLY4 was unaffected.

AN-based chemically-granulated compounds*

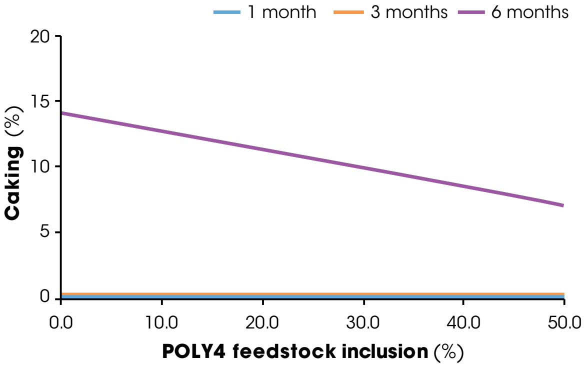


* Genstat regression data

Caking tendency

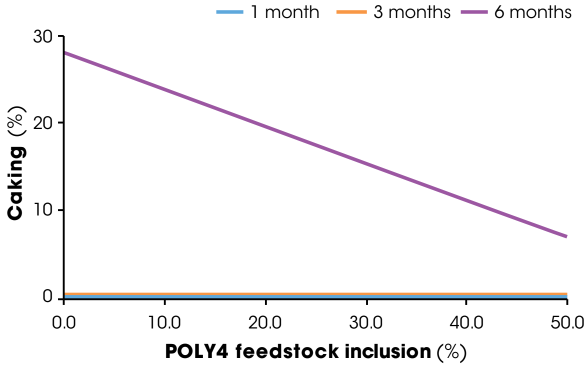
Caking was observed in both the urea-based and AN-based NPK products after a storage period of six months. Testing showed that increased POLY4 inclusion rates reduced the tendency for caking.

Urea-based steam-granulated compounds*



* Genstat regression data

AN-based steam-granulated compounds*



* Genstat regression data

Phosphorus in POLY4 chemically-granulated NPKs

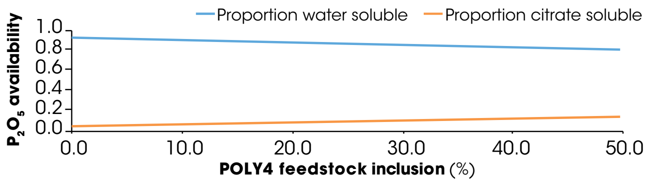
Reactive calcium (Ca) and phosphorus (P) can form dicalcium phosphate, which is known to have a low solubility. POLY4 contains Ca yet testing showed that P availability was not impaired.

A selection of a better grade phosphate rock is important to assure a desirable calcium to phosphorus ratio. Steam and chemical processes that use phosphate rock to make compounds must consider the Ca content.

IFDC analysed both urea-based and AN-based final products for water and citrate soluble phosphate (P_2O_5).[12] Inclusion of POLY4 showed only a small change from water soluble to citrate soluble forms of P_2O_5: 5% for the urea compound and 9% for the AN compound. Even at the highest POLY4 feedstock inclusion rate, 89% of P_2O_5 was available in a water-soluble form in urea-based and 83% in AN-based NPKs. Therefore, use of POLY4 successfully introduces calcium into NPKs without inhibiting P availability.

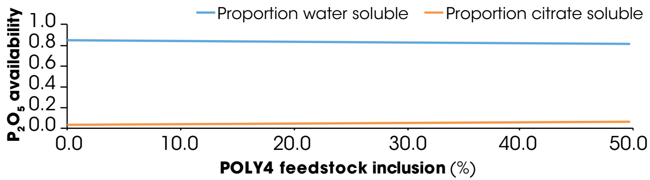
Plants access P in water-soluble form. Manufacturing NPKs with products that contain Ca could restrict water soluble phosphorous. Testing showed that inclusion of POLY4 in the granulation had a minimum impact on P_2O_5 availability: see water soluble trend lines in graphs. The citrate soluble trend line demonstrates that P has not been lost as part of the manufacturing process.

Chemically-granulated urea-based compounds*



* Genstat regression data

Chemically-granulated AN-based compounds*



* Genstat regression data

SPREADING

Solid fertilizers are commonly applied mechanically. A poorly set up spreader can have significant costs to a farmer. Machine calibration should be undertaken at least once a year. Disc speed, machine pitch angle, bout width and wind can have large impacts on the evenness of spreading, known as the spread pattern.

Fertilizer application rates remain valid if farmers can maintain a required level of accuracy. A coefficient of variation (CV) of more than 20% generates stripes in the crop. A lower CV means a more even distribution of fertilizer. Uneven spreading increases the cost of crop production due to yield penalties and required corrective actions.

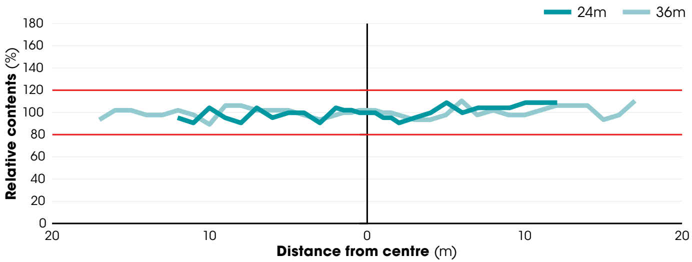
The quality of the fertilizer product also has a big impact on spreading. The main segregation-inducing properties are particle size, particle density and particle shape.[13] Angle of repose, particle resistance and friction coefficient have also been related to segregation.[14] Low quality products have inconsistent particle size which affects the spreadability of fertilizer. Poor spreading can cause the fertilizer to fail to conform to its declared nutrient content. Irregular field distribution also causes patchy crop growth.

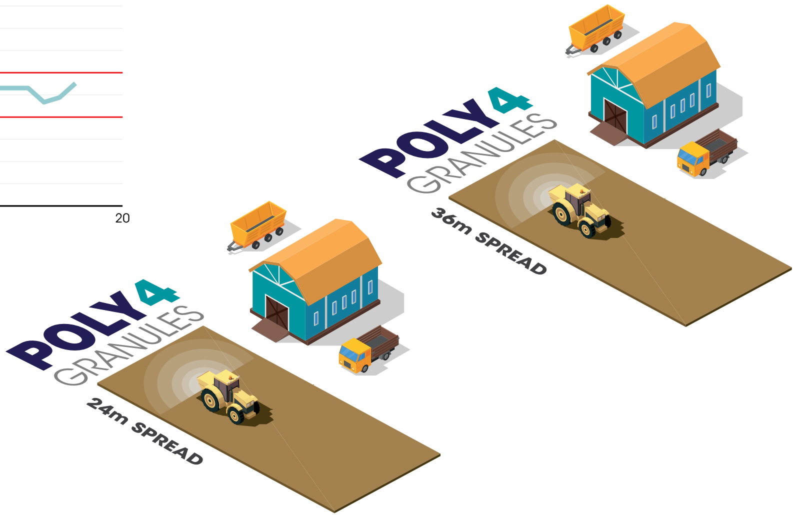
Spreading — straight POLY4 granules

The physical properties of the POLY4 granule and spreading patterns alone and in dry blend mixtures were examined. POLY4 granules were tested using spreading machinery set to spreading bout widths of 24m and 36m, typical distances for fertilizer application.

The straight POLY4 granules spreader testing graphs show the results to be within the 20% CV tolerance limits. POLY4's quality spread pattern reduces the risk of expensive corrective action.

Straight POLY4 granules testing[15]

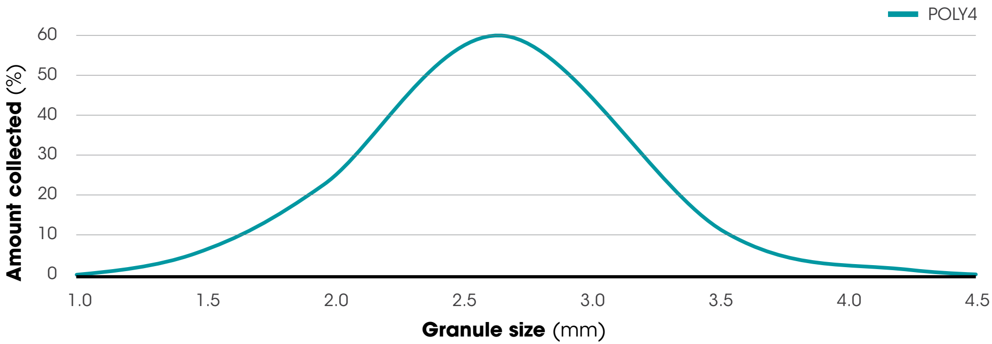




Spreading — particle size distribution

POLY4 granules were tested for particle size distribution. Consistent particle size is important to assist with distribution by mechanical application. The particle size distribution graph below shows the testing result. POLY4 granules are graded from 2mm to 4mm in diameter. 92 per cent of POLY4 granules were within this particle size specification.

Particle size distribution[16,17]



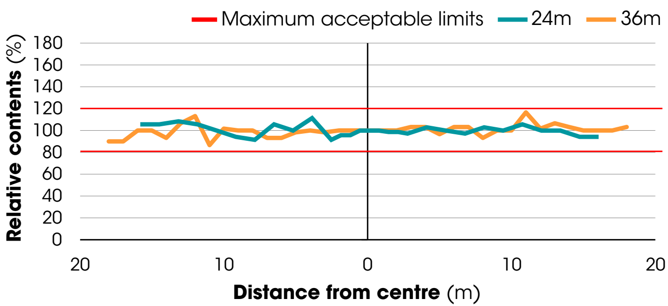
Spreading — blends

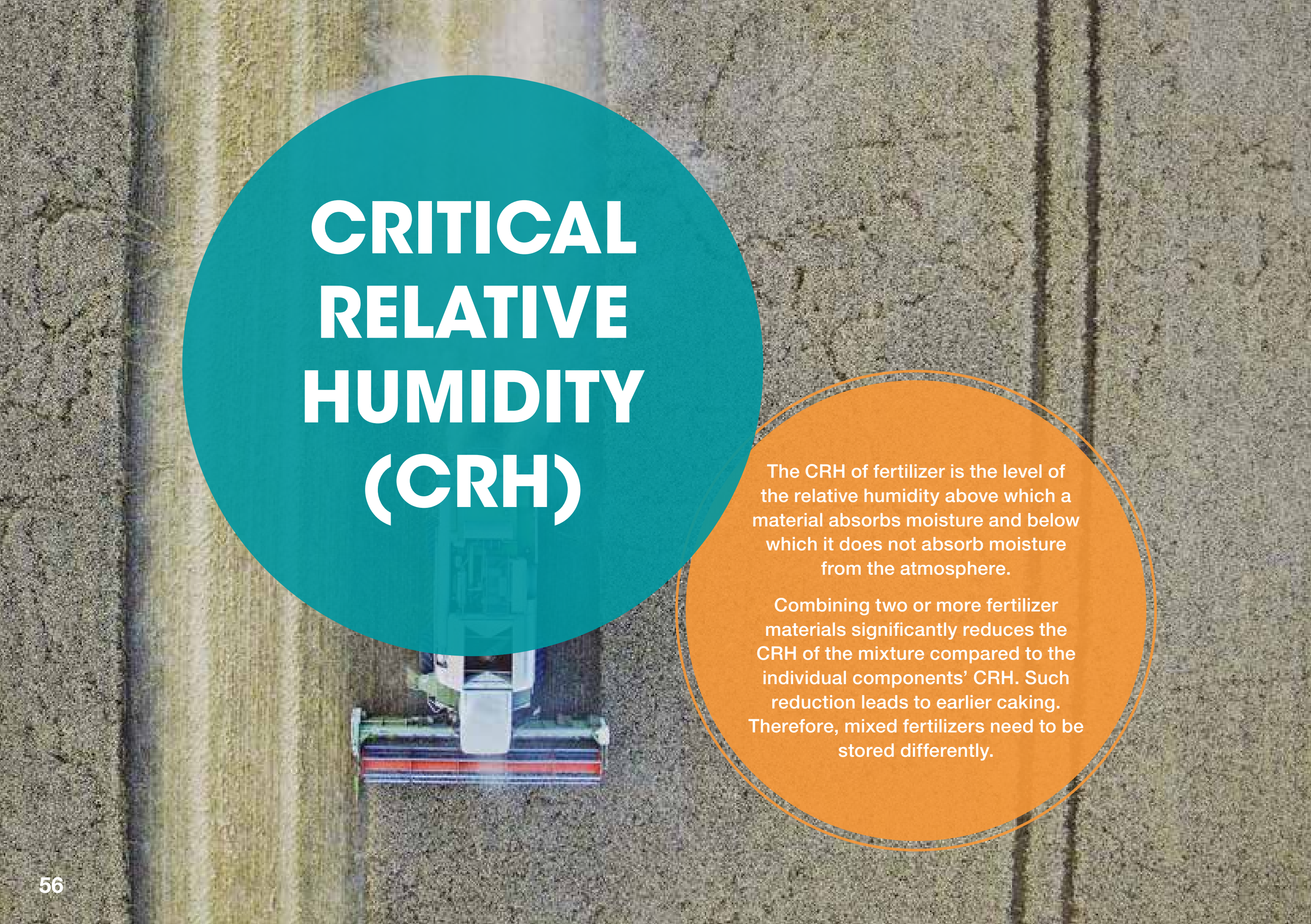
Spread patterns in 20:10:10 POLY4 blends across 24m and 36m bout widths were also examined.

20:10:10 POLY4 blends testing[18]

Blend	Granules	Spreader bout width	CV
20:10:10	2mm-4mm	24m	5.03%
20:10:10	2mm-4mm	36m	5.52%
20:10:10	2mm-4mm	24m	7.82%
20:10:10	2mm-4mm	36m	6.4%

24m and 36m spread pattern[18]





CRITICAL RELATIVE HUMIDITY (CRH)

The CRH of fertilizer is the level of the relative humidity above which a material absorbs moisture and below which it does not absorb moisture from the atmosphere.

Combining two or more fertilizer materials significantly reduces the CRH of the mixture compared to the individual components' CRH. Such reduction leads to earlier caking. Therefore, mixed fertilizers need to be stored differently.

CRH determinations were performed on 50:50 mixtures of NPK bulk blends. The testing was conducted on products in both granular and powdered forms.[19] Minimal differences were encountered between granular and powder 50:50 mixtures. Conditioners or coating agents increased CRH by 5%. The lowest CRH percentage was found with ammonium nitrate, which is consistent with the accelerated caking test results (see *Compatibility in blends* on page 9).

CRH values for 50:50 mixtures

Sample	CRH
POLY4:urea — granular	70-75%
POLY4:urea — powder	70-75%
POLY4:AN — granular	55-60%
POLY4:AN — powder	50-55%
POLY4:DAP — granular	75-80%
POLY4:DAP — powder	70-75%
POLY4:phosphate rock — granular	85-90%
POLY4:phosphate rock — powder	80-85%
POLY4:KCl — granular	80-85%
POLY4:KCl — powder	75-80%

CRH — urea NPK bulk blends

A determination of the chemical compatibility, when producing the following NPK grades, was undertaken on urea, diammonium phosphate (DAP), potassium chloride (KCl) and POLY4.

Urea bulk blend compositions

Nutrient ratio	Grade	Material (% w/w g/100g)			
		Urea	DAP	KCl	POLY4
2:1:1	27:14:14	47.57	29.51	22.92	0.00
	24:12:12	42.49	26.36	17.34	13.81
	20:10:10	34.39	21.34	8.44	35.83
	16:8:8	28.86	17.91	2.36	50.87

Upon completion of the testing, all four of the urea-based NPK bulk blends were compatible. The 16:8:8 grade was found to be particularly robust. The table provides the CRH testing results of urea-based NPK bulk blends. Increasing POLY4 content from 0 to 51%, with consequential reduction of potassium chloride content from 23 to 0%, had no effect on CRH. A significant impact of coating/conditioning agents can be seen (results of granular product series).

CRH of the urea NPK bulk blends

Sample	CRH
27:14:14 — granular	70-75%
27:14:14 — powder	50-55%
24:12:12 — granular	70-75%
24:12:12 — powder	50-55%
20:10:10 — granular	75-75%
20:10:10 — powder	50-55%
16:8:8 — granular	70-75%
16:8:8 — powder	50-55%

CRH — ammonium nitrate NPK bulk blends

The chemical compatibility of the NPK grades was determined on ammonium nitrate (AN), phosphate rock, potassium chloride (KCl) and POLY4.

AN bulk blend compositions

Nutrient ratio	Grade	Material (% w/w g/100g)			
		AN	Phosphate rock	KCl	POLY4
1:1:1	13:13:13	36.80	42.29	20.91	0.00
	12:12:12	35.68	41.00	19.38	3.95
	10:10:10	29.44	33.83	10.85	25.88
	7:7:7	21.83	25.08	0.46	52.63

After the 30-day accelerated testing of the AN-based NPK bulk blends, some ammonia could be detected, and so additional testing was conducted to determine the source. Six 50:50 mixtures and two 13:13:13 grades were evaluated for chemical compatibility: granular AN/phosphate rock, prilled AN/phosphate rock, granular AN/KCl, prilled AN/KCl, granular AN/POLY4, AN/POLY4, 13:13:13 using granular AN and 13:13:13 using prilled AN. The additional chemical compatibility testing showed that phosphate rock-AN mixture generated the ammonia, whereas POLY4 did not.

The table below provides the CRH testing results of AN-blends. Increasing POLY4 content from 0 to 53%, with consequential reduction of potassium chloride content from 18 to 0%, did not affect CRH.

CRH of the AN NPK bulk blends

Sample	CRH
13:13:13 — granular	65-70%
13:13:13 — powder	60-65%
12:12:12 — granular	65-70%
12:12:12 — powder	60-65%
10:10:10 — granular	65-70%
10:10:10 — powder	55-60%
7:7:7 — granular	65-70%
7:7:7 — powder	55-60%

NOTES

Page 2 1) United Nations, Department of Economic and Social Affairs, Population Division (2017) World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. Working Paper No. ESA/P/WP/248; 2) FAO (2015) Current fertilizer trends and outlook to 2018 http://www.fao.org/3/a-i4324e.pdf (accessed 18 February 2018).

Page 8 3) IFDC methodology ratifies methods of Walker et al (1998) and published findings of Albadarin et al (2017); 4) In accordance with the Manual for Determining Physical Properties of Fertilizer (IFDC–R-10).

Page 9 5) EFMA, 2006; 6) Sources: 66000-IFDC- 60010-17; 32000-LIM-32011-15; 7) Compatible means dry and free-flowing; reduced compatibility means damp and free-flowing to damp and non-flowing; incompatible means wet and non-flowing.

Page 12 to 15 8) Physical properties were determined according to the IFDC procedures S-107, S-115, S-116, S-118, S-122, S-101 and S-100 described in Manual for Determining Physical Properties of Fertilizer (IFDC–R-10).

Page 24 to 27 9) Physical properties were determined according to the IFDC procedures S-107, S-115, S-116, S-118, S-122, S-101 and S-100 described in Manual for Determining Physical Properties of Fertilizer (IFDC–R-10).

Page 35 10) According to the AOAC International methods.

Page 38 to 41 11) Physical properties were determined according to the IFDC procedures S-107, S-115, S-116, S-118, S-122, S-101 and S-100 described in Manual for Determining Physical Properties of Fertilizer (IFDC–R-10).

Page 51 12) According to the AOAC International methods.

Page 52 13) Hoffmeister et al., 1964; Johanson, 1978; Williams, 1976 and 1990; 14) Williams, 1976; Carson and Marinelli, 1994.

Page 53 15) SCS, Spreader & Sprayer Testing Ltd. (UK), 2013.

Page 54 16) Genstat means; 17) Novochem (2016) results based on shaker plate sieve analysis.

Page 55 18) SCS, Spreader & Sprayer Testing Ltd. (UK), 2013.

Page 57 19) CRH testing was performed according to procedure IFDC S-101 described in the Manual for Determining Physical Properties of Fertilizer (IFDC—R-10).

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