Knowledge grows

Our Position on Nitrogen Use Efficiency and Nutrient Management

February 2024

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Executive Summary

Nutrient management to achieve nutrient use efficiency is a fundamental topic in sustainable agriculture. Applying a balanced supply of the right essential nutrients at the right time, at the right rate and in the right place increases nutrient use efficiency, providing farmers with the best yield for their nutrients and best return for their investment. As nitrogen is a building block for protein and an essential element to life, nitrogen use efficiency is a significant and measurable part of balanced nutrient management that has an impact on human health, climate and the environment.

Today, nitrogen fertilizers provide food for half of the world's population[1], but increases in nitrogen use efficiency are required to feed the world without trespassing regional and planetary nitrogen boundaries[2].

This paper will focus on nitrogen use efficiency, abbreviated to NUE, as a key metric in all farming systems and in scaling regenerative agriculture. Yara's 65 years of scientific research, agricultural trials and nutrient management solutions development is an important contribution towards improving both nitrogen and nutrient use efficiency.

Balanced and efficient nutrient management is key to crop productivity and environmental sustainability. Yara is committed to ensuring that agricultural crops receive all the necessary nutrients[3] and that farmers are enabled to optimize the use of precious mineral resources within our food system without losing them into the natural environment where they have polluting effects.

Nitrogen Use Efficiency (NUE) is a key metric in sustainable agriculture and environmental science that indicates how effectively plants and crops utilize nitrogen from sources such as mineral and organic fertilizers, biological nitrogen fixation, and deposition of atmospheric nitrogen. In its simplest form, the NUE calculation is "all nitrogen output (harvested crop), divided by nitrogen input (such as above), multiplied by 100" and is expressed as a percentage[4]. Generally, the optimum NUE range is 75%-90%, ideally measured over a full crop rotation, but the range varies depending on the crop and location. The objective is that the plant takes up the optimum amount of nitrogen for a targeted yield, leaving the soil neither depleted nor oversaturated of nitrogen. NUE is a recognized indicator in the transition to regenerative agriculture and has been adopted within the OP2B framework[5], the Sustainable Market Initiative[6], and is being proposed for the Taskforce on Nature-related Financial Disclosures[7] to support food industry transformation. NUE is linked to nature-positive outcomes such as reducing crop carbon footprint, improving water use efficiency, sustaining soil health, optimizing the use of arable land, while improving farm economics, yield and food security.

Yara's NUE expertise and nutrient management solutions are core to Yara's sustainable and regenerative agriculture offerings enabling farmers to unlock the full potential of their crops. We believe that balanced nutrient management and improved NUE are fundamental to all farming systems and implementing regenerative agriculture at scale, helping Yara achieve our mission to responsibly feed the world and protect the planet and our ambition of Growing a Nature-Positive Food Future together with our customers and stakeholders.

The Balancing Act of Nitrogen Management

Nitrogen is at the core of several Sustainable Development Goals related to food security and a clean environment.[11] The earth system boundary for nitrogen has been exceeded due to nitrogen pollution from multiple sources including from overuse of inputs such as manure and mineral fertilizers, emissions from traffic and industry, and nitrogen discharge in wastewater.[12]

Whilst some locations have severe perturbations from overuse of nitrogen causing runoff, water pollution, and greenhouse gas emissions, other regions, notably in Africa, face soil depletion and significant yield gaps.[13]

Where there is overuse, the goal should be to optimize nitrogen use to reduce the risk of losses while ensuring adequate yields. Where there is underuse, more and better-targeted crop nutrition can help to close yield gaps, support soil health and to optimize the use of agricultural land to spare nearby natural habitats and avoid land-use-change and related carbon losses as CO_2.[14]

Too little nitrogen leads to stunted crop growth and reduced yields. Nitrogen deficiency in plants can result in visible symptoms (reduced size, yellowing leaves) and reduce the overall health and quality of crops (e.g. protein content), making them susceptible to pests and diseases and less resilient to weather shocks including extreme temperatures and droughts. Lower crop yields due to nitrogen deficiency have economic and societal consequences for farmers and the wider food markets, impacting food security via availability and affordability. Continuing to grow crops on soil without replacing nutrients also mines it over time, decreasing soil health and fertility for future agricultural activity. Mining of nitrogen sequestered in soils also results in the release of carbon as both are sequestered in the same soil organic compounds.

Too much nitrogen and inappropriate nitrogen management leads to unintentional losses of nitrogen into natural land, rivers, lakes, coastal zones, and air. These losses cause air pollution in the form of ammonia (NH_3) and nitrogen oxides (NOx), contaminate groundwater, and harm natural ecosystems after deposition, altering soil chemistry, disrupting nutrient cycling, and favoring some plant species over others, potentially leading to shifts in plant communities and biodiversity loss. Too much nitrogen can also cause crop quality deficiencies and may have a negative impact on farm economics as precious resources are wasted. Excess application of nitrogen in the field also leads to increased release of nitrous oxide (N_2O) into the atmosphere which acts as a potent greenhouse gas.[15]

Deep Dive: The Nitrogen Cycle

Nitrogen gas (N_2) makes up approximately 78% of the Earth's atmosphere by volume and nitrogen (N) is the main element in proteins and nucleic acids which are essential for growth, development, and reproduction of all living organisms. However, nitrogen in the air cannot be directly used by most organisms, so to play its part in the food system, it is transformed into reactive nitrogen, which cascades through the environment and all living matter in the "nitrogen cycle".

Atmospheric nitrogen (N_2) is fixated into reactive nitrogen (Nr) naturally (e.g. by bacteria or lightning), through combustion of fossil fuels (e.g. in traffic), or industrially through the Haber-Bosch method into biologically accessible forms such as urea ($CO(NH_2)_2$), ammonia (NH_3) or nitrate (NO_3^-). Plants take up nitrogen from soil mainly in the form of nitrate (NO_3^-), and in some cases also ammonium (NH_4^+) and synthesize it into proteins and other essential molecules. The plant-based nitrogen is then removed with the harvest, consumed by animals and/or humans, and returned to the soil through decomposition of organic matter by microorganisms that break it down, releasing ammonium ions (NH_4^+) in the process, mostly into a different ecological system.[8]

These ammonium ions are converted by nitrifying bacteria into nitrate ions (NO_3^-) which can be again taken up by roots. The nitrogen cycle in soil is not a closed system and some inherent losses such as nitrate leaching, runoff, ammonia volatilization can happen and must be managed responsibly.

To complete the cycle, denitrifying bacteria convert nitrate back into atmospheric nitrogen (N_2), the harmless gas we breathe, but under certain conditions,[9] the intermediary product of the denitrification, nitrous oxide (N_2O), a potent greenhouse gas 265 times more impactful than carbon dioxide (CO_2),[10] is also released into the atmosphere.

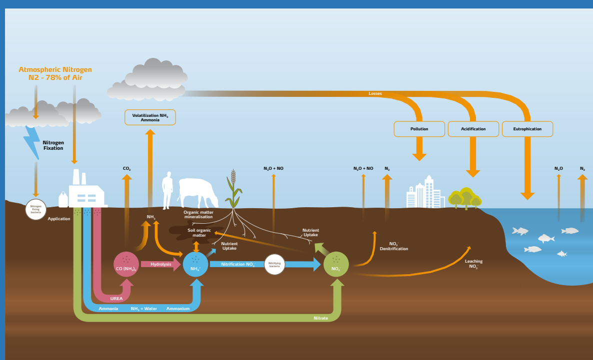


Figure 1. The Nitrogen Cycle.

Watch Yara's scientists explain the Nitrogen cycle in the soil.

Our Position on Nitrogen Use Efficiency and Nutrient Management

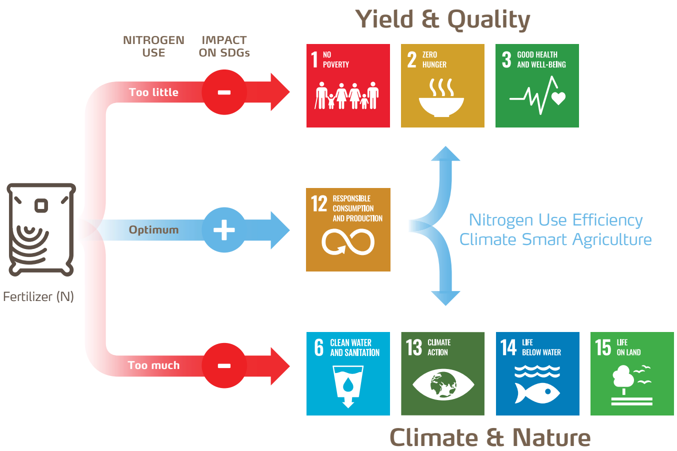


Figure 2. Optimum nitrogen management strikes the balance between yield and quality, and climate and nature.

What is Nitrogen Use Efficiency and how do we work with it as an indicator?

Whilst the **nitrogen surplus** metric shows difference between the total quantity of nitrogen inputs entering the soil and the quantity of nitrogen outputs leaving the soil annually, **nitrogen use efficiency** is the ratio between nitrogen inputs entering the soil and the quantity of nitrogen leaving the soil (output).[16]

By using this ratio to indicate efficiency, the important dimension of productivity is included, which ensures that farmers can maximize their yields within a "safe corridor". This corridor concept includes thresholds for the minimum N required to achieve a reasonable crop yield and the maximum N surplus which can be tolerated by the ecosystem.

Optimizing NUE can help to achieve the desired outcomes of high yield, land use efficiency, and minimal negative climate and nature impacts - enabling farmers to safely increase productivity on existing farmland to meet demands for food production[17] and spare natural habitats[18].

The framework combines NUE with a maximum nitrogen surplus and minimum productivity

(numbers illustrative only; will vary by context)

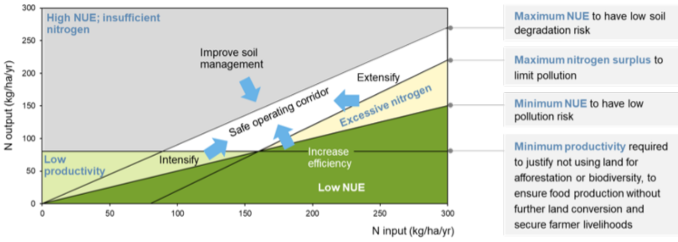


Figure 3. The NUE framework identifies a "safe operating corridor" where crops express their full potential and pollution is limited.

At Yara, we recommend that wherever possible, nitrogen use efficiency of the full crop cycle is measured, considering the entire rotation. The boundaries of the metric can be expanded from farm gate to the entire value chain depending on data insights. Innovation and clarification from academia and industry bodies[19] is ongoing to ensure that nitrogen use efficiencies will become a solid performance indicator for production systems and their products.

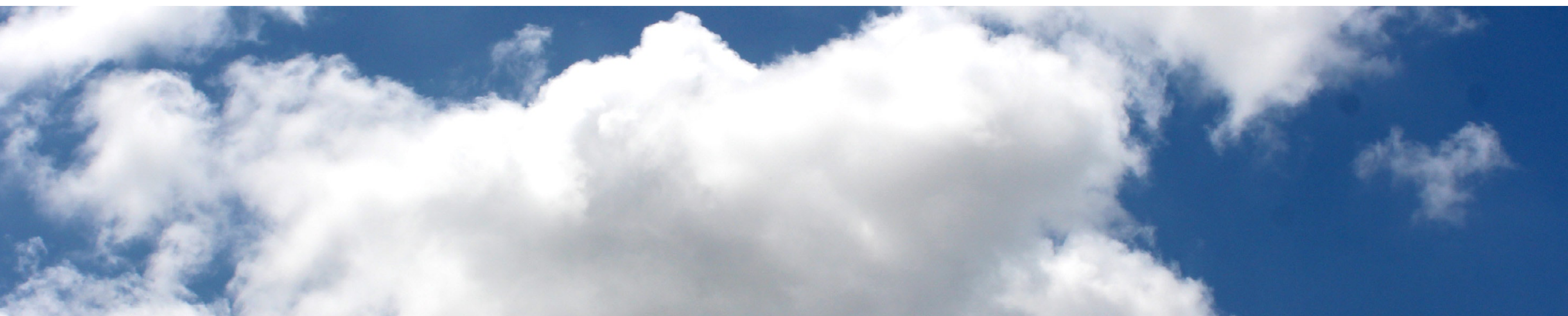
Field trials and research indicates that having a good NUE (i.e. a productive system) can also result in an improved carbon footprint[20] and better water footprint of crops[21]. As such, a high NUE can be particularly important for water-stressed areas.

NUE Calculation Example

Nitrogen Output
Grain yield at 100% Dry Matter = 10 t/ha
Grain protein at 100% Dry Matter = 13.5%
Grain nitrogen = 2.37% N
Total nitrogen output = Grain Yield x Grain N %
= 10,000 x 2.37% = 237 kg N / ha

Nitrogen Input
Nitrogen residues from pre-crop = 40 kg N/ha
Organic manure N application = 40 kg N/ha
Inorganic nitrogen applications = 220 kg N/ha
Total nitrogen supply = 40 + 40 + 220 = 300 kg N/ha

Nitrogen Use Efficiency
= Nitrogen Output / Nitrogen Input = 237 / 300 = 79 %



How do we improve nitrogen use efficiency?

Yara promotes sustainable nutrient management practices on farms with the aim of optimizing nitrogen use efficiency, reducing nitrogen pollution, and minimizing environmental and societal impacts of nitrogen-related issues.

As each farm is unique, the “safe corridor” needs to be adapted to the specific context, including the crop yield potential, location and whether livestock system is included. Yara is working with farmers to adopt best practices, digital tools and services as part of our regenerative agriculture framework, and to help farmers pragmatically measure and improve their nitrogen use efficiency and balanced nutrition management.

Our tailored, granular crop nutrition recommendations always aim to include organic and circular nutrient streams, supplemented by specific mineral fertilizer product and application recommendations, depending on the needs of the crop and soil. The focus is always to help farmers stay within the “safe corridor”, which requires continuous monitoring, testing and split application of nutrients to ensure precision and efficiency where practically feasible.

It takes more time and effort from farmers to measure the actual demand and apply the nitrogen in several dressings, but there may also be cost reductions in the inputs required and farmers may be increasingly incentivized by the food sector concerned and keen to avoid greenhouse gas emissions, soil mining and nitrogen pollution.

Examples of solutions to improve nitrogen use efficiency include:

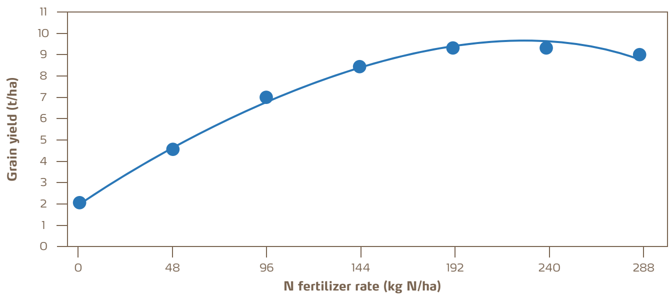


Figure 4: Yield response of winter wheat to increasing N fertilizer rates identifies an optimum rate after which yields decline.
Source: F. Brentrup et al, 2004.[22]

Improved nutrition management

Employing enhanced timing and application of plant nutrients ensures that roots can access nutrition to match demand more closely and minimize soil nitrate concentrations by the end of the growing season. Using fertilizers with a quick and predictable nitrogen release, such as nitrates, alongside solutions such as split application, fertigation and biostimulants may improve NUE. Sufficient supply of other plant nutrients, such as phosphorus, potassium and magnesium, is also critical for optimum NUE. Long-term trials with cereals and potatoes at Yara’s R&D Centre in Germany showed that only a fully balanced nutrition with all essential nutrients allowed NUE to reach the safe corridor space (75%) compared with a lack of phosphorus, potassium or magnesium reduced crop growth and NUE.

Precision agriculture

Using advanced technologies like GPS-guided equipment, remote sensing, and soil and plant monitoring to optimize nitrogen application based on the specific needs of each field or crop. This reduces over- and underapplication and minimizes nitrogen waste. Yara’s precision farming solutions include dynamic nutrient management planning, in-field variable application through Yara AtFarm & Yara N-Sensor, digital tools such as Yara N-Tester to measure average crop status and the Megalab analytical service for soil and tissue analysis to support science-based decision-making and efficient nutrient management.

Regenerative agriculture practices

Cover cropping, crop rotation and mulching reduce nitrogen losses to the environment while boosting soil health and productivity. In addition, combined water and nutrient management contributes to more crop resilience, which in turn drives more nitrogen use efficiency.

Agronomic advice

Implementing diverse cropping systems, including rotations and cover crops, can enhance soil health and reduce nitrogen losses. Implementing practices to minimize nitrogen loss, such as using inhibitors, buffer strips, and conservation tillage can improve NUE.

Click here and listen to Yara’s agronomists talk through Yara’s digital tools, services and products to improve NUE.

Accelerating adoption of nitrogen use efficiency

Nitrogen use efficiency and balanced nutrient management can unleash the potential for scaling up regenerative agriculture when it is mainstreamed into scientific frameworks and regenerative agriculture metrics and tools, such as the Cool Farm Tool.[23]

Nitrogen use efficiency is a no regrets move to drive resource efficiencies in food systems, and we consider it is the right thing to do regardless of reporting requirements. Practices to optimise the use of nitrogen on the field result in a reduction of greenhouse gas emissions embedded in agricultural products, thus enabling scope 3 emission reductions for food companies. For fertilizer companies, however, such emission reductions are beyond their scope 3 boundary, and do not currently contribute to the progress towards SBTi targets.

Measuring nitrogen use efficiency in practice is also a low hanging fruit for farmers: the indicator is closely correlated with the data used for calculating the product carbon footprint and as such is already a part of existing reporting requirements. The calculation is well defined and can be made a key driver for regenerative outcomes through close collaboration with farmers to obtain concrete data on N-input and N-output. We advocate working together to incentivise farmers to collect and share data about their nitrogen use efficiency securely and transparently.

Further work is needed to agree operational metrics in the context of global agreements that work across the value chain to support farmers with implementation metrics at national, local, farm & crop levels. Yara advocates for nitrogen use efficiency being included in the Science Based Targets initiative, Science Based Targets network and TNFD indicators and metrics.

Yara is a driver and key player in driving a future with more nitrogen use efficiency and better nutrient management. Today we have proven, effective solutions. We are cognizant of the size of the issue of nitrogen and willing to collaborate with farmers, governments, food companies, academia and NGOs to ensure a balanced approach for more sustainable outcomes.

Partnering to Make Every Nutrient Count

Yara's AtFarm™ platform uses an optimized index to enable farmers to monitor the nitrogen uptake and biomass development of their crops and access field specific variable rate application maps. This data is seamlessly shared with John Deere's Operations Center™ which makes it much easier for farmers to reduce nutrient losses and produce more yield with less input. Yara's agronomic trials show that farmers can achieve up to 7% yield increase while securing up to 14% nitrogen savings in fertilizer use. Read more here.

Driving Nitrogen Use Efficiency in California

Following excess nitrate in groundwater, California State Water Boards are requiring farmers to submit their NUE and tracking improvements annually from year to year. To maximise profit, farmers need to maximise produce and minimize input costs especially in the context of volatile fertilizer prices, and therefore ensure that their plants get exactly the nitrogen they need – nothing more, nothing less.

Listen to Yara's agronomist relate this complex topic to his experiences in California, where many different factors in the cropping system need to be looked at holistically to implement the best crop management practices.
Yara's Crop Nutrition podcast: Nitrogen Use Efficiency - Why Should We Care? (libsyn.com)

Did you know that...

- Nitrogen is needed to build soil organic matter for a healthy soil
- Water management plays a critical role in optimizing NUE
- Cover crops are a good way to absorb excess N in soil
- Too much N can also cause problems in crop quality
- The optimum NUE is specific to each crop (e.g. almonds on a mature tree can recover up to 90% of the N applied)
- Deficiencies in other nutrients such as zinc, manganese and copper can negatively impact NUE

References and footnotes

[1] Erisman, J. W., Sutton, M. A., Galloway, J., Klimont, Z., & Winiwarter, W. (2008): How a century of ammonia synthesis changed the world. Nature Geoscience, and Our World in Data: https://ourworldindata.org/grapher/world-population-with-and-without-fertilizer

[2] Schulte-Uebbing et al. 2022.

[3] Liebig's "Law of the Minimum" states that if one essential nutrient is deficient, plant growth is poor despite all other essential nutrients being abundant.

[4] United Nations Environment Programme (UNEP) & EU Nitrogen Expert Panel (EUNEP): "Nitrogen Use Efficiency (NUE) - an indicator for the utilization of nitrogen in agriculture and food systems", https://www.unep.org/resources/report/nitrogen-use-efficiency-nue-indicator-utilization-nitrogen-food-systems

[5] OP2B's Framework for Regenerative Agriculture - World Business Council for Sustainable Development (WBCSD)

[6] Agribusiness Task Force | Sustainable Markets Initiative (sustainable-markets.org). "Scaling Regenerative Agriculture: Levers for Implementation" report 2023

[7] Discussion_paper_on_proposed_sector_disclosure_metrics_v1.pdf (tnfd.global)

[8] E.g. food exports redistribute nutrients around the world. When nutrients are removed from soil, they need to be restored for optimum soil fertility in that farm.

[9] In oxygen-deprived or anaerobic environments, such as waterlogged soils or wetlands, nitrogen is lost to the atmosphere as nitrous oxide (N_2O), a harmful greenhouse gas, in a process called nitrification.

[10] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[11] Kanter, D.R., Zhang, X. & Howard, C.M. Nitrogen and the Sustainable Development Goals. 2016 International Nitrogen Initiative Conference, "Solutions to Improve Nitrogen Use Efficiency for the World" 2016; Dobermann, A. Looking Forward to 2030: Nitrogen and the Sustainable Development Goals. 2030 International Nitrogen Initiative Conference "Solutions to Improve Nitrogen Use Efficiency for the World" 2016

[12] Nature "Safe and Just Earth System Boundaries", May 2023 https://www.nature.com/articles/s41586-023-06083-8; United Nations Environment Program, "Facts about Nitrogen Pollution" https://www.unep.org/facts-about-nitrogen-pollution

[13] Schulte-Uebbing, L. F., Beusen, A. H. W., Bouwman, A. F., & De Vries, W. (2022). From planetary to regional boundaries for agricultural nitrogen pollution. Nature, 610(7932), 507-512.

[14] Falconnier, G. N., Cardinael, R., Corbeels, M., Baudron, F., Chivenge, P., Couëdel, A., ... & Giller, K. E. (2023).

[15] According to IPCC Emission Factors, about 1% of the nitrogen in mineral fertilizers is lost as N_2O emissions.

[16] OECD's "Nitrogen Use Efficiency as an Agro-Environmental Indicator" study from 2010 explains how different definitions of NUE are used and how important the interpretation of the results is. https://www.oecd.org/greengrowth/sustainable-agriculture/44810433.pdf. Output can be estimated using standards, such as those published by the International Fertilizer Association https://api.ifastat.org/reports/download/12965

[17] Schulte-Uebbing and de Vries (2021) show that NUE improvements allow compliance with threshold of N pollution without crop yield losses, and Schulte-Uebbing et al (2022), shows that large increases in nitrogen use efficiencies are required to feed the world without trespassing regional and planetary nitrogen boundaries.

[18] Nature 21 June 2023: "Current conservation policies risk accelerating biodiversity loss" https://www.nature.com/articles/d41586-023-01979-x

[19] E.g. EU Nitrogen Expert Panel (EUNEP)

[20] A reduction in N per unit of food produced automatically reduces the crop carbon footprint.

[21] Brueck, H., & Lammel, J. (2016). Impact of fertilizer N application on the grey water footprint of winter wheat in a NW-European temperate climate. Water 8, 356. https://doi.org/10.3390/w8080356

[22] "Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology II. The application to N fertilizer use in winter wheat production systems" https://www.sciencedirect.com/science/article/abs/pii/S116103010300039X

[23] Impact of NUE on climate mitigation is documented in IFA's report "Reducing Emissions from Fertilizer Use" https://www.fertilizer.org/key-priorities/fertilizer-use/emissions-reduction/ and acknowledge by OP2B, Sustainable Markets Initiative, Cambridge University, among others.

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 17,000 employees and operations in over 60 countries.

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