



Carbon Footprint

Climate impact and mitigation potential
of plant nutrition



Agriculture and climate change

This brochure aims to explain some of the complex mechanisms defining the climate impact and mitigation potential of modern agriculture. It also provides insight into recent technological achievements to reduce greenhouse gas (GHG) emissions of fertilizer production and use.

Food security

Since its beginning about 10 000 years ago, agricultural development has been closely linked to the rise of human civilization. During the past half-century, the "green revolution" allowed a tripling of global food production while world population grew steeply from 3 to 6 billion people.

With world population expected to grow to some 8.5 billion people by 2030, food production will need to increase again by more than 50% [source: ref. 1]. Since land suitable for conversion to agriculture is dwindling, maximizing yield from the existing agricultural surface is a necessity (Figure 1 and 3).

Plant nutrition

Since the 19th century, when Justus von Liebig proposed the "Law of the Minimum", we have known that if one of the nutritive elements required by a crop is deficient or lacking, plant growth will be poor, even when all the

other elements are abundant. If the deficient element is supplied, growth will be increased up to the point where some other element then becomes the limiting factor.

With each harvest, nutrients are exported from the field with crops, depleting the soil. Mineral fertilizers are applied to replace the missing nutrients, ensuring an optimal balance for plant growth (Figure 2).

From a climate change perspective nitrogen (N) is the most important nutrient, while phosphorus (P) and potassium (K) have minor impacts.

Climate protection

Best agricultural practices are a strategic aspect of securing food supply for a growing world population. Today, almost half the people on Earth rely on mineral fertilizers for their food. [source: ref. 2]

But agriculture also raises environmental concerns and questions about its impact on

climate change and global warming.

Are agricultural productivity and sustainability compatible? What about GHG emissions from fertilizer production and application?

Yara, with its century long knowledge and experience in production and application of plant nutrients, believes that sustainable agriculture is part of a solution to climate change. Using Yara's proven low-carbon footprint fertilizers and best practice application tools, the carbon footprint of crop production can be decreased by more than 50% while saving land and maintaining yields.

The conversion of land to agricultural use is one of the major global sources of GHG emissions. Arable land is scarce and it needs to be used in the most appropriate way in order to ensure food security.

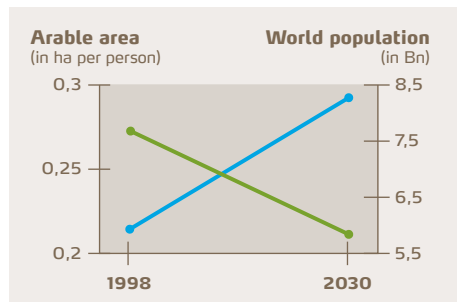


FIGURE 1: Since available arable area per capita will decrease, productivity will need to increase. [source: ref. 1]

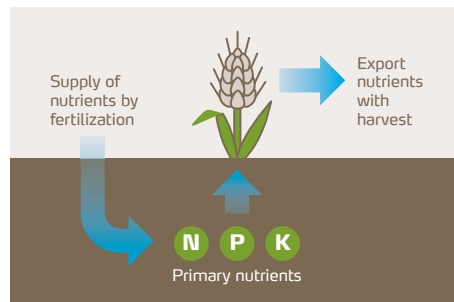


FIGURE 2: Mineral fertilizers replace nutrients exported during harvest to avoid soil depletion. N (Nitrogen), P (Phosphorus) and K (Potassium) are taken up in high quantities by plants during growth.

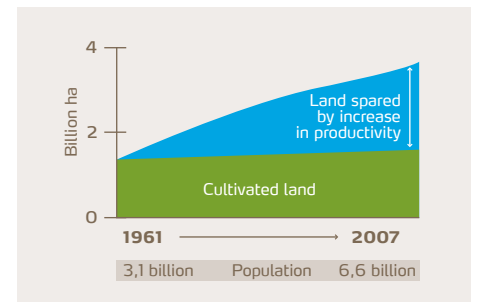


FIGURE 3: Global estimate of land required to produce sufficient food, if cereal yields had remained at the same level as in 1961. [source: ref. 3]

Life cycle perspective

A holistic approach

Production, transportation and use of mineral fertilizers contribute directly and indirectly to emissions of greenhouse gases, notably carbon dioxide (CO₂) and nitrous oxide (N₂O). At the same time, fertilizers enhance agricultural productivity and stimulate CO₂ uptake by the crop. They increase yield and reduce the necessity to cultivate new land, thus avoiding GHG emissions from land use change.

Life-cycle analysis of fertilizers determines GHG emissions and absorptions in fertilizer production, transportation and storage, as well as during application and crop growth, i.e. throughout every stage of the 'life' of a fertilizer. This allows a better understanding of what can and shall be done to improve the overall carbon balance.

On the pages to the right, Figure 4 illustrates the life cycle of ammonium nitrate (AN), the most common source of nitrogen in European agriculture. It can be found in commercial products such as CAN, NPK, NP, NK etc. The illustration explains the carbon footprint from production, transportation and application, to growing of crops, their consumption as food, feed or bio-energy, and the protection of natural CO₂ sinks such as forests and wetlands.

To make different GHGs comparable, they are converted into CO₂-equivalents (CO₂-eqv). For example 1 kg N₂O corresponds to 296 kg CO₂-eqv, as it has a 296 times stronger effect on the climate than CO₂. To further ease comparisons, all data are expressed per kg of nitrogen applied.

Optimizing fertilizer production

Ammonium nitrate (AN) is made up of ammonia and nitric acid. Its carbon footprint depends on the energy consumption and the feedstock used in the ammonia production, as well as the N₂O emissions from nitric acid production.

EU has defined "best available techniques" (BAT) for these processes. Using BAT results in a total emission of 3.6 kg CO₂-eqv per kg N for fertilizers that use ammonium nitrate as the nitrogen source, which is the predominant case in Europe. This is 50% less than the emissions of an average European plant not operating with BAT. Plants outside Europe generally have even higher footprints than average European plants [source: ref. 4, 5 and 6].

Yara's plants are rated amongst the most energy efficient in the world. Yara has also developed and implemented catalyst technology reducing N₂O emissions from nitric acid plants by as much as 90%. As a result, Yara's fertilizers sold in Nordic countries have a low carbon footprint, below the European BAT level, and are fulfilling the emission standard set by the Swedish food industry for climate branding (4 kg CO₂ per kg N) [source: ref. 7].

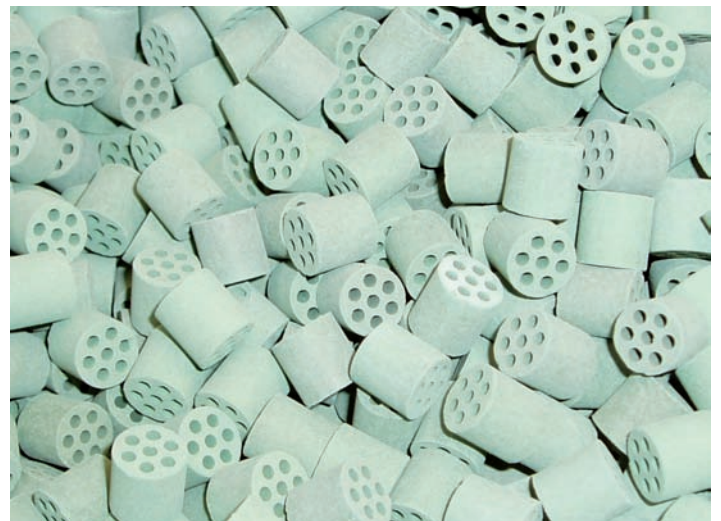


FIGURE 5: Catalyst prills. Catalytic cleansing technology developed by Yara abates about 90% of N₂O emissions.

A FERTILIZER PRODUCTION

When operating with 'Best Available Technique' (BAT) ammonia and nitric acid plants, the total carbon footprint of AN is 3.6 kg CO₂-eqv per kg N.

Ammonia production

Binding nitrogen from the air requires energy. Natural gas is the most efficient energy source. Yara plants are among the best performers in terms of energy efficiency worldwide.

- European average energy consumption: 35.2 GJ per ton ammonia
- EU BAT energy consumption: 31.8 GJ per ton ammonia (= 2.2 kg CO₂ per kg N in AN)

Nitric acid production

Nitric acid is used for making AN-based fertilizers. Its production releases N₂O. Catalytic cleansing developed by Yara reduces N₂O emissions below BAT level.

- N₂O emission without cleansing: 7.5 kg N₂O per ton nitric acid
- EU BAT emission with cleansing: 1.85 kg N₂O per ton nitric acid (= 1.3 kg CO₂-eqv per kg N in AN)

Solidification

AN solutions made from ammonia and nitric acid are granulated or prilled to form high-quality solid fertilizer. Solidification needs energy.

- European average energy consumption: 0.5 GJ per ton of product (= 0.1 kg CO₂ per kg N in AN)

MITIGATION POTENTIAL:

- Improve the energy efficiency of ammonia production and other production systems
- Install and further optimize catalytic cleansing of N₂O

B TRANSPORTATION

Ammonium nitrate is transported by ship, barge, road or rail.

- European average: 0.1 kg CO₂ per kg N

MITIGATION POTENTIAL:

- Optimize logistics chain from production sites to farmers

C FERTILIZER USE

Nitrogen, whether from organic or inorganic sources, is subject to natural microbial conversion in the soil. During this process N₂O can be lost to the air. In addition, CO₂ is also released by liming and farming machinery.

- Average footprint for AN: 5.6 kg CO₂-eqv per kg N

MITIGATION POTENTIAL:

- Assure balanced nutrition
- Tailor N-application according to actual crop needs
- Use placement fertilization when appropriate
- Just-in-time application to ensure rapid uptake
- Use of precision farming tools (N-Sensor, N-Tester, online applications)
- Maintain good soil structure (draining, avoid packing)
- Select appropriate fertilizer (AN or CAN based rather than ammonium or urea)
- Efficient manure management

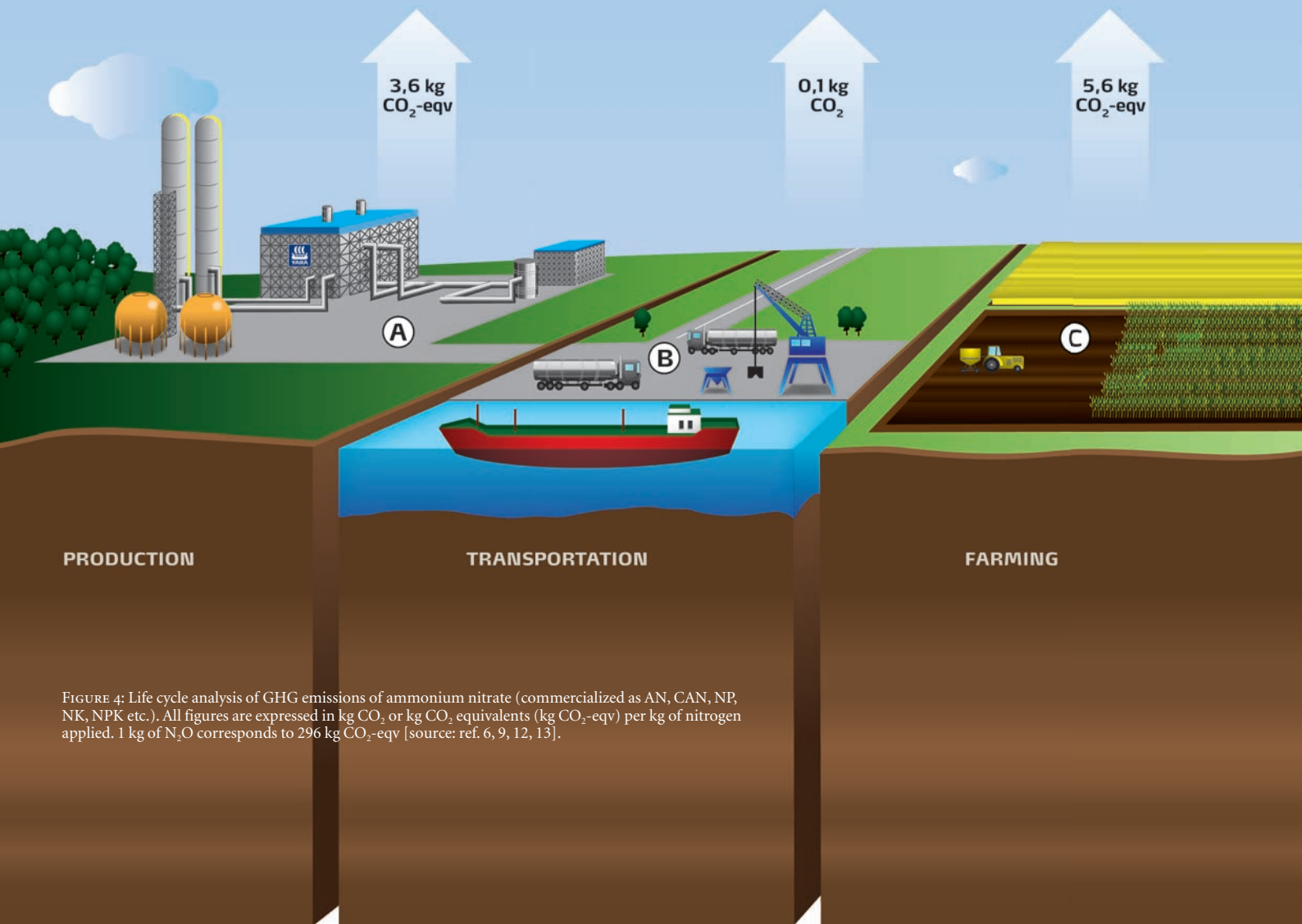


FIGURE 4: Life cycle analysis of GHG emissions of ammonium nitrate (commercialized as AN, CAN, NP, NK, NPK etc.). All figures are expressed in kg CO₂ or kg CO₂ equivalents (kg CO₂-eqv) per kg of nitrogen applied. 1 kg of N₂O corresponds to 296 kg CO₂-eqv [source: ref. 6, 9, 12, 13].

D BIOMASS PRODUCTION

Plants capture large amounts of CO₂ during growth. Optimum fertilization can increase biomass production, and thus CO₂ uptake, by a factor of 4-5 compared to fields that remain long-term unfertilized. For example, at a yield of 8 t / ha achieved with 170 kg N / ha, the grain fixes 12 800 kg / ha of CO₂. This corresponds to 75 kg of CO₂ fixed per kg of N applied.

- Example footprint: -75 kg CO₂-eqv per kg N

MITIGATION POTENTIAL:

- Ensure optimal fertilization to increase biomass production and CO₂ uptake per ha.
- Avoid land-use change at one place to compensate for reduced efficiency at another place
- Preserve and improve soil carbon stocks by increased inputs of organic material to the soil (e.g. residues) and conservation tillage techniques
- Catch and cover vegetation in between actual crops in order to reduce N leaching losses and to produce additional CO₂-fixing biomass
- Restore degraded agricultural land

E BIOMASS CONSUMPTION

Most of the biomass produced is consumed as food or feed. CO₂ fixation is therefore only short term and cannot be considered a saving on a global scale. The balance is different for bio-energy since it avoids the burning of fossil fuels. For example, using biomass instead of mineral oil for heating purposes reduces the CO₂ emission by as much as 70-80%.

MITIGATION POTENTIAL:

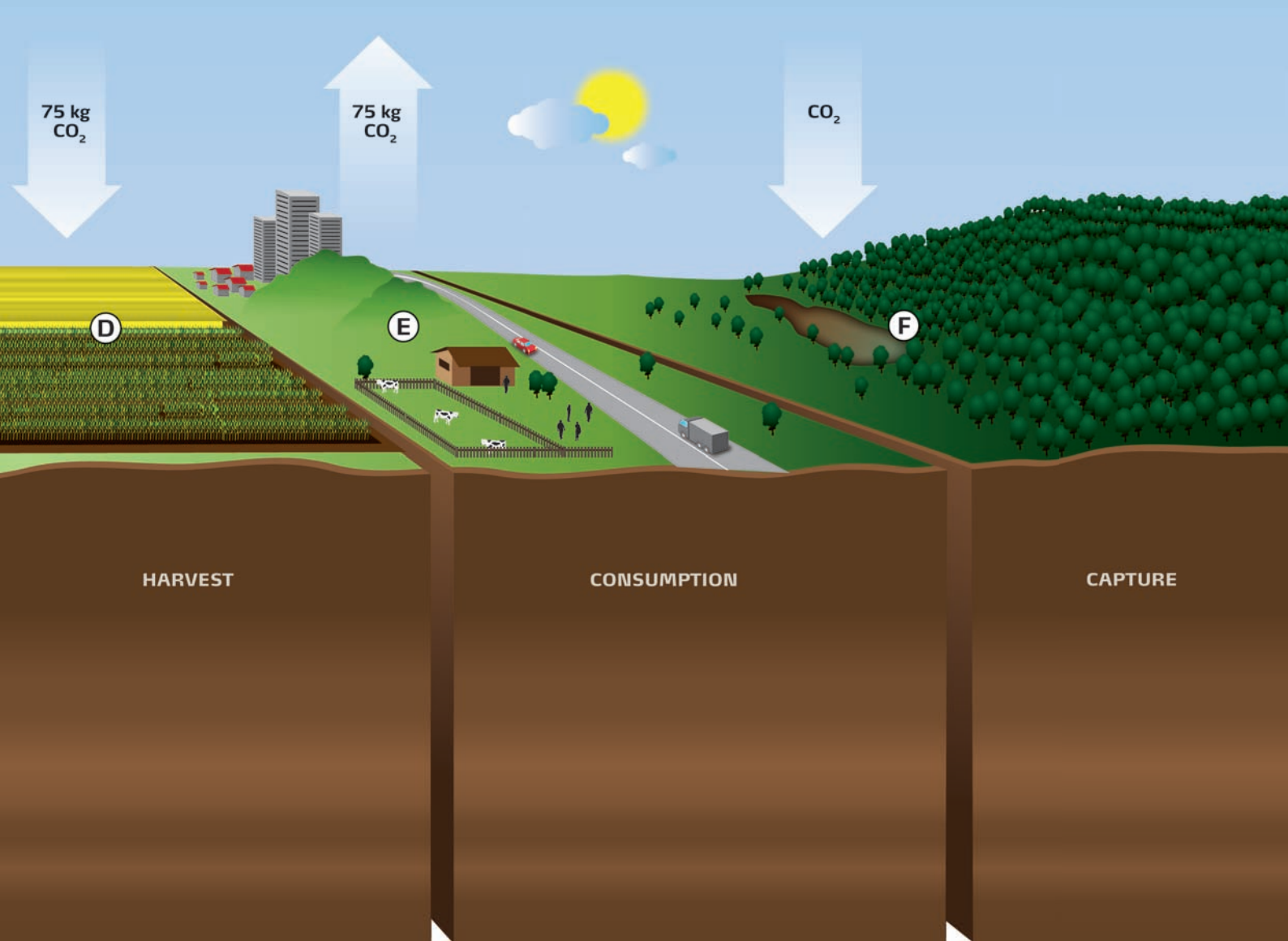
- Optimize efficiency of bio-energy production
- Increase productivity in food and feed production, allowing more acreage for bio-energy production

F FOREST AND WETLANDS

Forests and wetlands store 2-8 times more CO₂ than croplands. Land use change, mainly due to burning of tropical forests, is a large source of CO₂ emissions, accounting for 20% of manmade CO₂ emissions. Preserving tropical and boreal forests is the most important contribution to mitigate climate change.

MITIGATION POTENTIAL:

- Protect tropical forests and wetlands
- Reforestation, restoration of wetlands
- Forest fertilization to increase long-term carbon capture
- Avoid further land-use change by increasing productivity on existing agricultural land





Optimizing fertilizer use

The overall impact and mitigation potential of fertilizer management with regard to GHG emissions is important (Figure 6). The average carbon footprint from using AN fertilizer is 5.6 kg CO₂-eqv per kg applied N [source: ref. 3]. Improved nitrogen management can reduce the emissions significantly, depending on soil and weather conditions.

Growers need to ensure that the form and type, as well as amount and timing of nitrogen being applied will not result in significant losses due to denitrification, volatilization or leaching. A good soil structure further increases N-use efficiency and reduces N₂O losses. Optimizing N efficiency does not only reduce climate and other environmental impact, but it is also a key in maintaining and even increasing productivity and profitability.

Crop nutrition programs developed by Yara help to choose the right product and apply it in the most efficient way. An array of management tools such as the N-Sensor™ and the N-Tester™ as well as software applications such as the Internet based Megalab™ assist farmers in keeping profitability up and environmental impact down.

In agriculture as in any other domain, less is sometimes more. A field study conducted on multiple farms in Germany [source: ref. 8] examined the effect of fertilizer application using the N-Sensor. The findings demonstrated that use of the N-Sensor increased yields by 6% while reducing N fertilizer use by 12%. This increase in N efficiency reduces the carbon footprint by 10 to 30%.

Avoiding land use change

Arable land is a scarce resource that needs to be used in the most appropriate way in order to ensure food security without further land use change. Clearing of native vegetation such as rain forest accounts for up to 20% of world GHG emissions [source: ref. 10]. Stopping land-use change and deforestation therefore is a primary objective in climate protection.

The amount of carbon stored in forests and wetlands is the highest of all land types. On the other hand, cropland has the lowest carbon content of all land types, except for deserts and semi-deserts. Intensification of arable production can save rainforests, grassland savannahs and wetlands from being converted into croplands. It therefore has a positive effect on carbon balance [source: ref. 11, 12, 13].

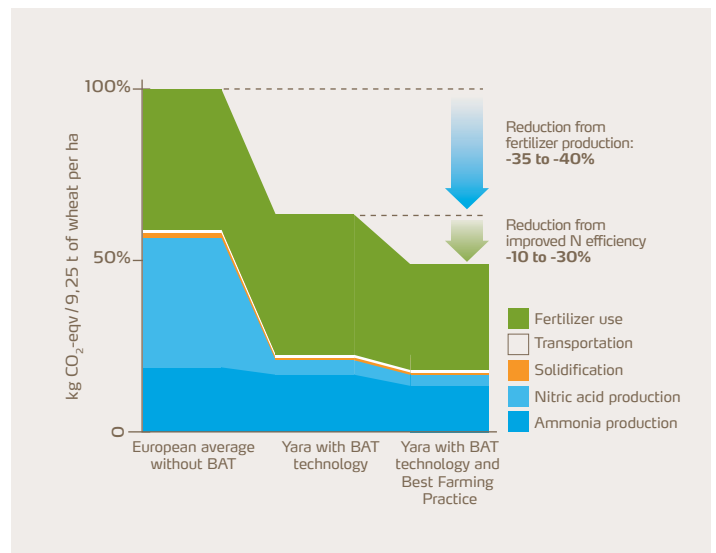


FIGURE 6: Yara has reduced the carbon footprint of nitrate fertilizer production by 35 - 40%. Enhancing N efficiency in fertilizer use can contribute by another 10-30% [source: ref. 8, 9].

Which fertilizer to use?

In many regions of the world, urea is used as a source of nitrogen. Under European climate and soil conditions though, ammonium nitrate based fertilizers (such as AN, CAN, ammonium nitrate based NPKs) have proved to be the most efficient for farmers and more environmentally friendly than urea.

Urea has a lower carbon footprint at the production stage of the fertilizer life cycle than ammonium nitrate. This is mainly due to the fact that part of the CO₂ generated in ammonia production is captured in the urea. However, the CO₂ is released as soon as the urea is spread on the field. In addition, more N₂O is emitted from urea by the nitrification process.

Urea also emits more ammonia to the atmosphere during farming than AN, increasing the risk of not meeting the national limits on emissions of acidifying substances defined by the Gothenburg Protocol. The loss of ammonia from urea also requires higher dosage to compensate for higher losses. In conclusion, the actual life cycle carbon footprint of urea is higher than that of ammonium nitrate.

Reducing our footprint

Carbon footprint guarantee

Yara is committed to provide information on its carbon footprint. This enables farmers, retailers and other stakeholders in agriculture to make decisions according to environmental considerations and thus minimize the climate impact of farming.

- Yara guarantees that the carbon footprint for fertilizers produced by Yara as of January 1st, 2010 for sale in Denmark, Finland, Norway and Sweden is below 4 kg CO₂-eqv per kg N.
- Yara's guarantee supports the initiative of the Swedish food industry for setting emission standards for food production. Yara supports application of this initiative internationally.
- Yara carbon footprint is verified by an independent third party, DNV (Det Norske Veritas).
- Yara has developed and installed catalyst technology for the reduction of GHG emissions from the production of nitric acid (nitrous oxide, N₂O). The technology qualifies as Best Available Technique, as defined by the EU Directive on Integrated Pollution Prevention and Control.
- Yara promotes its catalyst technology to be used by fertilizer producers worldwide.
- Yara's manufacturing sites are certified to ISO 9001 (quality management) and ISO 14001 (environmental management) by DNV, and are certified by SGS (Société Générale de Surveillance) to satisfy the European fertilizer industry's Product Stewardship Program.
- Yara shares its knowledge on plant nutrition and best farming practice with the agricultural community in order to optimize fertilizer use and reduce the environmental impacts and carbon footprint of agriculture.





Knowledge grows

For further information please contact:
Yara International ASA
Bygdøy allé 2,
P.O. Box 2464, Solli
N-0202 Oslo, Norway
www.yara.com

Literature

- [ref. 1] Food and Agriculture Organization of the United Nations (2003): World Agriculture towards 2015/2030. An FAO Perspective. Ed. Jelle Bruinsma, Earthscan Publications Ltd, London, UK.
- [ref. 2] Erisman J.W., M.A. Sutton, J. Galloway, Z. Klimont, W. Winiwarter (2008): How a century of ammonia synthesis has changed the world. *Nature Geoscience* 1: 636-639.
- [ref. 3] Fertilizers, Climate Change and Enhancing Agricultural Productivity Sustainably. IFA (2009).
- [ref. 4] IPCC Reference Document on Best Available Techniques for the Manufacture of Large Volume Inorganic Chemicals - Ammonia, Acids and Fertilizers, EU Commission, August 2007.
- [ref. 5] Energy Efficiency and CO₂ Benchmarking of European Ammonia Plants - Operating Period 2007-08, Plant Surveys International Inc, December 2009.
- [ref. 6] Methodology for calculating the carbon footprint of AN-based fertilizers (2010), www.yara.com
- [ref. 7] Climate labeling for food (2009), www.klimatmarkningen.se/in-english/
- [ref. 8] Agri Con GmbH (2010), www.agricon.de
- [ref. 9] Brentrup F., Palliere C. (2008): GHG Emissions and Energy Efficiency in European Nitrogen Fertiliser Production and Use. Proceedings of the International Fertiliser Society 639. York, UK.
- [ref. 10] IPCC (2007): Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland.
- [ref. 11] Food and Agriculture Organization of the United Nations (2006): Livestock's long shadow - environmental issues and options. FAO, Rome, Italy.
- [ref. 12] Bellarby J., Foeroid B., Hastings A., Smith P. (2008): Cool Farming: Climate impacts of agriculture and mitigation potential. Greenpeace International, Amsterdam, NL.
- [ref. 13] Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko (2007): Agriculture in Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

About Yara

Yara International ASA is a global company specializing in plant nutrition and industrial solutions. As the world's largest supplier of mineral fertilizers, Yara helps provide food and renewable energy for a growing world population. Our products are also used to cleanse the air and eliminate toxic gas. The company is based in Norway and has about 7,600 employees with operations in more than 50 countries.

