Knowledge grows

Reasons for Choosing Nitrates over Urea

The purpose of this publication is to describe the role and importance of nitrogen to arable crops and review the best sources available to British farmers.

Before fertilizer types are compared it is necessary to review the sources available and the forms best utilised by plants.

Contents

The following issues will be covered:

- Significantly increased yields from nitrates over urea in the most recent independent study.
- Higher nitrogen efficiency as a result of ammonium nitrate supplying nitrogen in immediately plant available forms.
- Lower nitrogen losses due to higher ammonia volatilisation from urea.
- Better efficiency of nitrogen uptake and conversion to grain protein from ammonium nitrate than urea.
- Reduced risk of seedling damage due to higher concentration of ammonia from urea.
- Better spread pattern at bout widths greater than 24 metres from heavier ammonium nitrate particles than lighter urea.
- Same quantity of nitrogen in a hopper with ammonium nitrate and urea.
- Lower carbon footprint from abated ammonium nitrate due to significantly lower emissions in the field.

The Importance of Nitrogen to Arable Crops

Nitrogen is critical for plant growth. It is responsible for protein production and as the central component of chlorophyll it is the essential ingredient for photosynthesis. It's also the key to achieving high yields, and this contributes to making it one of the highest returning inputs in arable production systems. For arable crops nitrogen typically returns between £2.50 and £4.00 for every £1 spent.

Deficiency Symptoms

Crops that are deficient in nitrogen generally appear stunted, with leaves becoming pale or yellow. This can be seen on the older leaves first as nitrogen is very mobile within plants. Plants may also have smaller and fewer leaves, reaching maturity earlier than plants with an adequate supply.

Natural nitrogen supply is reduced on light or sandy soils especially those low in organic matter as it is readily leached. High rainfall will also lead to increased leaching. Restricted root growth as a result of poor soil conditions, drought or damage from pests and diseases will reduce the plants ability to take up nitrogen.

Deficiencies, especially moderate ones, can be difficult to identify visually within a field. Yara's CheckIT app for smartphones provides a library of images to help identify the visual symptoms of nutritional deficiencies.

Nitrogen Recommendations

The majority of arable crops require a combination of soil nitrogen and additional fertiliser nitrogen to meet their full demand and reach the optimum yield. Recommendations are based on assessing the level of nitrogen supplied by the soil as a result of the soil type and previous crop to calculate the amount of additional nitrogen required.

For those farming within Nitrate Vulnerable Zones, additional measures are required to ensure that maximum nitrogen applications by crop type, Nmax limits, are not exceeded. Where these Nmax limits are restrictive, nitrogen source plays an important role, as a less efficient form of nitrogen could result in yield penalties from an under supply of nitrogen.

Yara has a range of tools available to help with nitrogen recommendations, including:

Yara N-Plan - a field-specific nitrogen recommendation tool based on previous cropping, soil type, rainfall, crop type and variety.

Yara N-Tester - a handheld non-destructive measuring device for assessing the level of chlorophyll in leaves to fine tune nitrogen recommendations later in the season.

Yara N-Sensor - a tractor mounted sensor for variably applying nitrogen in real-time according to the crops requirements.

Yara ImageIT - a smartphone app to provide nitrogen recommendations for oilseed crops based on nitrogen uptake assessed through images of the crop taken using the phone's built-in camera.

Sources of Nitrogen - Evaluation of Nitrogen Sources in the Soil

Although nitrogen constitutes nearly 80% of the earth's atmosphere, only leguminous crops e.g. peas and beans can utilise nitrogen in this form. All other arable crops access their nitrogen requirements from the soil.

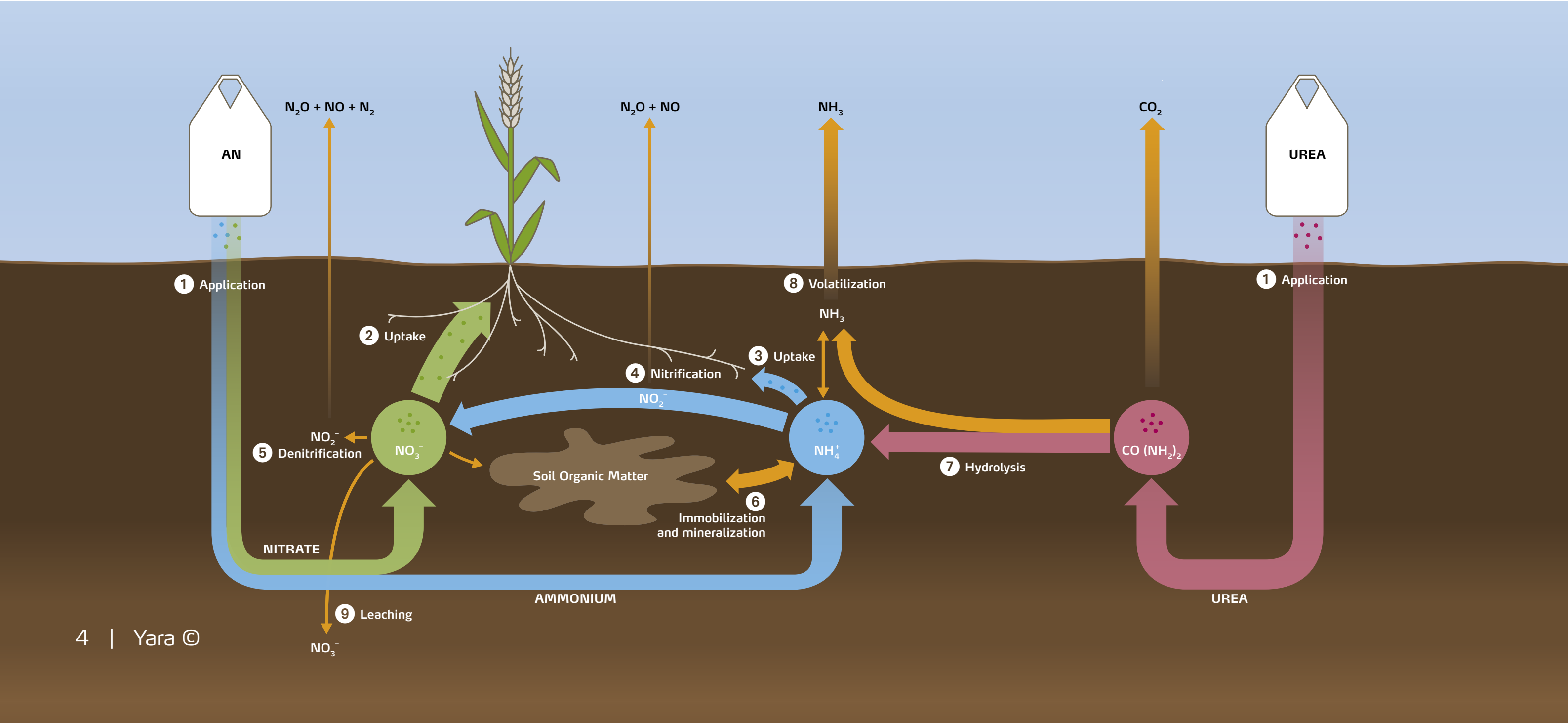
The soil contains a significant amount of nitrogen but this is largely present in complex organic forms unavailable to plants. These are slowly converted to nitrate which will be absorbed by plants. The quantity of this natural nitrogen supply varies considerably with different soils and climates. On average between 50 and 100 kg N per hectare per year is supplied in arable soils - mainly from the breakdown of organic matter and deposition from the atmosphere.

There are three forms of nitrogen in the soil:

1. **Organic-N** is held in plant and animal residues and the various insects, bacteria and fungi in the soil. It is not available to plants until it has been converted to mineral (ammonium and nitrate) forms
2. **Ammonium-N** is a positively charged ion (cation) and is therefore attracted to negatively-charged soil particles. It is held as an exchangeable cation in soil and does not easily leach.
3. **Nitrate-N** is a negatively-charged anion and is repelled by negatively charged soil colloids. Nitrate salts are highly soluble, so nitrate moves with soil water and can be easily leached through soil.

The majority (about 95%) of soil nitrogen is in the organic form, as part of soil organic matter. Although this nitrogen is unavailable to plants in this form, it is easily converted to available forms through a process called mineralisation. This occurs as micro-organisms decompose organic materials for their energy supply, whilst surplus nitrogen is converted to the inorganic ammonium and nitrate forms. If the organic material is high in carbon and low in nitrogen, the micro-organisms will consume mineral nitrogen through a process called immobilisation. These two processes can occur simultaneously in the soil, however the rate of mineralisation is usually faster than immobilisation, creating a pool of available nitrogen.

Figure 1. Graphic to show how plants absorb nitrogen in the nitrate and ammonium forms (directly available from ammonium nitrate fertilizers) and the transformations required from applications of urea fertilizer



Ammonium is the first product of mineralisation of organic nitrogen. Under conditions that favour plant growth (warm, moist and aerobic soils) ammonium is quickly converted to nitrate (nitrification). Ammonium may accumulate in soils when the nitrification process is limited or completely stopped. This may occur if one or more of the following conditions are met:

- Low soil pH conditions substantially depress microbial NH_4+ oxidation.
- Lack of oxygen (e.g. waterlogged soils).
- Low organic matter (as a source of carbon for bacteria).
- Dry soils.
- Low soil temperature, due to low soil micro-organism activity.

High concentration of ammonium-N in the soil can lead to volatilisation (loss to the atmosphere) of nitrogen as ammonia.

Importance of Nitrates in the Soil

- Low immobilisation of nitrates by soil microbes.
  - ammonium is the preferred nitrogen source for soil microbes
  - immobilised ammonium is not plant available
- No fixation of nitrate at soil particles.
  - the ammonium cation (NH_4^+) can be fixed at clay minerals
  - fixed ammonium is not plant available
- Ammonia formed from ammonium nitrogen can damage seedlings.
  - low NH_3 volatilization losses from nitrates
- Ammonium can be lost to the atmosphere as gaseous ammonia (NH_3).
  - lower N_2O emission from nitrates
- N_2O is a strong greenhouse gas.
- N_2O stems from nitrogen conversion processes in the soil.

Sources of Nitrogen -
Evaluation of the Value of Nitrogen Sources to Plants

Nitrogen is required by plants for chlorophyll synthesis and as part of the chlorophyll molecule is involved in photosynthesis. The green pigment in chlorophyll absorbs energy from sunlight to convert carbon, hydrogen and oxygen to sugars. These sugars are used within the plant for growth and development. A lack of nitrogen reduces the amount of chlorophyll in leaves meaning plants will not utilise sunlight as an energy source and will not therefore reach their full yield potential.

Nitrogen is also an essential component of all amino acids which form plant proteins and has roles in vitamins and energy systems in the plant. Nitrogen uptake is therefore directly responsible for increasing plant protein content.

Plants take up both ammonium and nitrate nitrogen from the soil, whether this is supplied from the conversion of organic nitrogen or through applications of mineral fertilizer.

Role of Ammonium

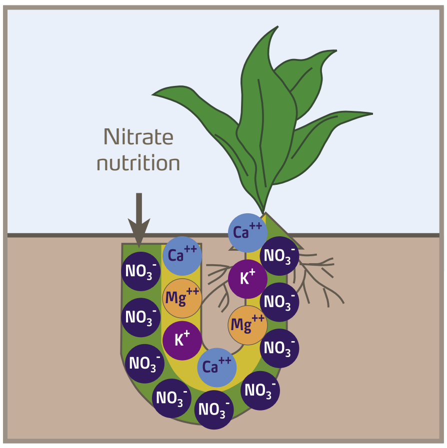
Nitrogen taken up in the ammonium form requires less energy to convert into amino acids in the plant than nitrate, meaning more energy is available for growth or grain formation.

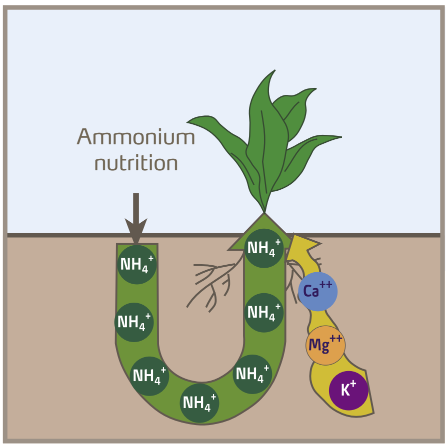
Role of Nitrate

Nitrates improve balanced nutrition as the uptake of nitrate anions enhances cation uptake (including potassium, magnesium, manganese and calcium).

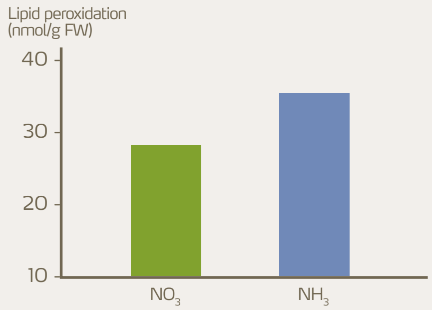
There are also physiological advantages for the plant from nitrate as it is non-toxic to cells, can enhance a plants tolerance to radiation and temperature induced stress and most importantly improves root growth.

Intensive solar radiation can damage the crop. Lipid peroxidation, the impairment of cell walls, is an indicator for plant damage. This has been found to be lower with nitrate grown plants than those where ammonium was the source of nitrogen.





The effect of nitrogen source on lipid peroxidation



Source: Gerendas at al. 1996

Key Benefits of Nitrates to Plants:

- Nitrate is immediately and easily taken up by plants.
  - urea needs conversion
  (urea -> ammonium -> nitrate)
  - always plant available
  (not fixed to soil particles)
- Nitrate improves balanced nutrition.
  - uptake of nitrate anions enhances cation uptake
  (Ca, K, Mg)
- Nitrate has physiological advantages for the plant.
  - nitrate is non-toxic in cells, whereas ammonia (NH_3) is phytotoxic
  - enhanced stress-tolerance with nitrate nutrition
  - improved growth with nitrates

Fertilizer Forms Available to Farmers

There are two main forms of nitrogen used in the UK, these are nitrates (which includes ammonium nitrate, calcium ammonium nitrate, calcium nitrate and urea ammonium nitrate) and urea.

Nitrates

Applications of ammonium nitrate provide nitrogen in ammonium and nitrate forms, which are both readily available for plant uptake. The nitrate is mobile and is therefore immediately and easily taken up by actively growing plants. The ammonium can be fixed onto clay particles in the soil and rapidly undergoes nitrification, converting it to nitrate.

Urea

Urea applied to the soil is unavailable to plants requiring conversion by soil microbes to ammonium and then to nitrate. These processes are mediated by soil bacteria and the rates at which they occur depend on temperature and moisture.

Comparison of Ammonia Losses from Ammonium Nitrate and Urea

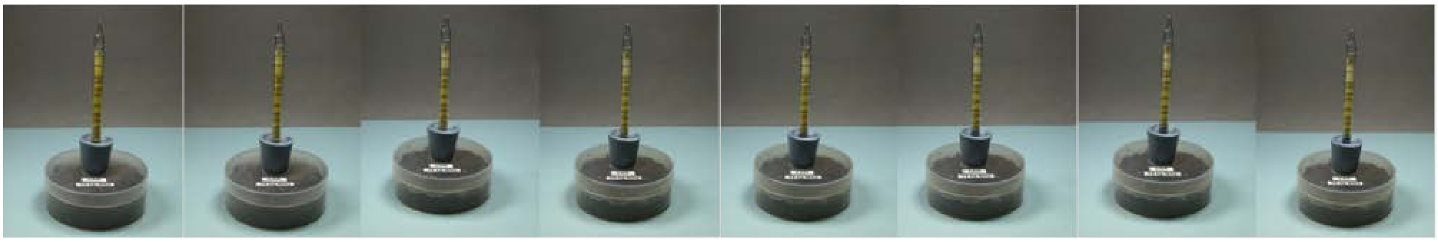
Nutrients are taken up by plant roots in soil solution, therefore any surface applications need to enter the soil solution before being available for uptake. The speed this occurs will depend on a number of factors including the soil surface moisture and rainfall following application. All nitrogen sources that add ammonium-N to the soil, to varying degrees, are at risk of being lost to the atmosphere through a process known as ammonia volatilisation.

Volatilisation is the loss of nitrogen to the atmosphere, usually as ammonia gas. Fertilizer supplying nitrogen in the ammonium (NH_4) or amide form (urea) may be subject to volatilisation loss when surface applied. When urea is applied to the soil it is rapidly converted to ammonia in the presence of adequate moisture, warm temperatures and the enzyme urease. Without sufficient moisture to wash the nitrogen into the soil, this ammonia can be lost to the atmosphere through volatilisation.

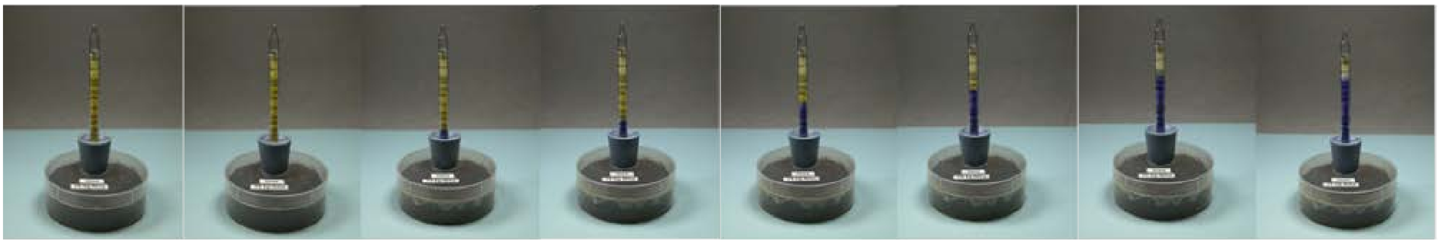
The risk of volatilisation occurring is increased by light rain (or heavy dew) followed by a dry period, warm temperatures and windy conditions.

The pictures below show the amount of ammonia lost (indicated by the blue colouring) over the first 8 days after application from 75kgN/ha as ammonium nitrate (top) and urea (bottom).

AN 75kgN/ha (Day 1-8)



Urea 75kgN/ha (Day 1-8)



Defra studies have shown the potential losses possible from different sources of nitrogen as a result of ammonia volatilisation. Small plot experiments were carried out by ADAS over two years for both grassland and cereals using wind tunnels to capture the ammonia released from application of different sources of nitrogen.

The grassland results showed the average loss from urea applications to be 27% of the total nitrogen applied, although one experiment resulted in 58% being lost. This compared with just 3% from ammonium nitrate. In cereals, the average loss from urea was 22%, with maximum of 43% lost, compared to ammonium nitrate which again averaged just 3%.

The addition of a urease inhibitor to urea, aimed at reducing these losses had a significant impact, although loss was still 100% greater than that from ammonium nitrate in cereals and 120% greater in grassland.

Comparison of Carbon Footprint of Ammonium Nitrate with Urea

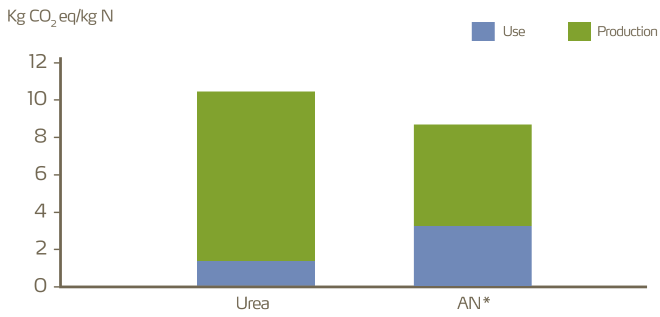
With ever greater focus being paid to carbon accounting, the production and use of fertilizers have come under increasing scrutiny. For this process, it is important to take a life cycle approach (LCA) taking into account the carbon footprint from the production at the factory through to the use in field.

The carbon footprint from the manufacturing process for nitrate nitrogen is around 50% higher than for urea production BUT the emissions from the field applications are significantly lower. Higher losses in the field from urea are caused by it breaking down in the soil to plant available ammonium and nitrate during which process high levels of CO_2 are released increasing its carbon footprint.

Yara has developed and installed N_2O catalytic abatement technology in the ammonium nitrate fertiliser plants , reducing emissions of this potent greenhouse gas by 90%. This means Yara's abated nitrate nitrogen products have a significantly lower carbon footprint than urea products as shown in the graph below.

Urease inhibitors may slightly reduce the carbon footprint of urea products, but it will always be significantly greater than that of abated nitrate fertilizers.

The lower carbon footprint of Yara's abated ammonium nitrate compared with urea



*AN production includes N_2O abatement catalyst, data from Brentrup & Palliere (2008)

The Importance of Accuracy of Spreading in Product Choice

A lot of the benefits of calculating optimum nitrogen rates can be undone if it is applied incorrectly. Fertilizer quality is becoming even more important as tramline widths increase in arable cropping systems to improve farm efficiencies. At bout widths greater than 30m achieving a good spread pattern from a solid fertilizer can be very difficult, especially under field conditions. At this width lighter, less dense particles with poorer particle size distribution, are likely to be more heavily affected by external factors, such as wind, during application. Granular ammonium nitrate, such as YaraBela EXTRAN, has been found to achieve an acceptable spread pattern at greater widths than granular urea, which has a lower particle weight.

Liquid fertilizers such as Chafer NURAM are least affected by tramline width as they are capable of achieving an accurate spread pattern at all bout widths.

Photograph 1. Striping due to uneven application from 1st application of urea in the spring

Photograph 2. Lodging caused by over fertilized areas from poor spreading of urea resulting in significant yield loss.

Importance of Bulk Density on Spreading Efficiency

Bulk density is important as it affects the amount of fertilizer a spreader hopper will hold. Ammonium nitrate has a bulk density of around 0.98 kg/litre and granular urea around 0.74 kg/litre. A 1000 litre hopper will hold 980 kg ammonium nitrate but only 740 kg urea. So, although urea contains 46% N and ammonium nitrate 34.5% N, the amount of N in the hopper will be 338-340kg for both products

Key Benefits of Nitrate Fertilizer vs Urea

- Reduced ammonia emissions from nitrates compared to urea.
  - reduced nitrogen losses leads to high nitrogen efficiency, uptake, yield and protein
  - reduced risk of seedling damage
- Lower carbon footprint from nitrates.
- Improved spread patterns from nitrates.
  Heavier particle size of nitrates:
  - increases the spreading width
  - reduces the sensitivity of wind

Inhibitors

There are two types of inhibitor:

- Urease inhibitors inactivate the urease enzyme slowing the conversion of urea to ammonium. They are included to try to reduce ammonia volatilisation from urea to perform closer to ammonium nitrate. Yara had exclusive world-wide rights for five years for the urease inhibitor Agrotain but relinquished them after extensive trials.
- Nitrification inhibitors act on soil bacteria to delay the nitrification of ammonium to nitrate.

Urease Inhibitors

Pros	Cons
Benefits are expected under conditions that favour ammonia losses (high soil pH, dry weather and high temperatures).	Inclusion rate is critical for inhibitors to be effective.
Small reduction in risk of leaching on very sandy soil / high rainfall.	Limited stability during storage, reducing shelf life.
Reduces ammonia loss by up to 70%.	Urea plus inhibitor still has higher ammonia emissions than AN.
The nitrogen use efficiency of urea is increased.	Increased cost per tonne of urea.

Nitrification Inhibitors

Pros	Cons
Keeps nitrogen in ammonium form, reducing potential nitrate leaching.	Agronomic field trials mostly show no yield advantage of nitrification inhibitors because: a) the performance depends on climatic conditions (e.g. water, temperature) b) adverse effects of ammonium nutrition on crop physiology such as cation imbalances in the crop c) leaching within the growing period is not a main cause of nitrogen loss
Reduced number of nitrogen applications.	
Reduced greenhouse gas losses and emissions (NO and N_2O).	

Nitrogen Source Trials

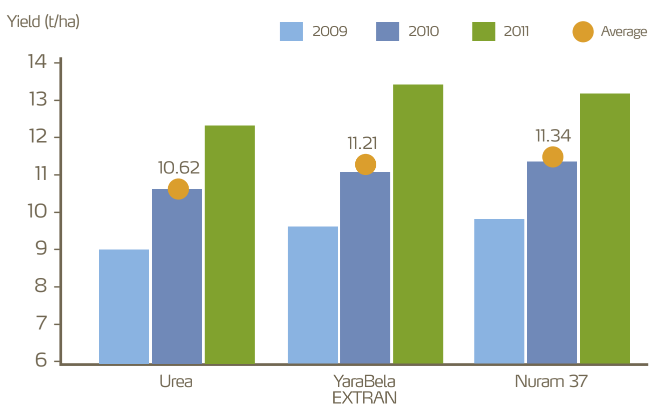
1958-2015 Conclude Nitrates Outperform Urea

Yara has an extensive set of nitrogen source trials dating back to the Levington days in the 1950's right through to trials currently in the ground. Over this period substantial evidence has indicated nitrates to be the most efficient source of nitrogen for UK conditions.

As with any trial, when looking at nitrogen source trials it is important that like-for-like comparisons are made, so the only variable in the trial is the source of nitrogen applied. It is also important that the rate of nitrogen used is close to the optimum, as over application of nitrogen can mask any other differences. This can be difficult as the optimum is only known at the end of the season, so a full nitrogen dose trial using different nitrogen sources at each rate (applied at the same time)is the only way to identify the real differences.

This was the protocol used for the most recent set of Yara trials, carried out independently by Velcourt R&D in 2009-2011. These trials compared YaraBela EXTRAN (AN) and Chafer NURAM (UAN) with urea in winter wheat. The results over the three years showed an average yield increase of 0.65t/ha from nitrates over urea, with the biggest response coming in 2011 at 0.97t/ha, a result that was statistically significant.

Yield at 225kgN/ha (Yara 2009-11)



The findings of this series of trials highlight the impact of the season on the efficiencies of nitrogen source. Greatest yield differences between nitrates and urea occurred in years with low rainfall during the spring. Moving urea applications earlier in the season to counter the effect of volatilisation when the temperatures increase later in the season has also been shown to be ineffective. The risk of losses following application relate strongly to the period of time between application and sufficient rainfall to wash the nitrogen into the soil. Although the likelihood of rain is greater earlier in the season, this is not always the case.

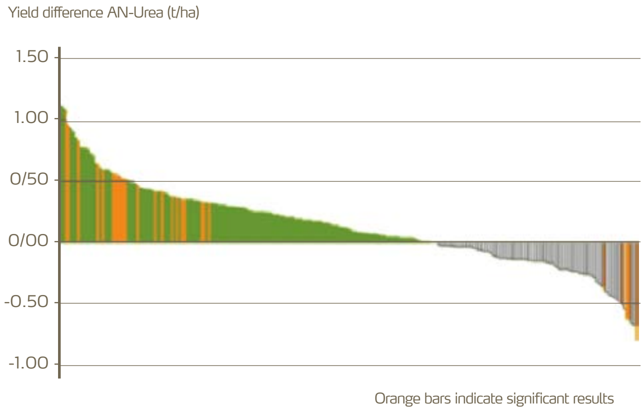
Without an accurate long term weather forecast, using a product that is unreliable in dry conditions can be risky. Growing crops is all about managing what is in our control to make the best of the factors that are outside of our control, primarily the weather.

Long Term Trends Show Clear Advantage of Ammonium Nitrate over Urea

Yield differences up to 10% between fertilizer treatments are difficult to demonstrate as statistically significant in a single field trial. This is because the benefit of the difference is not great enough to be detected with certainty above the background noise of a field trial. However these small but economically important yield differences can be detected where a large number of trials has been carried out over years. In addition to Yara's trial dataset, there is also data from large numbers of trials by other research organisations including ADAS and NIAB TAG.

When put together, these show clear benefits from nitrates in 65% of the trials. Although very few showed a statistically significant yield advantage, there were more trials which were statistically significant in favour of nitrates (9% of all trials) than there were in favour of urea (only 2% of trials).

Benefit of ammonium nitrate over urea
236 trials 1958-2015 (Levington Agriculture, TAG, ADAS & Yara)

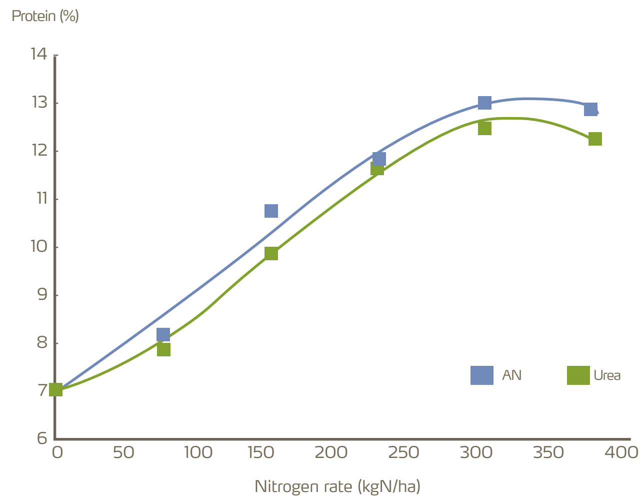


Higher Grain Protein from Ammonium Nitrate than Urea

The other important measure of nitrogen use efficiency as well as yield is grain protein levels, especially important in quality wheat. Trials comparing nitrates with urea fertilizers regularly show poorer grain protein levels from applications of urea than where nitrates are used, even when differences in yield are small.

Yara's most recent trials showed a 0.31% grain protein advantage from the use of nitrates over urea. This trend is similar to the other trial data, including Yara's previous dataset from the 80's and 90's which showed a 0.24% advantage, ADAS work which showed a 0.29% benefit and recent NIAB TAG results which gave a 0.24% benefit.

Effect of nitrogen source and dose on protein of winter wheat (Yara 2011, Alford)



The series of trials above show the difference between urea and nitrates in a series of annual trials across a range of different seasons. Recent work in France has shown that continued use of urea compared to nitrates increases the difference in efficacy between the two sources. In these trials, carried out over 10 years, a long-term 'system' effect of urea was observed.

As expected an 'annual' effect seen in the season of application gave average yield increases in favour of ammonium nitrate as well as increasing in grain nitrogen and content, showing that ammonium nitrate allowed a better nitrogen uptake for the same nitrogen rate applied with plants containing 5% to 8% more N compared with those fed with urea. This effect is most likely related to the higher risk of ammonia volatilisation following spreading of urea.

Interestingly, an effect of 'past' fertilization saw additional yield increases due to fertilizer choice in the previous season. This was most obvious in the unfertilized treatments, with the unfertilized plots which had received ammonium nitrate in the past yielding 5% higher than in the unfertilized plots previously fertilized with urea. This effect is thought to be due to an increase in N content in crop residues that are partly mineralised during the next crop cycle.

Together these effects gave an average yield increase of double that of the annual trials in favour of nitrates due to the effect of both 'annual' and 'past' fertilization.

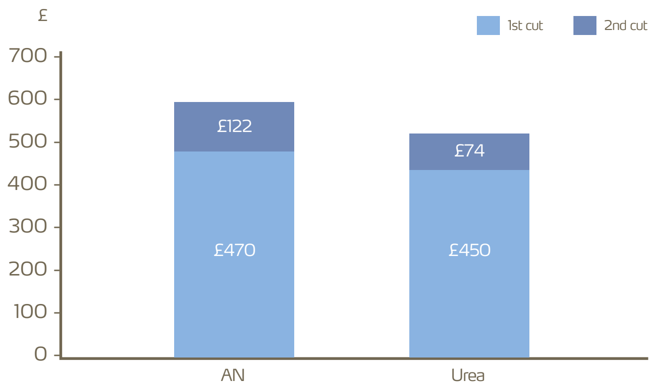
Grassland Trials

The benefits of nitrates is not limited to arable crops, there is significant benefit to be gained in grassland crops also, in particular 2nd and subsequent cuts. This trend for increasing differences between nitrogen sources matches the findings of the long-term 'systems' comparison showing greater disparity between the sources under continued use.

2015 Results

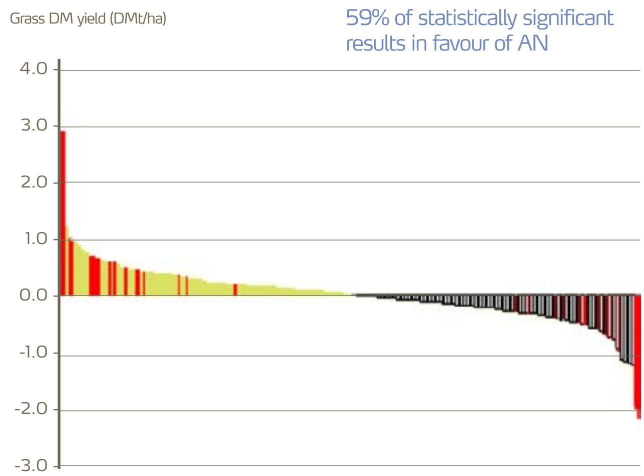
Trials conducted independently on behalf of Yara in 2015 again showed nitrates, (and NPK's) to be a better option than urea. The optimum rate of nitrogen at the site was around 120kgN/ha for both first and second cut giving a 0.7 DMt/ha yield increase for the nitrates above urea.

Margin over fertilizer at 120kg N/ha



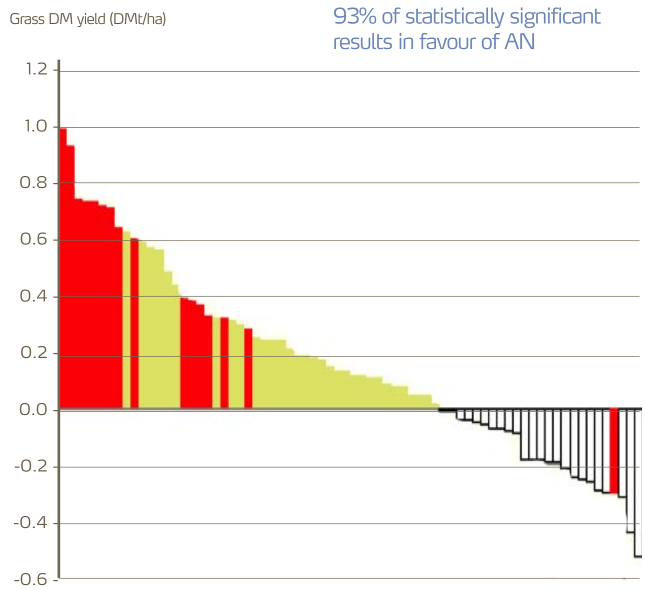
Benefit of ammonium nitrate over urea for 1st cut silage

(average of 217 trials Levington Agriculture, Yara & Defra 1971-2015)



Benefit of ammonium nitrate over urea for 2nd cut silage

(Levington Agriculture, Yara & Defra 1951-2015)



Key Benefits of Nitrates from Research Trials

- Reduced ammonia emissions from nitrates compared to urea.
  - reduced nitrogen losses leads to high nitrogen efficiency, uptake, yield and protein
  - reduced risk of seedling damage
- Lower carbon footprint from nitrates.
- Improved spread patterns from nitrates. Heavier particle size of nitrates:
  - increases the spreading width
  - reduces the sensitivity of wind

Summary of Benefits from Nitrates over Urea

Plants require nitrogen in the ammonium and nitrate forms, therefore application in these forms provide nutrients that are immediately available. Applied in any other form (urea) requires transformations in the soil which introduces more risk and reduces the efficiency of the product.

As legislation surrounding nitrogen applications tightens, the focus on efficiency of a product will increase to ensure that crops are fully supplied with the optimum rates to maximise their potential. Nitrates are the most efficient form of nitrogen and will be key to achieving optimum yield, especially in situations where there is pressure on rates.

The losses from urea are important, and in some situations have been shown to be dramatic, with over half of the amount applied lost before it has entered the soil. This highlights the risks involved with using this form of nitrogen, a risk which is virtually eliminated through use of ammonium nitrate.

Key Benefits of Nitrates

- Higher nitrogen efficiency as a result of ammonium nitrate supplying nitrogen in immediately plant available forms.
- Lower nitrogen losses due to higher ammonia volatilisation from urea.
- Better efficiency of nitrogen uptake and conversion to grain protein from ammonium nitrate than urea.
- Reduced risk of seedling damage due to higher concentration of ammonia from urea.
- Better spread pattern at bout widths greater than 24 metres from heavier ammonium nitrate particles than lighter urea.
- Same quantity of nitrogen in a hopper with ammonium nitrate and urea.
- Lower carbon footprint from abated ammonium nitrate due to significantly lower emissions in the field.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YaraBela™
EXTRAN
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OXIDIZING AGENT
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UN 2067
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Based Fertilizer
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About Yara

Yara grows knowledge to responsibly feed the world and protect the planet. Supporting our vision of a world without hunger and a planet respected, we pursue a strategy of sustainable value growth, promoting climate-friendly crop nutrition and zero-emission energy solutions. Yara's ambition is focused on growing a nature positive food future that creates value for our customers, shareholders and society at large and delivers a more sustainable food value chain.

To achieve our ambition, we have taken the lead in developing digital farming tools for precision farming and work closely with partners throughout the food value chain to improve the efficiency and sustainability of food production. Through our focus on clean ammonia production, we aim to enable the hydrogen economy, driving a green transition of shipping, fertilizer production and other energy intensive industries.

Founded in 1905 to solve the emerging famine in Europe, Yara has established a unique position as the industry's only global crop nutrition company. We operate an integrated business model with around 17,500 employees and operations in 60 countries, with a proven track record of strong returns. In 2022, Yara reported revenues of USD 24.1 billion.

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