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REDUCING THE ENVIRONMENTAL IMPACT OF CHEMICAL FERTILIZERS IS INCREASINGLY IMPORTANT FOR SUSTAINABLE AGRICULTURE

— IT IS ALSO SPURRING ON THE CREATION OF NEW BUSINESS —

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SUMMARY

- It is essential to increase food production to accommodate a global population that is expected to grow to nearly 10 billion by 2050, and chemical fertilizers are indispensable. However, chemical fertilizers have a significant environmental impact. The environmental impact of chemical fertilizers consists of GHG emissions during production and pollution due to environmental runoff during use, and these impacts need to be reduced.
- Keys to reducing the environmental impact of chemical fertilizers include (1) decarbonization of the production process, and (2) prevention of environmental runoff during use. In the case of (1), the challenge is the decarbonization of the Haber-Bosch process, an energy intensive process for producing ammonia, which is the main raw material of fertilizers. Initiatives to tackle (2) include, managing the application of fertilizers to soil to minimize their use, monitoring of the runoff from farmland of fertilizer that is not absorbed within the soil, and technologies to increase the efficiency of fertilizer use. This report outlines the current issues and promising technologies for tackling them.

1. WHY WE NEED TO REDUCE THE ENVIRONMENTAL IMPACT OF CHEMICAL FERTILIZERS

Chemical fertilizers are chemically processed fertilizers made from minerals and other natural substances. They are produced industrially and are characterized by low cost and stable quality.

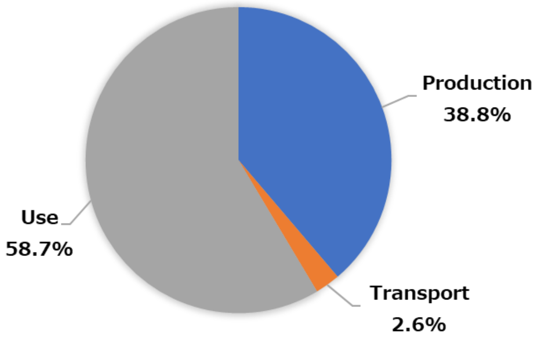
Nitrogen is an extremely important element in food production. Many chemical fertilizers contain nitrogen, which is an essential ingredient for supporting food production to meet the needs of a growing population that is expected to reach approximately 10 billion by 2050. Meanwhile, there is also concern that chemical fertilizers place a burden on the environment. The challenges are decarbonization in chemical fertilizers production and optimization in nitrogen cycling. In terms of decarbonization, for example, the full process for nitrogen fertilizer (from production to use) accounts for 2.1% of total GHG (greenhouse gas) emissions. The largest share of these emissions arises during production and use, with approximately 39% occurring during the production process and about 59% during use, while the remainder occurs during transportation[1] (Figure 1). It has been pointed out that the emissions that occur during use give rise to issues relating to the circulation of nitrogen. It is said that only about half of the ammonia used to make nitrogen fertilizer contributes to crop growth, while the remaining ammonia that is not returned to the atmosphere as nitrogen gas causes environmental pollution, including an increase in greenhouse gas and the eutrophication of rivers.

[1] Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture | Scientific Reports (nature.com)

It is against this backdrop that the EU has set an ambitious goal of reducing the use of chemical fertilizers by 20% by 2030 under its Farm to Fork strategy with the aim of achieving sustainable agriculture. Japan has also set a target of reducing chemical fertilizer use by 20% by 2030 compared to the 2016 level. However, there are concerns that simply reducing the amount of fertilizer used will lead to a decline in production[2].

In the future, chemical fertilizers are expected to play a vital role in supporting increased food production, and attention should be paid to how to reduce their environmental impact.

Figure 1 GHG emissions from chemical fertilizers



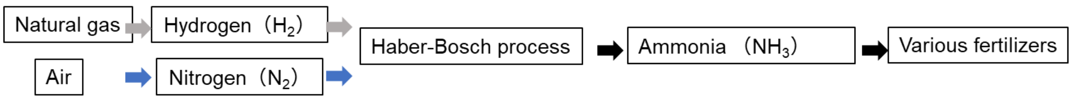
Source: Created by MGSSI based on scientific reports 12 (August 2022), "Greenhouse gas emissions from global production and use of nitrogen synthetic fertilizers in agriculture".

2. THE ENVIRONMENTAL IMPACT OF CHEMICAL FERTILIZERS

2-1. Challenges in production: Decarbonization of ammonia, the principal raw material for chemical fertilizers

Ammonia, which is one of the raw materials for chemical fertilizers, is produced using the Haber-Bosch process, in which hydrogen is extracted from petrochemical resources such as natural gas and reacted with nitrogen in the air (Figure 2). The nitrogen and hydrogen are mixed in a ratio of 1:3 by volume, and ammonia is created under conditions of high temperature and pressure ranges of 500 to 600°C and 200 to 500 atm using an iron-based catalyst. Energy consuming processes such as this are more efficient when conducted on a large scale. The Haber-Bosch process is a technology for converting nitrogen, which makes up 78% of the air in the atmosphere, into ammonia, which is a raw material used to produce nitrogen fertilizer. It is no exaggeration to say that food production is so dependent on the Haber-Bosch process that without this technology, it is said that three billion of the world's population would go unfed.

Figure 2 Schematic of the Haber-Bosch fertilizer production process

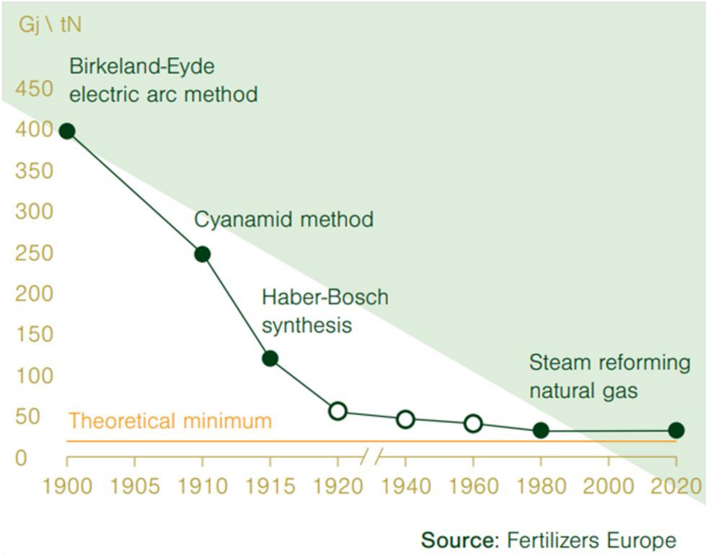


Source: Created by MGSSI based on various sources

Since its invention in 1906, the Haber-Bosch process has undergone continual improvement and been made more energy efficient, but optimization of the method is now close to its theoretical limit (Figure 3). At the same time, the need for decarbonization and increased food production requires more environmentally friendly methods of ammonia production.

[2] Impact assessment of EC 2030 Green Deal Targets for sustainable crop production — Research@WUR

Figure 3 Energy requirements for ammonia production



Source: Fertilizers Europe,"Paving the way to green ammonia and low-carbon fertilizers"
https://www.fertilizerseurope.com/wp-content/uploads/2020/07/Paving-the-way-to-green-ammonia-and-low-carbon-fertilizers-digital.pdf

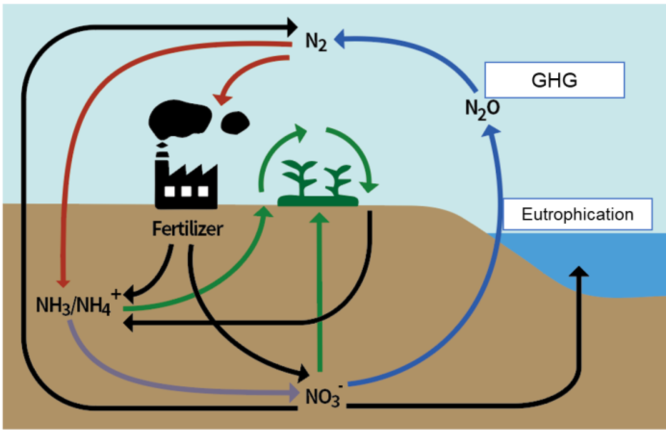
2-2. Challenges in use: Maintaining a healthy nitrogen cycle

Nitrogen fertilizers eventually become nitrate ions through the action of microorganisms in the soil. While about half of these ions are absorbed by the crop as nutrients, the ions that are not absorbed remain in the soil. Some of these ions are returned to the atmosphere as nitrogen gas, but most are washed into rivers by rainwater (Figure 4). Rivers and other waterways into which nitrate ions are discharged suffer from a proliferation of plankton and the depletion of oxygen in the water through a process of eutrophication, which threatens the survival of organisms in the water.

With the increase in nitrogen fertilizers, the level of nitrate ions exceeds that in the natural nitrogen cycle whereby nitrate ions are returned to the air as atmospheric nitrogen. As a result, nitrate ions and other forms of nitrogen continue to accumulate in the environment and impose an environmental burden.

This causes an additional negative impact on the environment as it is released into the atmosphere as nitrous oxide, which is a type of greenhouse gas. Even if decarbonization of fertilizer production were to be achieved, the impact on the environment would not change as long as excessive amounts of fertilizer continue to be used.

Figure 4 Schematic of the nitrogen cycle



Source: Created by MGSSI based on various sources

3. TECHNOLOGIES TO REDUCE THE ENVIRONMENTAL IMPACT OF CHEMICAL FERTILIZERS

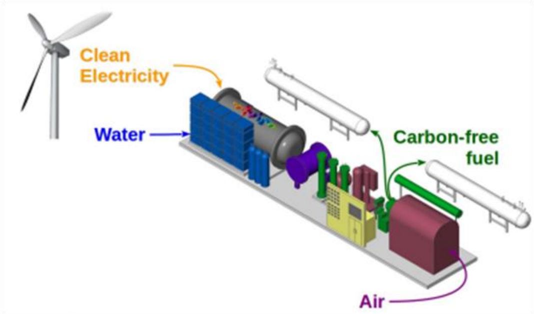
3-1. Technologies to reduce the environmental impact from production

Efforts to decarbonize the production of hydrogen, which is one of the raw materials used to make ammonia, are progressing. Hydrogen can be produced by the electrolysis of water using renewable energy. Leading

Norwegian fertilizer company, Yara, is working on one such project with the intention of starting commercial production in 2023, making it possible to reduce its carbon emissions by approximately 80-90% compared to the company's conventional products[3]. However, fertilizer companies will need to make process changes, such as replacing steam reformers with electrolyzers, and adopting large-scale hydrogen storage processes.

As far as improving the Haber-Bosch process is concerned, in recent years, attention has been focused on making improvements to the catalysts. For example, the US company Starfire Energy has improved the catalyst and developed the Rapid Ramp NH3 distributed green ammonia production module[4] (Figure 5). Not only does the company's technology allow the process to be operated at lower pressure, but it can also use power derived from renewable energy sources, which are prone to fluctuations in output. The conventional Haber-Bosch process requires a large-scale plant as well as continuous production to stabilize the process. For this reason, certain measures are required to ensure steady operation, such as storing the hydrogen used as feedstock in large tanks. In contrast, a distributed process such as that developed by Starfire can operate flexibly to cope with fluctuations in the amount of hydrogen without the need for large tanks. Denmark's Haldor Topsoe is also looking at a similar process, and it is expected to be operational in Denmark in 2023[5]. Other companies, including Japan's Tsubame BHB and the US startup ReMO Energy, are also working on similar projects.

Figure 5 Rapid Ramp NH_3



Source: Starfire Energy, "Modular, carbon-free NH_3 fuel production & use" https://www.energy.gov/sites/default/files/2021-08/7-modular-carbonfee-nh3.pdf

Alternative methods to the Haber-Bosch process are also being studied. Iceland's Atmonia is working on a method to synthesize ammonia directly using air, water, and electricity. Ammonia will be produced in water and can be used as a liquid fertilizer[6]. That being said, this process is still at the research stage and it is expected to be some time before commercialization is possible.

3-2. Technologies to reduce the environmental impact from chemical fertilizer use

The 4R Nutrient Stewardship program is one initiative that has been introduced in relation to the use of chemical fertilizers. This initiative encourages use of the appropriate type of fertilizer (Right Source) at the appropriate time (Right Time) in the appropriate amount (Right Rate) and in the appropriate place (Right Place) based on scientific principles. Following these guidelines is believed to reduce GHG emissions from fertilizer use by 15-25%[7]. Soil management using digital technology is an important element in the 4R Nutrient Stewardship program. Smart farming technology, which uses sensing technology, AI, and robotics to improve production efficiency, is also attracting attention from the perspective of reducing the environmental impact. For example, improving sensing technology will enable real-time monitoring of nutrients in soil, which can help prevent excessive application of fertilizer. In fact, by optimizing fertilizer application through smart farming, Norway's Yara has increased yields by 6% while reducing nitrogen fertilizer use by 12%[8]. Yara's handheld N-Testor sensor measures the nitrogen content of the leaves of crops, and by combining the reading with crop growth data obtained from satellite images, the company's AtFarm app recommends the appropriate amount of fertilizer

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3 https://www.yara.com/crop-nutrition/products-and-solutions/green-fertilizers/what-you-need-to-know-about-green-fertilizers/
4 https://www.mhi.com/jp/news/210409.html
5 https://blog.topsoe.com/danish-partnership-receives-support-from-the-danish-energy-technology-development-and-demonstration-program-eudp-for-worlds-first-industrial-dynamic-green-ammoni-1624599909696?utm_content=170812783&utm_medium=social&utm_source=linkedin&hss_channel=lcp-164107
6 https://www.youtube.com/watch?v=toxrl0YtUi4
7 https://unfccc.int/files/documentation/submissions_from_non-party_stakeholders/application/pdf/598.pdf
8 https://www.yara.com/crop-nutrition/why-fertilizer/environment/fertilizer-life-cycle/

to be applied (Figure 6). In addition, Yara has provided these services free of charge from 2022, making it easier for farmers to use them.

Figure 6 N-Testor gives the recommended application rate

Source: atfarm (https://www.at.farm/gb/n-tester/)

One mechanism for making fertilizer use more efficient is the use of coated fertilizers, in which the fertilizer is coated with a polymer or other substance. Water permeates the coating membrane, dissolving the fertilizer inside, which seeps into the surrounding soil gradually over time. Because the elution pattern, period, and other characteristics of the components differ, coated fertilizers can be targeted at specific crops. Since the polymer coatings ultimately remain in the soil, the use of biodegradable polymers is being pursued.

Another new trend is to focus on microorganisms in the soil to improve the efficiency of nutrient absorption. One example of this approach is a product called SOURCE sold by the US startup Sound Agriculture. By spraying SOURCE onto the foliage, the active ingredients are delivered from the crop to the soil, where they activate nitrogen-fixing bacteria in the soil in the vicinity of the crop's roots. This allows crops to use atmospheric nitrogen more effectively as a nutrient, reducing chemical fertilizer use by up to about 30%. SOURCE has been available in the US since 2020, primarily for corn and soybeans.

4. SUMMARY AND FUTURE OUTLOOK

Following is a summary of the trends in environmental impact reduction technologies related to chemical fertilizers. A substantial portion of the GHG emissions from chemical fertilizers occurs during production and use, while there are also concerns from the perspective of maintaining a balanced nitrogen cycle. In the case of production, efforts are being made to decarbonize the hydrogen used as a feedstock and to improve the Haber-Bosch process, and studies are also underway on alternatives to the process. In terms of use, efforts have been made to improve the efficiency of fertilizers themselves, including through the adoption of the 4R Nutrient Stewardship program and smart farming, the use of coated fertilizers, and utilization of microorganisms in the soil. New initiatives in these areas are also emerging. For example, in 2022, leading Canadian fertilizer company Nutrien announced a program to pay farmers for the amount of nitrogen that they reduce in their soil through the company's Agrible digital platform. Nutrien markets its own high-efficiency fertilizers through this program. In fact, in a trial conducted in the US in 2021, farmers increased their income by $140,000 by optimizing fertilizer application, using high-efficiency fertilizers, planting cover crops[9], and other means, while Nutrien earned $200,000 from its products and services[10]. Although reducing the use of chemical fertilizers would appear to reduce the sales of fertilizer manufacturers, building win-win relationships such as this could represent a new business opportunity for the fertilizer manufacturers. It is hoped that, in the future, as technology progresses, efforts will be made to reduce the environmental impact of chemical fertilizers through such business mechanisms.

[9] A farming method that involves cultivating mainly leguminous crops and plowing them back into the soil as nutrients rather than harvesting them. It also referred to as green manure.

[10] Nutrien 2022 Virtual Investor Update