Knowledge grows

The Nutrition of Winter Cereals

Incorporating Yara's Complete Range of Fertilizers

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Background

Introduction

The winter wheat crop is one of the oldest crops in agriculture dating back over 2000 years. Throughout the generations the crop has been manipulated from its original genetic base through plant breeding to the modern varieties which have improvements in terms of standing ability, disease resistance, quality and most importantly yield.

Specialist varieties have been developed to give a choice to suit all markets from bread making to livestock feed. Arable producers are able to determine the market requirement and grow specifically for it, rather than producing large quantities of grain that has a limited end use.

Cultivated barleys first entered agriculture at a similar time to wheat over 2000 years ago in the eastern Mediterranean region. Throughout the generations the crop, like wheat, has been manipulated by plant breeding to give modern varieties which exist in three forms, either two row, six row or hybrids.

Interestingly the six row types predominated in the early years as barley was adopted into agriculture, with the two rows only being recorded in the Middle Ages. In recent history the two row varieties predominated with the six rows only coming back into favour as plant breeding improved grain quality aspects.

Specialist varieties have been developed to give a choice to suit all markets from livestock feed to specialist malting. The latest introduction of Hybrid barleys has further enhanced the potential output of this crop.

World Production

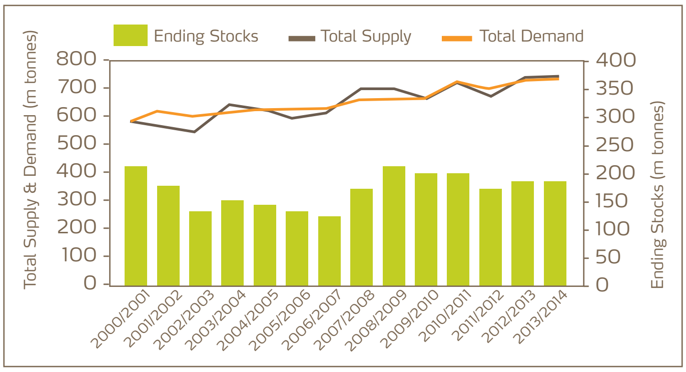
There are three global cereals produced around the world –maize, wheat and barley . Although rice is the second largest produced cereal in the world, its production is localised to Western and Eastern Asia. USDA figures for 2013/14 put world maize production at 963 m tonnes, wheat at 706 m tonnes and barley at 141 m tonnes.

China is the world's largest wheat producer at around 120 m tonnes, followed by India with 92 m tonnes and the USA and Russia both between 50-60 m tonnes. With a production of 12 m tonnes, the UK lies 14th in the world wheat producing list.

Figure 1 below shows the world wheat supply and demand together with ending stock levels over the previous 14 years.

In 2014 world wheat production reduced, meaning that supplies were falling fractionally faster than demand. This means ending stocks were also reduced slightly; with an ever growing population this could be cause for concern in the future. However ending stocks were still at 178m tonnes in 2014 and over the next 10 years are estimated to stay relatively stable (between 176- 182 m tonnes).

Figure 1. World wheat supply and demand *(Source: USDA)*

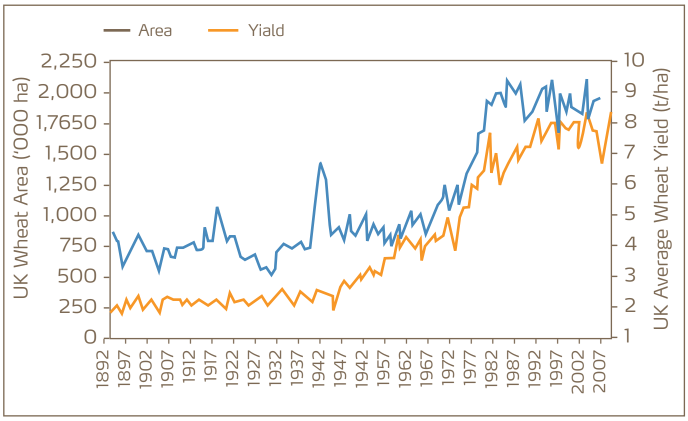


UK Production

The area of cereals in the UK has remained constant since the early 1990s at around 3m ha, placing it 7th in terms of area grown within the EU-28. The major cereal in the UK is wheat, with around 2m ha grown annually. Both the area of wheat grown and the yields increased dramatically in the 1950s through to the 1990s (Figure 2).

Since the large rise through the 1950s, wheat yields have remained static in the UK for 15 years at close to 8 t/ha. The eastern counties is the region producing the largest amount of wheat, with an average annual production of close to 4m tonnes over the last five years.

Figure 2. UK Wheat area and yield *(Source: Defra)*



Market Types

Wheat

In 2014 17% of the UK wheat crop was used for milling, with 25% of the UK area growing Nabim group 1 and 2 varieties. Approximately 50% of the milling wheat is used to produce bread, 10% for biscuit and 2% cakes.

Historically the UK has had a 2-4m tonne exportable wheat surplus, however three major bioethanol plants in Northeast England are likely to have a major impact on the demand dynamics of the UK wheat market. The Ensus biorefinery on Teesside started production in January 2010, and is due to be followed by the Vivergo plant later in 2010 and Vireol in 2011, both located on Humberside.

When the Ensus plant is running at full capacity it will require 1.2m tonnes of wheat as a feedstock, whilst if the two Humberside plants go ahead, they will have a combined requirement of 1.5m tonnes, creating an extra requirement for wheat in the UK for bioethanol of 2.7m tonnes.

Barley

60% of the barley grown in 2014 was used in the malting industry. Malting barley requirements depend on the end market, however they tend to fall into different grain nitrogen categories:

- Under 1.55%
- 1.55% - 1.65%
- 1.65%-1.85%
- Over 1.85%

Ensuring correct nitrogen use for each category is essential in order to meet the correct requirements.

Nutrients

Nitrogen

Nitrogen is critical for plant growth, being responsible for protein production and is the central component of chlorophyll, the essential ingredient for photosynthesis. It is also the key to achieving high yields, and this contributes to making it one of the highest returning inputs in arable production systems. Of all the nutrients, nitrogen is required in the greatest quantity.

If the crop is deficient in nitrogen, plants appear stunted, with older leaves becoming pale / yellow 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.

Nitrogen availability 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, which can have a more pronounced effect in the autumn, particularly on soils with low nitrogen reserves when the root system is still small. 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.

Nitrogen has an important but varied role in disease resistance. One of the most commonly assumed relationships of nitrogen to disease is that high N rates leads to an increase in disease, but optimum nitrogen nutrition normally suppresses disease. This is either as a result of resistance mechanisms, through the formation of various proteins and enzymes needed for both plant growth and disease resistance or through increased tolerance as vigorously growing plants outgrow the most damaging effects of some diseases.

Nitrogen is a key component of amino acids, therefore an excessive supply leads to higher amounts of amino acids in plant tissues. This mineral imbalance lowers the resistance to fungal diseases by creating a more favourable environment for pathogens.

As nitrogen content increases beyond sufficient levels, the amount of naturally occurring antifungal compounds in the plant decreases, increasing the risk of infection, but it also stimulates excessive weak vegetative growth favourable to disease and insect damage.

Nitrogen deficiency in Barley

Nitrogen deficiency in Wheat

Phosphate

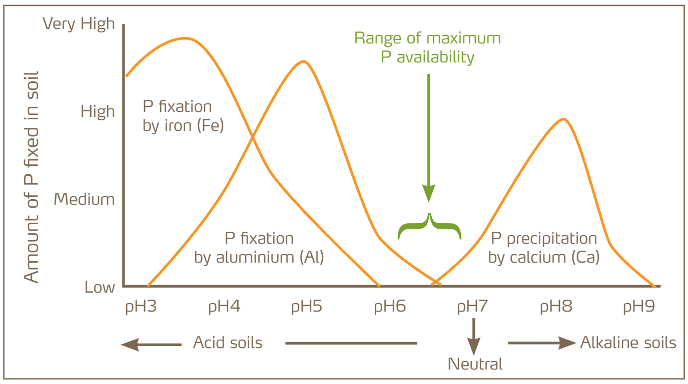
Phosphate plays an important role in energy transfer within the plant and is therefore vital during the periods of rapid growth. In early growth stages it promotes root development, which is also important for efficient uptake of other nutrients. The majority of soils will have sufficient phosphate to satisfy the early demand.

Later in the season phosphate is required for early flowering and plays an important role within the energy storage and transfer process. It is important for cereals to be supplied with sufficient phosphate to increase the protein content of the grains.

Plants deficient in phosphate appear stunted with poor root growth. As phosphate is mobile within the plant, it is the older parts of the plants that show signs of deficiency first, with leaves and stems appearing a deep reddish to purple colour round the margins. Other than stunted plants, phosphorus deficiencies can be difficult to visually diagnose in-field, therefore it may be necessary to conduct soil and/or plant tissue analysis.

Acidic, alkaline and heavy clay soils all have fixing properties that render the phosphate unavailable (Figure 3).

Figure 3. Influence of soil pH on the soil P availability



Phosphate is very immobile within soils, with crops only able to take it up from the soil solution very close to the roots within 1 - 2 mm (Figure 19).

Phosphate deficiency in wheat

Potash

Potassium acts within the transport system of plants and has a number of important functions in plant growth including protein production and the efficiency of photosynthesis. It also affects turgor pressure in the plant helping to strengthen it, reducing lodging and making it less susceptible to disease.

Potassium has an essential role in plant disease resistance, probably the most effective of all the nutrients. It is a regulator of enzyme activity, and therefore involved in nearly all cellular functions that influence disease severity. From over 200 literature reports on the role of potassium on plant diseases 70% improved plant health.

Potassium is required for the synthesis of proteins, starch and cellulose, cellulose being a component of cell walls. An adequate supply of potassium is therefore required for increasing the thickness of cell walls reducing the likelihood of lodging. The function of cellulose on cell wall thickness not only acts on the plants standing power, but also as a mechanical barrier to invasion and infection by pathogens by reducing the movement of sugars out of cells. Potassium deficiency reduces cellulose production, leading to thinner cell walls and higher sugar levels in the apoplast (space between cells) that stimulates fungal attack and germination of spores.

As a rule, susceptibility to disease decreases in response to potassium in the same way that the growth of a plant responds to increasing potassium supply (as shown in the graph below). Beyond optimal supply for growth, there are no further benefits from additional potassium supply in terms of plant health.

Deficiency symptoms become noticeable on older leaves first as marginal and interveinal chlorosis, becoming necrotic in severe cases. Plants also tend to show signs of wilting on hot, sunny days, even when no other symptoms can be seen.

Potassium is one of the major soil cations and is held on the charged sites of clay minerals, thus its presence in soil is largely determined by the clay content and soil texture. Soils that are low in clay content, such as light or sandy soils are prone to potash leaching, especially following heavy rainfall. Experiments on soils with high sand contents, and high rainfall have shown that 45 – 50 % of potash can be lost following application.

Availability to plants can also be reduced where the soil pH is low, or where the soil magnesium status is high, due to the interactions between these two nutrients.

Phosphate deficiency in wheat

Phosphate deficiency in barley

Sulphur

Sulphur plays an essential role in cereals as a component of proteins, therefore if deficient, protein synthesis is inhibited. As protein is located in chloroplasts, plants that are deficient in sulphur have paler leaves. Because of the central role of nitrogen and sulphur in the production of proteins there is a close relationship between the supplies of the two nutrients within the plant. High rates of nitrogen can cause deficiencies of sulphur if the supply is not sufficient and conversely, the efficiency of uptake of nitrogen is improved with an adequate supply of sulphur.

Sulphur also plays an important role in improving the quality of the grain, with improvements in bread-making quality in wheat through an increase in volume of the loaf and benefits in malting quality and beer flavour in barley.

Sulphur deficiency symptoms are similar to those for nitrogen, expressed as a paling of the leaves, and can be seen in younger leaves first as the nutrient is not very mobile within the plant.

Levels of sulphur in the atmosphere have been falling, with the average deposition rate now just 10 kg/ha/yr. Sulphur is very mobile within the soil, similar to nitrogen, making it easily leached, especially on light sandy soils and in high rainfall areas.

Sulphur deficiency in Barley

Magnesium

Magnesium is a central part of the chlorophyll molecule of green plants, and as such, plays an important role in photosynthesis, however only a small proportion of the total magnesium in the plant is found here. It also plays an important role in the synthesis of proteins and in phosphate and nitrate metabolism.

Older leaves are the first to show signs of deficiency with interveinal yellowing followed by purple colouration spreading from the leaf margins. Leaves may start to curl, and necrosis can occur, followed by premature defoliation resulting in reduced growth and yield.

Availability is reduced on light soils, due to the low portion of clay particles and the soils lack of ability to hold onto the nutrient allowing it to be readily leached. The situation is exacerbated on low pH, acidic soils, high levels of potassium in the soil, cold wet growth conditions, periods of drought and generally poor soil conditions can all further reduce the uptake by the plant.

An adequate soil magnesium status is important for satisfactory uptake, particularly at times of high demand. However due to the interactions with other nutrients such as potassium, this may not be sufficient to ensure adequate levels and it may be necessary to apply additional magnesium. Both foliar and soil applications can be used to correct deficiencies.

Magnesium deficiency in wheat

Magnesium deficiency in barley

Manganese

Manganese is key to establishment as it is necessary for photosynthesis and protein synthesis, aids meristem production and is an activator for many enzyme processes e.g. nitrate reductase.

Manganese has long been known to contribute to the suppression of fungal and bacterial diseases being frequently linked with powdery mildew and take-all. Manganese availability and the manganese concentration of the roots play a key role in root infection and severity of take-all. Any factor which decreases the availability of manganese leads to an increase in the severity of take-all. The role of manganese in lignin formation, which along with cellulose is another component of cell walls helps provide a physical barrier to infection by disease organisms.

Manganese deficiency appears as pale yellow mottling on the youngest leaves in cereals and often occurs in patches with plants growing better on the more consolidated areas e.g. close to tramlines. Plants require good soil to root contact for efficient uptake of manganese; therefore availability may be reduced on light, 'puffy' soils. Deficiency symptoms are aggravated by wet, cold conditions and uptake is further reduced on soils with a high pH and those with high levels of organic matter.

Foliar applications are the most effective at preventing or correcting manganese deficiency.

Magnesium deficiency in wheat

Copper

Copper is a catalyst in enzymes which convert nitrogen to protein. In cereals it is of major importance in grain production and ear development, being required for pollination. Cereal plants deficient in copper are more likely to have increased pollen sterility and reduced seed set may result from reduced pollen fertility.

Copper is important for the production and transport of fungus inhibiting compounds within the plant and if low tissue copper levels are low, plants are more susceptible to various diseases.
Copper is important for mildew, rusts, septoria and take-all in wheat as well as ergot in barley and common scab in potatoes.

Copper deficiency in wheat

Zinc

Zinc is a nutrient that is beginning to draw more attention worldwide due to its implications on human health, as well as the severe deficiencies seen in some parts of the world resulting in large reductions in cereal yields. It is required in cereals for protein synthesis and metabolism and is required for structural and functional integrity of cell membranes.

Zinc is essential to the integrity and stability of plant membranes and therefore helps to prevent leakage of sugars from plant cells. Zinc shortages lead to the accumulation of unused sugars in plants causing leakage onto leaf and root surfaces which can enhance the invasion of fungus and bacteria. In wheat this can lead to an increase in the severity of root rot diseases.

Signs of deficiency can be seen as a reduced leaf blade area with parallel yellow bands either side of the leaf midrib. In wheat this is followed by necrotic blotches and in barley it is followed by orange/brown blotches. Plants can remain small and stunted and high numbers of late tillers are produced which remain immature. At ear emergence, awns can be twisted and ears distorted.

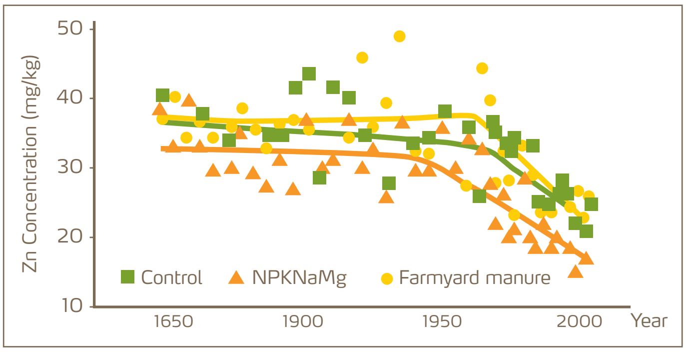
As with all nutrients, zinc availability and uptake is affected by a number of soil characteristics including:

- high $CaCO_3$
- high pH
- clay soils
- low organic matter
- low soil moisture
- high Fe and Al oxides

It has been suggested on a number of occasions that modern, high intensive arable farming methods have depleted the mineral levels in soils.

Although it is true that grain zinc concentrations have declined since the 1960s, and continues to decline, results from Rothamsted's 120 year Broadbalk trial suggest that other factors are behind the change. Having analysed the soil and grain samples over all the years of the trial, soil levels have not declined yet grain concentrations of zinc have declined more than any other nutrient (Figure 4).

Figure 4. Change in grain zinc concentration with time
(Rothamsted Long Term Experiment)



Effect of foliar zinc on Barley in Turkey (Cakmak et al)

Zinc deficiency in barley

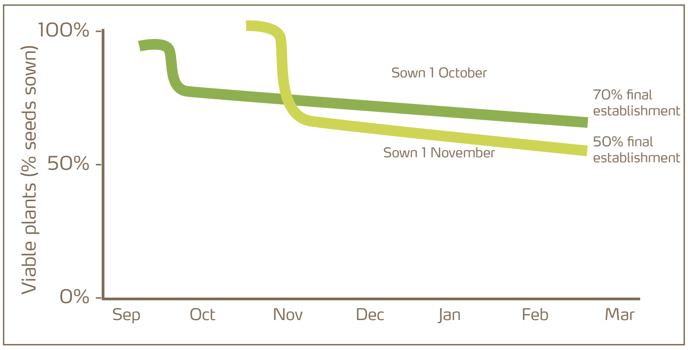
Autumn Managament

In 1840 Justus von Leibig stated in the famous “ Law of the Minimum” that crop growth is limited by the essential nutrient that is found in least supply (Figure 20). This can be modified, replacing ‘essential nutrient’ with ‘essential input’ as it is important that all inputs, soil, seed rates, variety, disease control, are correct to maximise the potential of the crop.

Establishment

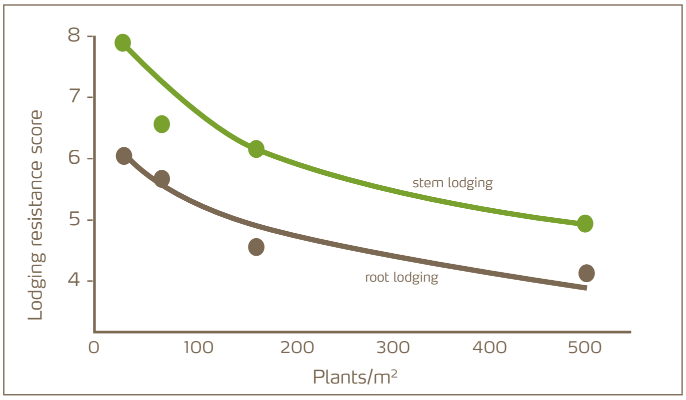
The objective of effective establishment is to produce the optimum number of ears for maximum yield, largely determined by seed rate and tillering. Where drilling is delayed, final establishment reduces, increasing the reliance on tiller production to produce the required number of ears. Figure 5 shows the final establishment percentages for a wheat crop sown on 1 October and 1 November, indicating a 20% reduction in establishment as a result of a 1 month delay in drilling.

Figure 5. Effect of sowing date on establishment *(HGCA)*



It is important to have a good understanding of expected establishment percentage in order to correctly calculate seed rates. If seed rates are too high this can result in too high plant populations, which as well as causing increased competition for inputs and being potentially detrimental from a disease aspect, can also lead to an increased risk of lodging (Figure 6).

Figure 6. Effect of crop density on lodging resistance *(HGCA)*



Nitrogen

Applications of nitrogen to cereals crops are not permitted until spring, where early applications can help to manipulate cereal growth and plant populations through encouraging tiller survival. Crops will generally produce a large number of tillers by GS 30, however a large proportion of these will be lost by harvest. Increasing early nitrogen rates, especially on backward or poorly established crops can be beneficial to maximise tiller survival.

Phosphate & Potash

In the autumn, cereal growth is relatively small and uptake of nutrients is similarly low. As cereals begin to germinate they will use the seeds nutrient reserves, after which the plants will need to obtain the small amounts of nutrients required from the soil. As the rooting system is small and relatively shallow at this time it is important for soils to be supplied with sufficient nutrients to meet this autumn requirement. It is generally accepted that soils with an index of 1 or greater should be capable of meeting the demand of the young crops at this early stage. Where soil indices are below this, autumn applications of phosphate and potash may be required.

Manganese

Manganese deficiency is the most common trace element deficiency found in cereals, which can encourage the development of Powdery Mildew. An application at GS 25 and repeated at GS 30 is required for the treatment of manganese deficiency and is especially important in mildew susceptible varieties.

Spring Management

Nitrogen

The nitrogen management strategy for cereal crops should contain four elements:

- The optimum application
- The optimum rate
- The optimum source
- The optimum timing

Yara's continued research programme focuses on all these areas helping to develop robust and reliable recommendations.

The Optimum Application

Ensuring nitrogen is applied as accurately as possible is essential for maximising the efficiency of what is applied. This may be through variable rate application, varying nitrogen rates within fields to more accurately match crop requirement; or through ensuring spreaders are set up correctly and have been calibrated for the products to be applied.

Poor application can have large financial impacts as a result of yield and quality losses, however it is also damaging to the environment as areas receiving too much nitrogen are more prone to leaching.

For more detail on the Yara N-Sensor for variable rate nitrogen applications see our Precise brochure or the In-field Expertise section on page 16.

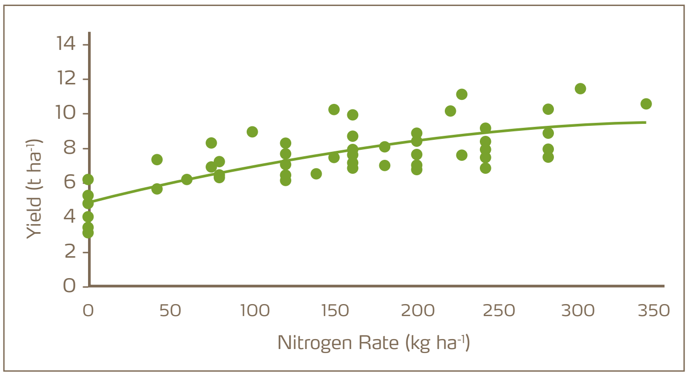
The Optimum Rate

Winter Wheat

Figure 7 shows the average dose response curve for all Yara nitrogen trials conducted on winter wheat since 1989, totalling over 200. Over this time, the yields have improved and optimum nitrogen rates have increased. The data set from 2006-14 shows optimum nitrogen rates are around 220-250 kg/ha depending on the actual price of nitrogen and value of wheat used.

These trials have been carried out on a large range of soil types with very different levels of soil nitrogen supply, varying from index 0 to 5. The results of these trials show that soil nitrogen levels do not have as big an impact on optimum rates as expected. Even at very high soil nitrogen levels optimum rates were alays substantially above the 40-80 kg/ha rates recorded by some sources.

Figure 7. Nitrogen Dose response trials
(Winter Wheat, 1980-2014)

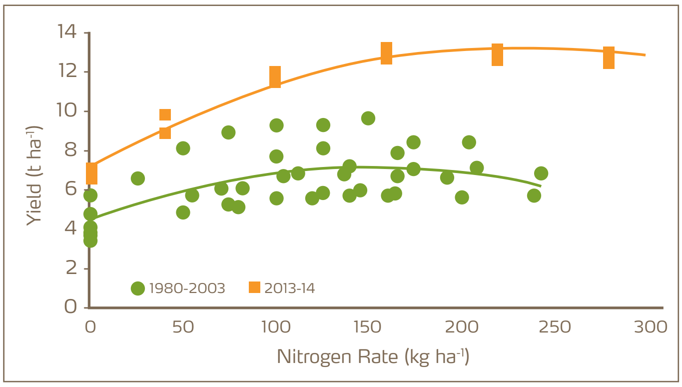


Winter Barley

Figure 8 shows the average dose response curve for all Yara nitrogen trials conducted on winter barley since 1980, totalling over 200. Optimum nitrogen rates over this period range from around 110-160 kg/ha depending on the actual price of nitrogen and value of barley used, although more recently the it has been closer to 220kgN/ha.

For malting barley, previous experience is important for deciding appropriate nitrogen rates in order to meet grain quality targets. Where premiums are expected to be low, slightly higher nitrogen rates will maximise the yield potential of the crop.

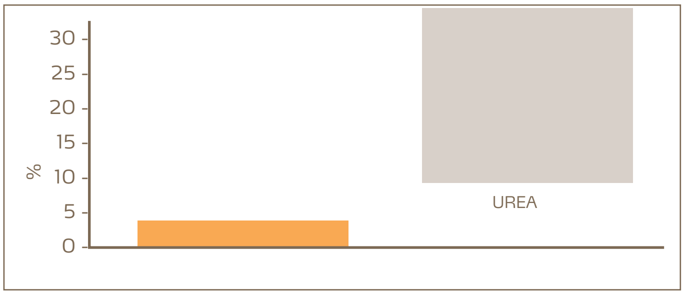
Figure 8. Nitrogen Dose response trials
(Winter Barley, 1980-2003)



The Optimum Nitrogen Source

Having established the optimum nitrogen rate it is important to select the most efficient form of nitrogen to apply. Cereals take up nitrogen in the form of ammonium and/or nitrate, therefore any other nitrogen form used (e.g. urea) requires chemical reactions in the soil before the crop can utilize it. During these reactions nitrogen can be lost from the soil as ammonia (Figure 9).

Figure 9. Loss of Nitrogen as ammonia

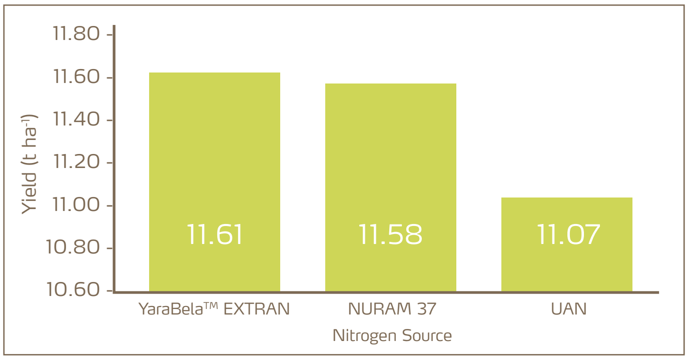


Yara has compared the differences between nitrogen sources in trials for more than 50 years. This extensive data set has helped in concluding that in the UK nitrate based fertilizers are the most efficient form helping to reduce risk.

Work that started in 2009 showed large losses in yield from applying urea compared to either ammonium nitrate or UAN (Figure 10). This research showed the risk of using urea where there is little rainfall following application, and the critical effect this has on the efficiency of nitrogen uptake.

Work carried out in 2009, showed large losses in yield from applying urea compared to either ammonium nitrate or UAN (Figure 10). This research showed the risk of using urea where there is little rainfall following application, and the critical effect this has on the efficiency of nitrogen uptake. Defra studies have also indicated the importance of rainfall in reducing ammonia losses from urea. As it is very difficult to predict the weather, the use of urea introduces uncertainty increasing the risk of a poor return on the investment in nitrogen.

Figure 10. Effect of Nitrogen source on yield of Winter Wheat at 225 kgN/ha *(Yara, 2009-14)*



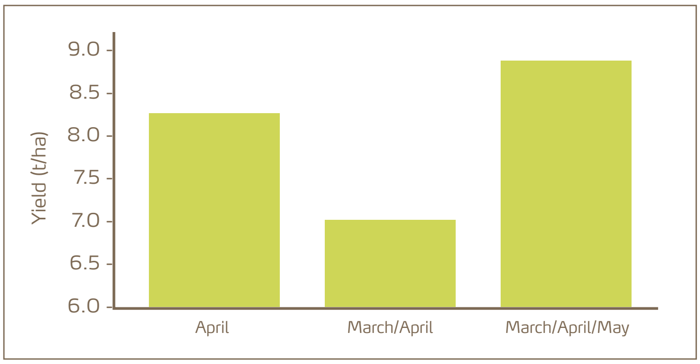
Vertical view of crop *(30/04 - after final N application)*

AN *UREA* *UAN*

The Optimum Nitrogen Timing

Yara, along with independent trials, have shown that, for winter cereals, the critical application timing for yield attainment is between GS30 and GS32 (Figure 11). The nitrogen can be applied in two or three splits depending on crop canopy size and soil type.

Figure 11. Critical timing of nitrogen for yield
(Levington Agriculture)



Lighter soils are more prone to leaching thus three applications reduce the risk of losses. These same soils tend to be less able to hold nutrient, thus earlier applications are beneficial (Figure 12) to prevent plant tiller loss in early spring. The key is to satisfy the crops requirement as it grows through the spring and early summer (Figure 13).

Figure 12. Effect of early nitrogen application in winter wheat

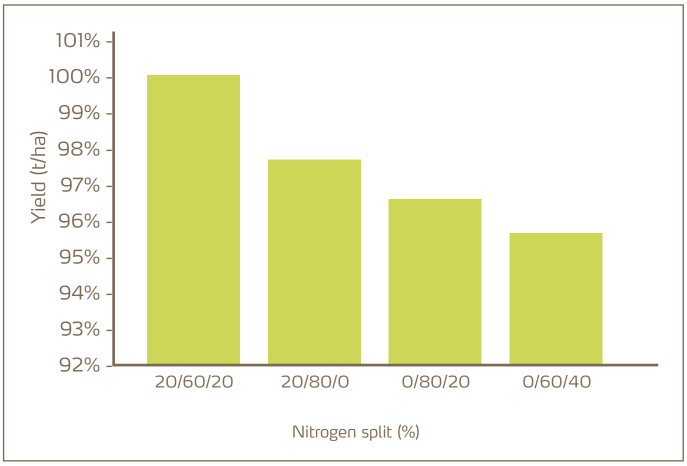
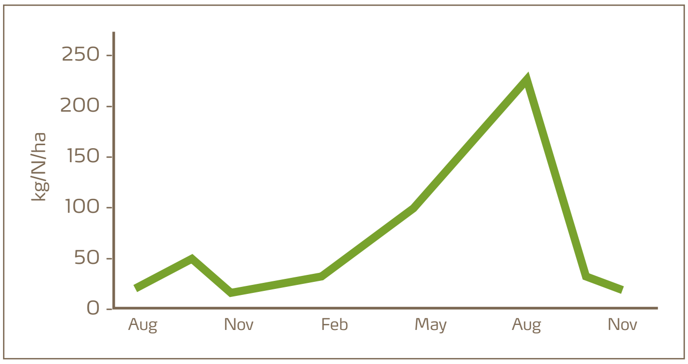


Figure 13. Nitrogen demand of a winter wheat crop



Milling Wheat

For milling wheat varieties it is important to ensure adequate grain protein levels in order to meet the quality criteria and guarantee a premium. To hit target grain proteins it is advisable to apply an extra 40-60 kgN/ha late on in the season, GS 70-79 if using foliar urea, earlier for ammonium nitrate.

Each year the HGCA carry out a Cereal quality survey which identifies the proportion of wheat sold for milling (Group 1 varieties) that failed to hit the quality parameters of protein, specific weight and Hagberg Falling Number. Each year there are large fluctuations in the proportion hitting the minimum specifications for all three criteria, with only 9% in 2014.

Malting Barley

For malting barley it is important to apply nitrogen early enough to ensure it is taken up by the plants for building yield rather than affecting grain quality (i.e. prior to GS 32).

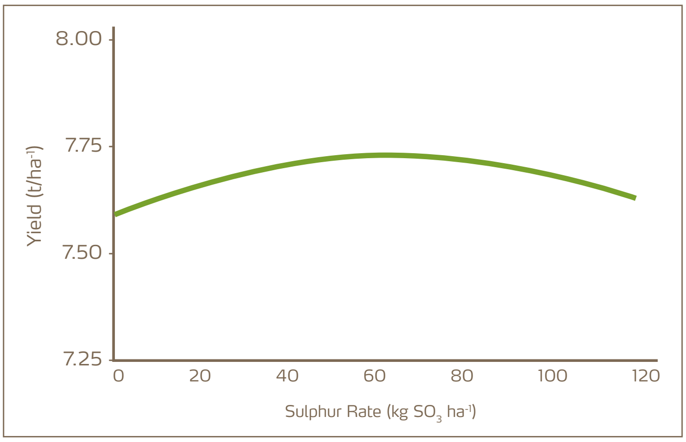
Sulphur

Sulphur Rates

In the late 1990s Yara carried out a number of trials investigating the optimum rates of sulphur on different soil types. The results of these trials showed that similar optimum rates were required for crops growing on light soils to those growing on medium and heavy soils, however the response to sulphur was greater on the lighter soils. Yield responses varied from around 0.1 t/ha on the medium to heavy soils up to 0.3 t/ha on the lighter soils.

The optimum rate of sulphur for cereals on all soil types is around 40-50 kg/ha SO_3 (Figure 14).

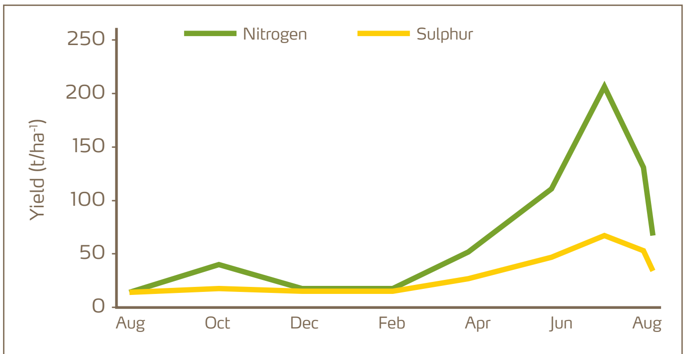
Figure 14. Optimum Sulphur rates *(Winter Wheat)*



Sulphur Timing & Source

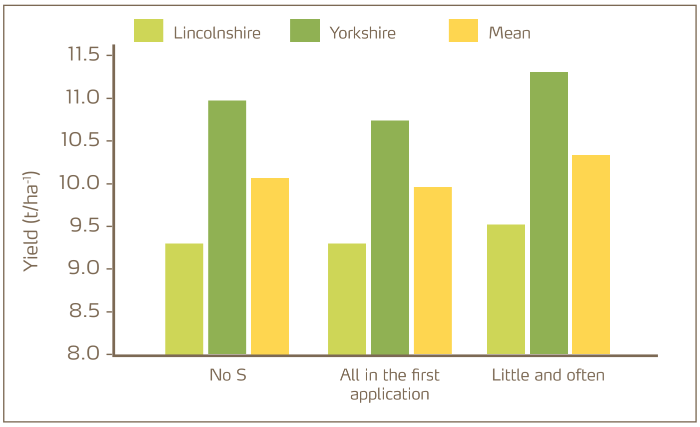
Sulphur is required by the plant in a sulphate form, and not as elemental sulphur, throughout March, April and May (Figure 15). Sulphate, like nitrate, is leachable and care must be taken in the timing of application. Multiple applications with nitrogen reduces the risk of sulphur leaching from the soil and helps to alleviate any risk of inadequate supplies of sulphate being available during the grand growth phases (mid April-early June). It is for this reason that Yara recommends applying 'little and often' at the nitrogen timings.

Figure 15. Nitrogen and sulphur uptake graph



Independent work carried out in 2000 looked at the benefits from applying small amounts of sulphur at the nitrogen timings compared with not applying any sulphur or applying it all in the first dose. The results showed a 4% yield increase from the 'little and often' approach compared to all the sulphur applied early (Figure 16).

Figure 16. The benefit of little and often sulphur *(Winter Wheat, 2000)*

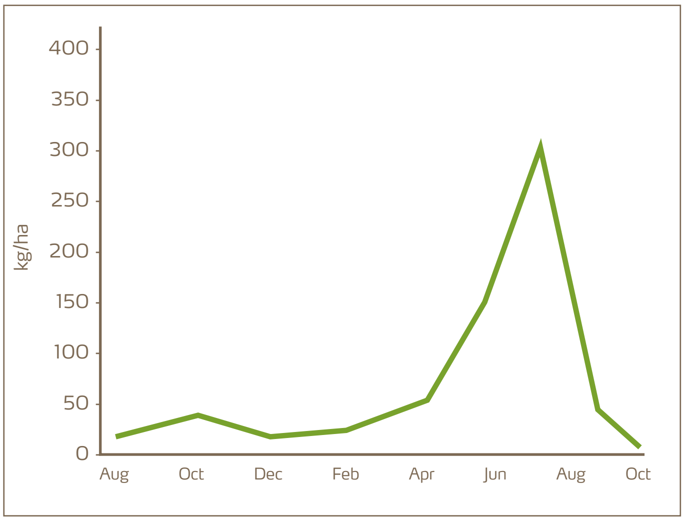


Sulphur does differ from nitrogen when in the plant. Unlike nitrogen the sulphur is not very mobile, hence symptoms show in young leaves first. A strategy that applies sulphur throughout the growing season ensures that a constant supply is readily available as new growth occurs.

Potash

In spring, as cereals reach tillering and crops begin to grow rapidly the uptake requirements of several nutrients increases dramatically, especially potash. The demand for potash may be in excess of 10kg/ha/day, with a total requirement of up to 250kg K_2O by the end of flowering. Where soil indices are low, or where root growth has been restricted (due to low phosphate availability / poor soil conditions) the plants may not be able to get hold of sufficient quantities of potash, therefore spring top dressing will help satisfy the large daily requirement (Figure 17).

Figure 17. Potash uptake in Winter Wheat



Phosphate

The demand for phosphate in the spring is not as great as that of potash, however it is still important that the crop is sufficiently supplied with phosphate due to its role in root development and hence the plants ability to extract nutrients from the soil.

Due to the very low mobility of phosphate in the soil (Figure 19), a lot of the nutrient in the soil will be unavailable to the plants whilst the rooting system is small. Fresh applications in the spring can help to supply plant available phosphate to the upper soil close to where the young roots are (Figure 18).

Figure 18. Phosphate in soil solution

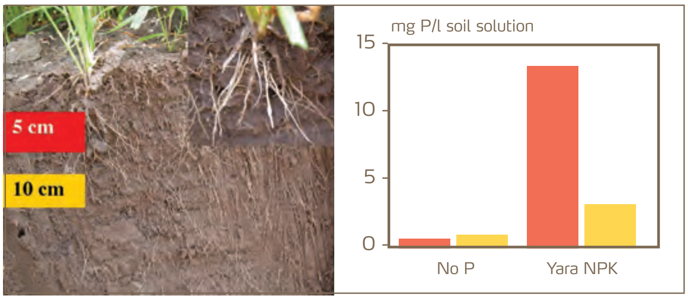
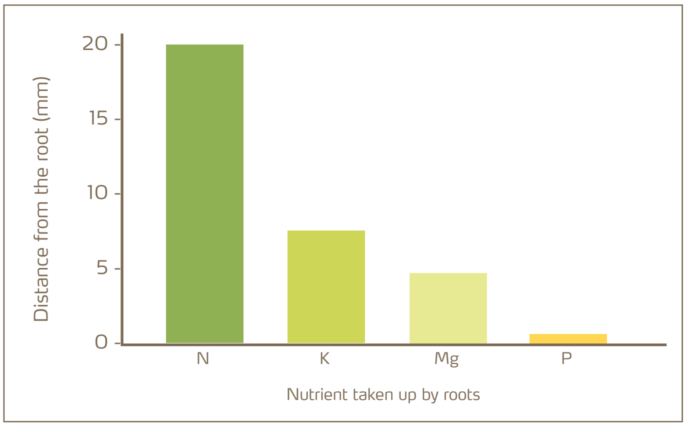


Figure 19. Distance of nutrient uptake by roots



Environmental Issues

Recently there has been increasing concern surrounding phosphorus losses to watercourses, as it can contribute to eutrophication. The effects of eutrophication include algal blooms and excessive weed growth. These effects are visually unattractive and can be hazardous to animal and human health.

Agriculture is not the main source of phosphorus pollution in watercourses in the UK, however, it only requires 0.035kg P/ha to cause problems, and therefore run-off from agricultural land is sufficient to cause eutrophication. It is important to take measures to reduce the risk of phosphorus pollution.

Full account of all nutrients supplied from organic manures should be taken into account when calculating how much inorganic fertilizer to apply. Phosphorus is held tightly by the soil and is therefore not leached in the same way as nitrate. The problems are caused by run-off, washing soil into watercourses, and solutions should therefore focus on minimising the risk of soil erosion. Applications of phosphate and potash on soils with an index 1+ should be made in the spring helping to meet crop demand.

Yara Crop Nutrition

Traditional methods of managing phosphate and potash in arable crops have been very soil focussed, with less attention paid when the crop requires these nutrients. Yara Crop Nutrition (YCN) seeks to address this imbalance, bringing all of its unique strengths in Crop Knowledge, Product Combinations and In-field Expertise together to produce a robust and reliable programme of crop nutrition that delivers the key nutrients at a time when there is high crop demand.

The YCN Wheat programme combines a granular compound NPK including Sulphur for the first topdressing in spring, with an NS fertilizer for the later applications to provide the required NPKS rates.

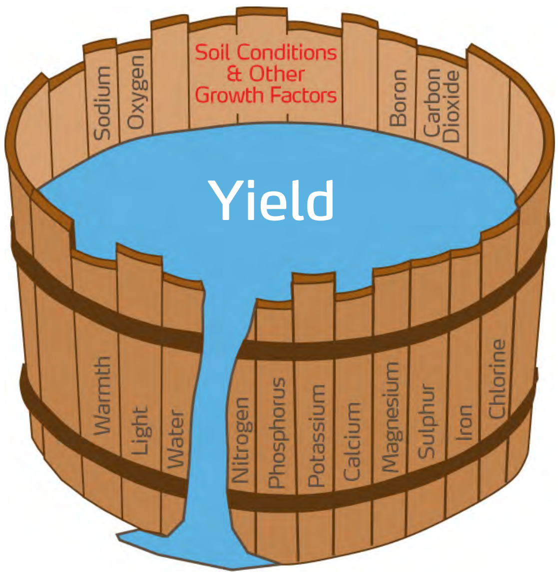
Micronutrients

Micronutrients should not be overlooked in any crop programme as although they are not required in such large quantities as the major and secondary nutrients, they are vital to optimising the crops performance and therefore yield.

In 1840, Justus von Liebig stated in the famous "Law of the Minimum" that crop growth is limited by the essential nutrient found in least supply. This still holds true today, with plants that are lacking in any major, secondary or minor nutrient less likely to reach their optimum yield (Figure 20).

For cereal crops, the secondary and micronutrients of greatest importance are magnesium, manganese, copper and zinc.

Figure 20. A deficiency of any single nutrient is enough to limit yield



(Justus Von Liebig 1803 - 1873)

For cereal crops, the secondary and trace elements of greatest importance are magnesium, manganese, copper and zinc. Even plants growing on soils containing sufficient quantities of these nutrients can suffer from deficiencies, as the plants struggle to access enough. This may be due to their distribution within the soil relative to the roots, restrictions in root growth or due to their requirement at a time of the year when the plant is growing rapidly.

Transient deficiencies such as these may not appear to last very long, but can cause harm to the plant during critical growth phases. In these situations foliar applications of the appropriate nutrients may be required in order to avoid the potentially negative impacts.

Winter Wheat

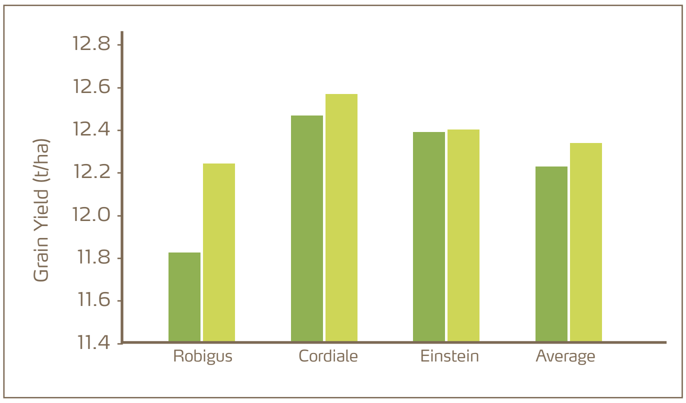
There have been a large number of independent trials carried out from the late 1990's looking at the impact of foliar applications of manganese to wheat crops. The results from these trials show an average yield increase of 6.2% where foliar manganese was applied.

In the 1980s a trial was conducted to look into the effects of applying magnesium to a crop of wheat. The results showed a 4.5% yield increase, equivalent to 0.4t/ha and benefits on grain quality through an 8.3% increase in thousand grain weight. More recent work showed a 5% increase in grain protein where foliar magnesium was applied at growth stage 55.

An Independent, fully replicated trial carried out in East Yorkshire in 2005 on winter wheat where the soil copper status was adequate showed a 1.5% yield increase from applying foliar copper at GS31, equating to a 0.18t/ha improvement (Figure 21).

It is often the case that a deficiency to one micro-nutrient does not occur in isolation. Results from Lancrop Laboratories between 2009 and 2014 have shown that nearly 50% of cereal samples showing a deficiency in either manganese, copper or zinc are either deficient in one or both other nutrients.
As a result Yara has developed the crop specific product YaraVita Gramitrel with the optimal balance of key micronutrients for cereal crops.

Figure 21. Effect of Copper Application on Wheat Yield



Barley

Trials from 1985-1991 showed a 20.4% yield increase from applying manganese to winter barley, equating to 0.93t/ha. Benefits were seen when this was applied in the autumn alone, or spring; however the greatest benefit was seen where both autumn and spring applications were made.

In-field Expertise

Yara has developed a range of decision making tools and analytical services that enable nutrient recommendations to be fine-tuned to field specific conditions.

Megalab

The key to unlocking a crops yield potential is in knowing what is limiting growth and development. Regular foliar and soil analysis will enable proactive decision making when planning a crops nutrient requirement, rather than expensive remedial corrections at a later date. The Yara Megalab service provides a report indicating the crops/soils nutrient status alongside the crop specific guideline figures. Such detailed information enables a more targeted approach to nutrient inputs ensuring all decisions are accurate, efficient and cost effective.

N-Plan

N-Plan is Yara's field specific nitrogen recommendation program, based on independent trials and Yara's own data sets to give timing specific optimum nitrogen rates.

N-Sensor™

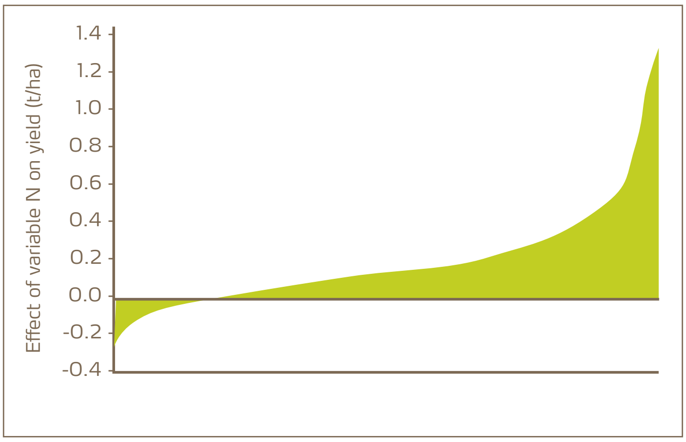
The Yara N-Sensor is the solution to addressing variable soil nitrogen supply. It enables real-time, variable rate nitrogen applications based on the condition of the crop at the time of application.

Crops can vary greatly within fields both in terms of plant numbers and crop growth stages, which may be due to differences in soil type, topography or environmental factors. As a result, the management required may differ, not least the amount of nitrogen required for optimum yield.

The N-Sensor is a cab-mounted system that can, at all times, gain a clear view of a large area of crop. By taking measurements of both the biomass and colour as it passes, it is able to calculate the nitrogen rate required, based on a predetermined optimum. This information is sent to the spreader or sprayer rate controller and the rate applied is adjusted.

The results of nearly 200 fully replicated trials comparing the use of the N-Sensor to standard farm practise have shown a 3.2% yield increase, with a maximum of over 12% (Figure 22). Recent work from 2001-2005 has also shown a fertilizer saving of 12.7%.

Figure 22. Yield advantage with the N-Sensor.
(1999-2005, 186 trials)



Independent work carried out in Germany showed the effect of variably applying nitrogen on grain protein in wheat. Table 1 below shows a 0.37% increase in average % protein, through reducing the variability in protein across the field.

Table 1. Effect of variable nitrogen applications on grain protein (%)

	Uniform N Rate	Variable N Rate
Maximum	13.40	12.70
Average	11.60	11.97
Minimum	9.37	11.19
Standard Deviation	2.02	0.76

N-Tester™

The N-Tester is a handheld, non-crop destructive analysis instrument for nitrogen management in cereals. Readings are taken within the growing crop and compared to varietal and growth stage specific target values. This allows fast and accurate field specific recommendations to help fine tune nitrogen application during the growing season (from GS 33). This results in more accurate field scale nitrogen recommendations, improving profitability and minimising environmental effect.

For more details on Yara's range of decision making tools, visit our website at www.yara.co.uk/tools-and-services.

Crop Programmes

Winter Wheat - Solid

	Growth Stage 25-30	Growth Stage 31-32	Growth Stage 32-33	Growth Stage 37	Growth Stage 39-45
YaraMila®	**ACTYVA S*** 350 kg/ha**				
YaraBela®		**AXAN*** 650 kg/ha**			**EXTRAN** 120 kg/ha
YaraVita®	**MANTRAC PRO** 1 l/ha				
YaraVita®	**MAGFLO 300** 2-4 l/ha	**MANCOZIN** 1 l/ha		**MAGFLO 300** 2-4 l/ha	
YaraVita®	**GRAMITREL** 1-3 l/ha		**GRAMITREL** 1 l/ha		

*** Alternative N+S or NPK+S grades are available as required**
**** Rate depending on SNS and N-Plan recommendation**

Read label before application of any YaraVita product

Soil applied products | Foliar applied products

Winter Barley - Solid

	Growth Stage 25	Growth Stage 30	Growth Stage 31-32	Growth Stage 37	Growth Stage 55-69
YaraMila®	**ACTYVA S*** 350 kg/ha**				
YaraBela®		**AXAN*** 500 kg/ha**			
YaraVita®	**MANTRAC PRO** 1 l/ha	**MANTRAC PRO** 1 l/ha			
YaraVita®	**MAGFLO 300** 2-4 l/ha			**MAGFLO 300** 2 l/ha	
YaraVita®		**GRAMITREL** 1-3 l/ha	**MANCUFLO** 1 l/ha		

*** Alternative N+S or NPK+S grades are available as required**
**** Rate depending on SNS and N-Plan recommendation**

Read label before application of any YaraVita product

Soil applied products | Foliar applied products

Winter Wheat - Liquid

	Growth Stage 25-30	Growth Stage 31-32	Growth Stage 32-33	Growth Stage 37	Growth Stage 55-69
CHAFER™	**CHAFER 11-10-10+5% SO_3*** 500 l/ha**				
CHAFER™		**CHAFER NURAM 35+S** 300 l/ha**	**CHAFER NURAM 35+S** 200 l/ha**		
YaraVita®	**MANTRAC PRO** 1 l/ha	**MANTRAC PRO** 1 l/ha			
YaraVita®	**MAGFLO 300** 2-4 l/ha	**MANCOZIN** 1 l/ha		**MAGFLO 300** 2-4 l/ha	
YaraVita®	**GRAMITREL** 1-3 l/ha		**GRAMITREL** 1 l/ha		
CHAFER™					**CHAFER NUFOL** 200 l/ha

* Alternative N+S or NPK+S grades are available as required
** Rate depending on SNS and N-Plan recommendation

Read label before application of any YaraVita product

Soil applied products | Foliar applied products

Winter Barley - Liquid

	Growth Stage 25-30	Growth Stage 31-32	Growth Stage 32-33	Growth Stage 37	Growth Stage 55-69
CHAFER™	**CHAFER 11-10-10+5% SO_3*** 500 kg/ha**				
CHAFER™		**CHAFER NURAM 35+S** 200 l/ha**	**CHAFER NURAM 35+S** 150 l/ha**		
YaraVita®	**MANTRAC PRO** 1 l/ha	**MANTRAC PRO** 1 l/ha			
YaraVita®	**MAGFLO 300** 2-4 l/ha	**GRAMITREL** 1-3 l/ha		**MAGFLO 300** 2 l/ha	
YaraVita®			**MANCUFLO** 1 l/ha		

* Alternative N+S or NPK+S grades are available as required
** Rate depending on SNS and N-Plan recommendation

Read label before application of any YaraVita product

Soil applied products | Foliar applied products

Cost Benefits of Using Yara Fertilizers

Yara Crop Nutrition Winter Wheat

This data looks at the costs of the full Yara Crop Nutrition Programme compared with a traditional crop nutrition system, highlighting the cost of the two as well as the financial benefits possible through adopting the Yara Crop Nutrition system.

Current Yield	- tonnes / ha	**9**
Yara Target Yield	- tonnes / ha	**10.87**
Crop Value	- £ / tonne	**£125**
Crop Value Index		**5**

	Cost £/ha	N	P_2O_5	K_2O	SO_3	B	Mn	Ca	Mg	Cu	Zn	Mo
Yara Crop Nutrition Programme	286.20	218	53	53	58	0	1100	0	1600	200	320	0
Standard Programme	207.20	188	54	54	0	0	2000	0	0	0	0	0
Yara Crop Nutrition Cost £/ha	79.00	53.20										
Break even Yield Increase t/ha	0.63	0.63										

Benefits of Yara Crop Nutrition	t/ha	Value £/ha
Response to optimum N rate	0.34	£42.09
Value of spring P&K	0.23	£28.91
Response to Gramitrel	0.29	£36.36
Response to the Yara N-Sensor	0.32	£17.38
Response to a uniform NPK vs a blend	0.15	£18.75
Response to Mantrac Pro	0.17	£20.75
Response to Magflo	0.17	£21.13
Response to Sulphur	0.22	£26.97
Total Yara value Proposition (over standard)	1.87	£212.34
Yara Crop Nutrition return on £ investment (over standard)	**£2.69**	

The values shown as benefits of the Yara Crop Nutrition Programme are calculated using average yield increases from trials conducted by Yara.

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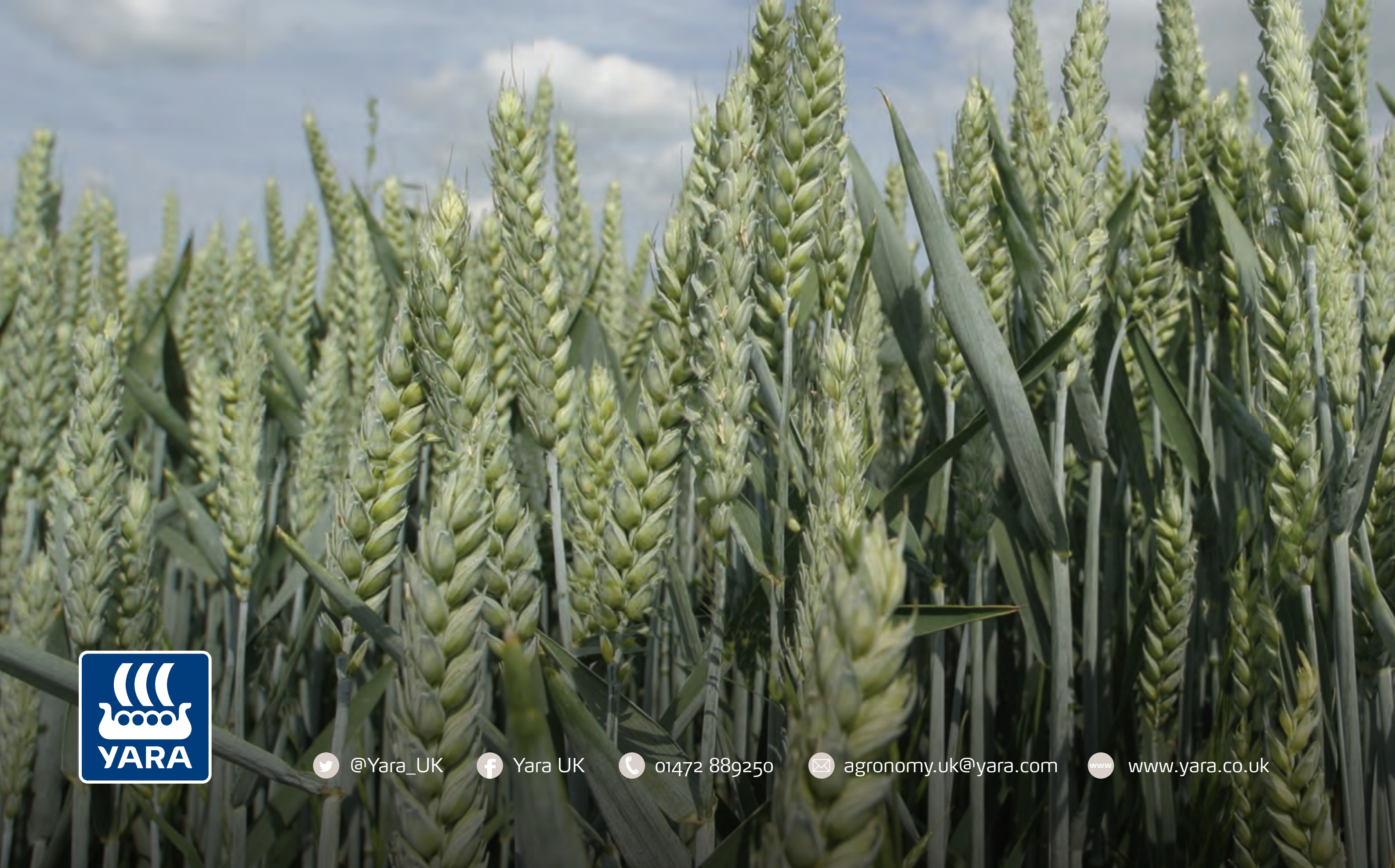
About Yara

Yara's knowledge, products and solutions grow farmers and industrial customers' businesses profitably and responsibly, while nurturing and protecting the earth's resources, food and environment.

Our fertilizers, crop nutrition programmes and technologies increase yields, improve produce quality, and reduce environmental impact from agricultural practices. Our industrial and environmental solutions reduce emissions and improve air quality from industry and transportation, and serve as key ingredients in the production of a wide range of goods.

Founded in 1905 to solve emerging famine in Europe, Yara today has a global presence with more than 12,000 employees and sales to more than 150 countries. **www.yara.com**



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