Feeding Our Food; Starving Our Environment: The Impacts of Synthetic Fertilizers

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Abstract

For thousands of years, farmers have utilized organic soil additives to enhance their crop yields and livelihoods. Today, modern agriculture relies on synthetic fertilizers to produce enough crops for our global population and its competitive markets. While these fertilizers successfully increase crop production, previous research has proven that they perpetuate long-term environmental and human health risks. My research seeks to examine how human-environment relationships with fertilizers have changed over time and how capitalism influences the socio-environmental impact of synthetic fertilizers on our world today. Through the Institutions and Commons lens, I examine how fertilizer-related pollution and limited fertilizer regulations pose significant risks to the environmental commons of society and to the health of communities. Additionally, I utilize the Political Economy perspective to examine how capitalistic greed in the fertilizer industry has significantly contributed to global warming, overproduction of resources, and an altered human perception of nature as a whole. While there are advantages of synthetic soil-enhancement technologies, it is clear that more stringent agricultural regulations and responsibility measures are needed to minimize the negative long-term consequences of synthetic fertilizer use in modern farming practices.

Introduction

Agriculture has relied on human intervention for centuries, with each farmer's goal being to produce the largest, healthiest crop of the season. Additives such as manure are known to have encouraged soil health and plentiful crop yields, making fertilizer very popular in farming. As fertilizers have evolved from organic to synthetic, these additives have become an integral part of farming that agriculture simply cannot function to its fullest without. Despite the increased production and access to food that synthetic fertilizers have induced in the agricultural industry over time, a comprehensive analysis finds that the human commodification of nature through the Green Revolution has resulted in damage to the commons of society as well as the health of our environments as a whole.

The Evolution of Fertilizers

Fertilizer has evolved over centuries of agricultural practices from organic to synthetic materials. The main purpose of fertilizer is to replace the nutrients that crops extract from soils and to enhance crop growth as a whole (Wills, 2016). Specifically, fertilizers seek to add nitrogen (N), phosphorus (P), and potassium (K) into the soil, which are the three macronutrients that plants use in large concentrations as they grow (Weisenhorn, 2021).

Although it was previously accepted that the concept of fertilizer may have only dated back 2,000 to 3,000 years ago, a team led by archaeobotanist Amy Bogaard at the University of Oxford found that farmers were using manure fertilizers as long as 8,000 years ago (Hergert, Neilsen, & Margheim, 2015). At that time, the predominant source of fertilizer was manure due to its higher-than-normal concentration of N-15 nitrogen that intensified crop growth. Early farmers likely discovered the efficacy of manure by observing enhanced crop growth in areas of natural dung accumulation where animals gathered, likely from herding (Hergert, Neilsen, & Margheim, 2015). According to Gary Hergert, a Soil and Nutrient Management Specialist at the University of Nebraska Lincoln, the Babylonians, Egyptians, Romans, and early Germans later recorded using minerals or manure to increase yields on their farms. However, the most widely used method of agricultural fertilizer for the next few thousand years was manure due to its convenience and abundance on farms (Hergert, Neilsen, & Margheim, 2015).

As agriculture progressed[1], farmers in South America began using guano, referring to bird excrement, eggshells, and carcasses, to fertilize their crops. Seabird guano[2] is very rich in phosphorus and nitrogen, and it would typically be collected from large piles on buildings or natural formations. The word Guano derives from the Peruvian original language Quechua, of "Huano", meaning "dung to fertilize" (Schnug, Jacobs, & Stöven, 2018, p.3). The first written description of guano use in Incan agriculture was provided by Cieza de Leon in 1553[3]. Later in Europe, the use of Guano fertilizer emerged in 1840 and lasted until the early twentieth century when Guano was replaced by industrial manufactured fertilizers (Schnug, Jacobs, & Stöven 2018). Today, nutrient-rich seabird guano is still used to fertilize crops in smallholder farming systems in developing countries such as Egypt (Schnug, Jacobs, & Stöven, 2018). Only a small quantity of guano is still exported to Europe as an additive to boost the efficacy of organic/mineral fertilizers[4].

The first synthetic fertilizer was developed in 1903 by two German chemists, Fritz Haber and Charles Bosch. Since nitrogen can only be processed by plants when it is a part of a chemical compound[5], Haber and Bosch developed a method for producing ammonia from nitrogen and hydrogen. According to the description of Haber's 1918 Nobel Prize in Chemistry, "When nitrogen and hydrogen gases pass through an apparatus at a controlled temperature, pressure, and flow rate, and in the presence of a catalyst, ammonia is formed" (Nobel Prize, n.d., p.1). Haber and Bosch discovered how to convert nitrogen from the air into ammonia that could be used to fertilize crops. In 1913, Bosch opened a factory to produce ammonia fertilizer commercially, which spurred the development of the fertilizer industry that we know today (Hammond, 2021).

Today, an estimated 150 million tons of ammonia are produced annually, and about 70-80% of it is used for fertilizer (Statista Research Department, 2023). Haber and Bosch are credited for helping the world's growing population avoid famine by coining a fertilizer-production process that increased crop yields significantly. Many

[1] Other types of early organic fertilizers that are not expanded upon here include bone meal, blood meal, horseshoe crabs, peat, sewage sludge, and even whale carcasses (Wills, 2016).
[2] Guano can also refer to bat excrement. This was also a very popular method of fertilizer, but this section uses "guano" to refer to seabird deposits.
[3] In order to ensure a constant renewal of valuable fertilizer, entry into the strictly guarded Inca bird islands during the breeding season was prohibited under penalty of death (Schnug, E., Jacobs, F., & Stöven, K. 2015).
[4] Guano deposits began to run out in the beginning of the 20th century. Without the creation of synthetic fertilizers, it is likely that famine would have occurred (Hammond, 2021)
[5] Naturally occurring Nitrogen in the air that we breathe cannot be processed by plants, hence why Haber and Bosch designed a method converting it to a form that plants could use.

synthetic fertilizers used today such as ammonium nitrate, ammonium phosphate, and superphosphate are derived from the natural gas by-products of petroleum – in a similar fashion to the Haber-Bosch method (Zalewski, 2020). It is estimated that if average crop yields remained at their 1900 levels, before synthetic fertilizers were created, then the crop harvest in the year 2000 would have required nearly four times more cultivated land than what was actually used (Hammond, 2021). For this reason, it has become necessary for farmers to utilize synthetic fertilizers to support large crop yields and profits.

While synthetic fertilizers have been revolutionary for rapid crop growth and the food production industry, there are several drawbacks involved with artificially producing fertilizers. Organic fertilizers such as manure are composed of organic matter that improves soil structure, water retention, and the presence of microorganisms that can break down contaminants in the soil, making them ideal for soil health and plant growth (Gach, n.d). However, synthetic fertilizers purely focus on growing plants as quickly as possible and do not contain the organic matter that is necessary to maintain soil health. As discussed later in this paper, synthetic fertilizers are responsible for several environmental issues, despite their usefulness in the agricultural industry.

Overall, synthetic fertilizers have changed the way that people see the agricultural industry and farming altogether. Instead of relying on organic matter such as manure and guano to fertilize our crops, large-scale farms have adopted the widespread use of synthetic fertilizers to ensure that their crop yields are plentiful, profitable, and reliable. Farming has become less about tending to individual crops to nourish a population and more about mass-producing food for capitalistic gain, no matter the costs that these new methods may have on the environment and the people who live in it.

The Institutions and Commons: Evaluating and Mitigating Environmental Damage

The agricultural, environmental, and societal effects of synthetic fertilizers can be analyzed through the institutions and commons perspective. According to *Environment and Society: A Critical Introduction*, "The institutions and the commons view focuses on cooperative (rule-based, institutional) management of resources and solutions to solve environmental problems" (Robbins, Hintz, & Moore, 2022, p.50). When analyzing synthetic fertilizers, common property or "the commons" refers to public land, resources, and parts of the environment that everyone in a community has access to. "Institutions" refer to rules and regulations regarding fertilizer production, application, and waste management to protect the commons and humanity as a whole.

The presence of synthetic fertilizers in society can be seen in the common spaces of humanity – such as waterways, soils, and ecosystems. Pollution, eutrophication, and water toxicity display how fertilizer byproducts, runoff, and production/application processes are damaging our environment. According to the U.S. Environmental Protection Agency, "excess fertilizer applied to crops and fields make agriculture one of the largest sources of nitrogen and phosphorus pollution in the country" (EPA, 2017, p.2). Synthetic fertilizers are responsible for the largest amount of nitrogen pollution in the United States because they are the most frequently used tool across the industry to grow the most profitable crops (Codamon & Blaustein-Rejto, 2019).

When nitrogen fertilizers[6] are applied faster than plants can use it, soil bacteria convert it to nitrate. Water soluble nitrate runs off of farms and

[6] This applies to both manure and synthetic fertilizers (Codamon & Blaustein-Rejto, 2019)

pollutes nearby common spaces such as rivers, lakes, and estuaries (Schlesinger, 2015). This causes a phenomenon called eutrophication, in which an overabundance of nutrients, primarily nitrogen and phosphorus, causes overstimulated aquatic plant growth and unbalanced ecosystems. Recurrent algal blooms feed on these nutrients and completely take over both still and flowing water sources, which causes the water to turn green and malodorous. Algae resting on the top of the water blocks the sunlight for plants and animals in the water below, and – upon its death – it requires oxygen to decompose. Oftentimes, too much algae decomposing at one time drains the water of oxygen that aquatic animals and plants need to respirate, creating a hypoxic 'dead zone' environment (Water Resources Mission Area, 2019). Eutrophication from fertilizer runoff destroys ecosystems and common areas that communities may utilize for various purposes, such as recreation, water resources, and breeding grounds for local and migratory species.

In addition to eutrophication, pollution from fertilizers destroys common resources of drinking water for both animals and humans. Fertilizers applied in residential or commercial landscapes can contaminate groundwater when runoff enters waterways and leaches into well water aquifers. Nitrates are present in chemical fertilizers[7], and they are converted to nitrites once taken into the body. According to the U.S. Environmental Protection Agency, high levels of nitrate pose the most serious health risks for infants. High levels of nitrate/nitrite contamination in drinking water can cause methemoglobinemia or 'blue baby syndrome', which reduces the blood's ability to carry oxygen. Infants under six months of age who drink water contaminated by fertilizers can become seriously ill and die (US EPA, 2023).

Besides negatively affecting common water resources, synthetic fertilizers degrade soil quality. Chemical fertilizers are often used in excessive and disproportionate quantities to increase crop yields and reap as much profit as possible. Synthetic fertilizers do not contribute any organic material to the soils which impedes their capacity to provide nutrients to plants and stay healthy season after season. Overuse of chemical fertilizers can cause soil acidification from this reduction in organic matter[8]. This acidic environment limits the presence of microorganisms that are helpful to plant and soil health, and it eliminates their role among the plant's natural defenses against pests and diseases (UNAcademy, n.d). This biological response exemplifies why over-fertilization is not the key to sustainable crop growth and soil health in the long term. In the words of USDA soil researcher Rick Haney, "It's like instead of feeding your children a balanced diet, let's just feed them vitamins. That's not going to work, is it?" (Schiffman, 2017, p.12).

As seen by eutrophication, water contamination, and soil degradation, irresponsible synthetic fertilizer usage contributes to a Tragedy of the Commons. The Tragedy of the Commons was a concept developed by Garret Hardin in 1968, and it refers to humanity's tendency to exploit natural resources for an individual's own benefit despite the fact that it will eventually negatively impact the whole (Robbins, Hintz, & Moore, 2022). While runoff may not seem significantly damaging to the environment if only one farmer is contributing to it, the widespread overapplication of fertilizers has made nitrogen pollution from fertilizers increasingly more common. The tragedy of the commons can be prevented with help from the Seven Design

[7] Heavy metals such as arsenic, lead, and cadmium can accumulate in soils after repeated phosphate fertilization (in contrast to nitrogen). Risk assessments by the EPA concluded that heavy metals are typically not in large enough amounts to pose risks to public health or the environment (Minnesota Department of Health, 2023)

[8] An increased concentration of hydrogen ions in soil from ammonium-nitrogen based fertilizers causes soil acidification. In other words, the pH of the soil becomes more acidic (Brookside Laboratories, n.d)

Principles of Successful Commons, a framework that provides references and guidelines to help us understand why commons succeed or fail (Robbins, Hintz, & Moore, 2022). Guidelines such as boundaries, monitoring, and sanctions can be enforced through institutions that seek to preserve the commons.

There are several institutions that seek to regulate fertilizer use in the United States. Legal proceedings, such as the Toxic Substances Control Act (TSCA) of 1975, provide the EPA with authority to require reporting, record-keeping and testing requirements, and restrictions relating to chemical substances such as synthetic fertilizers. All chemicals found in fertilizer products must be listed in the TSCA Inventory to ensure that they abide by the EPA's safety limits (US EPA, 2016). Hazardous materials that are used for fertilizer, such as anhydrous ammonia, also have strict transportation and packing requirements to ensure the safety of humans and the environment. Under the USDOT's Federal Hazardous Materials for Transportation Regulations (HMR), anhydrous ammonia must be transported in high pressure tanks via road trailers and insulated DOT 105J series insulated tank cars by rail. These vessels of transportation must have specific PSI measurements and be labeled as a hazardous material to abide by Title 49 of the USDOT's Code of Federal Regulations (Minnesota Department of Agriculture, n.d).

There are also regulations on the U.S. fertilizer manufacturing industry. The EPA designed the Fertilizer Manufacturing Effluent Guidelines and Standards (finalized in 1986) to establish U.S. national standards for wastewater discharges to surface waters. The EPA set a limit of how much ammonia, nitrate, organic nitrogen, phosphorus, and ammonium nitrate could be released into the environment[9] during the fertilizer manufacturing process in 1974 (US EPA, 2023). Much of applied fertilizer that runs into waterways gets broken down by microbes and releases nitrous oxide into the atmosphere, a greenhouse gas 300 times more potent at warming the atmosphere than CO2 (UN Environmental Programme, n.d).

In the scope of manufacturing, the Clean Air Act regulates phosphoric acid/phosphate fertilizer processing under the National Emission Standards for Hazardous Air Pollutants (NESHAP), which ensures that air pollution from manufacturing processes does not pose a threat to human health. However, CO2 emissions from transporting fertilizers still contribute to the growing issue of global warming (US EPA, 2022).

While institutions exist to regulate fertilizer production and pollution, there is still not enough protection for the environment in the U.S. government's existing policies. For example, in the Clean Water Act of 1972, farmers are not required to obtain a permit for releasing pollutants into the waters unless they are "waters of the United States", such as navigable coastal and inland lakes and rivers (EPA, 2017, p.2). This does not protect smaller bodies of water such as ponds and streams that are still important to their respective communities. Additionally, there are not widespread regulations regarding synthetic fertilizer application itself for farmers. Instead, farmers are suggested to apply certain amounts of fertilizers based on what they are growing. For example, the Natural Resources Conservation Service of the USDA recommends that farmers use 30 to 50 lbs per acre of nitrogen fertilizers for grass pastures alone (Goodrich, 2012). This lack of institutional cstructure displays how farmers have a wide range of freedom when it comes to using synthetic fertilizers, which often results in overapplication, run-off, and damage to the commons.

[9] Specific amounts are not available and vary by farm.

Political Economy: Perpetual Supply, Demand, and Waste in Food Production

The political economy perspective can be used to examine how the agricultural industry has commodified and exploited nature through the use of synthetic fertilizers on farms. Additionally, we can examine how large corporations have damaged the environment in acts of self-interest motivated by competitive capitalist markets. According to *Environment and Society: A Critical Introduction*, "the political economy perspective encapsulates that our perspective of and relationship with nature is affected by the power and profit structures of the capitalist system" (Robbins, Hintz, & Moore, 2022, p.98). In other words, this perspective leads to commodification and exploitation of nature due to its position as a market object.

The use of synthetic fertilizers has become the norm in the agricultural industry. Synthetic nitrogen fertilizer use, in particular, has grown 800% since the 1960s, and it is projected to rise 50% by 2050. Livestock and crop separation due to factory farming has disrupted soil nutrient cycles, making the use of chemical fertilizers necessary to perpetuate crop growth (Huber, 2021). According to the USDA, "agriculture policy has been focused on 'get big or get out'" for far too long (US Department of Agriculture, 2023, p.1), and – for this reason – farmers are pressured to use synthetic fertilizers on their crops to keep up with their market competitors. Optimizing production and financial gain is the main goal of many capitalist-minded farmers today in the agricultural industry, so they can maximize profit.

Fertilizer has always been a commodity that could be bought and sold, but the effects of overaccumulation[10] today can be seen in the way that large fertilizer manufacturers take advantage of the environment in order to produce the most amount of product possible. For example, Yara International, a Norwegian chemical company, is leading in the production of nitrogen fertilizers**.** In order to maintain this position in the market, Yara International owns several phosphate pit mines, actively lobbies for fracking, and operates manufacturing plants on six continents. When one producer has so much power it means they are able to exploit the environment while still maintaining popularity in the market. Despite Yara's environmental record, their products continue to sell because of high demand from industrial scale farming. According to the political economy perspective, in order for Yara International to remain a leader in the fertilizer industry, they must prioritize profit over the environment.

The market of food production is easy to observe in contemporary life. Power-profit structures such as supermarkets, college dining halls, and large food supply corporations require massive amounts of food in order to function, and every farm wants to be the one providing products to these big-buyers. Synthetic fertilizers have been a revolutionary tool to ensure that crop yields are viable, profitable, and plentiful – regardless of potential environmental challenges that may otherwise impede crop growth and harvesting. Amidst a market of rising fertilizer prices[11], farmers who do not have access to these resources may find themselves out of business altogether (Merrigan, 2022) due to crop failure, low production, and subsequent loss of customers. Crop enhancement has resulted in large demands for crops with quick turnaround times, creating competition between farms who strive to maximize yield and speed.

At the same time, a seemingly never-ending supply of food, thanks to rapid growth from synthetic fertilizers, means food waste is higher than ever before. Food waste as a result of overproduction

[10] Too much power held in too few individuals and/or organizations
[11] Higher natural gas prices correlate to higher fertilizer prices (Huber, 2021)

displays how the agricultural industry prioritizes capitalistic gain over feeding people with the products they produce. In the United States, 40% of edible food is wasted, which amounts to about $218 billion worth of products per year (Center for Biological Diversity, 2019). Half-eaten sandwiches, discarded salads, and other uneaten foods—which sit and emit methane gases as they decompose—account for the largest source of trash in U.S. landfills. According to the Center for Biological Diversity, wasted food accounts for 18% of the country's methane emissions, a greenhouse gas that is 87 times more potent than carbon dioxide over a 20-year period (Center for Biological Diversity, 2019).

The Second Contradiction of Capitalism examines the tendency for capitalism to undermine the environmental conditions for its own perpetuation, which can be seen today through the impact of food waste on climate change. Synthetic fertilizers exemplify how farms prioritize growing more crops and making more money selling them, even if they're never actually consumed – leading to heightened emissions from decomposition. Greenhouse gas emissions from food waste are one of the many causes of global warming that can be attributed to the widespread use of synthetic fertilizers. If synthetic fertilizers continue to perpetuate intense crop yields and competition between farms and buyers, the consequences of capitalism in the form of environmental and social damage[12] will worsen.

The production of nature, or the idea that the environment is now a product of human industry, can be seen in how the agricultural industry and demanding food markets have caused farmers to rely on technology developed during the Green Revolution. With farms that have dominated open land and fertilizers that have spiked natural crop growth, it is nearly impossible to see the environment as a separate entity from humanity today. Fertilizers made through the Haber-Bosch process and those enriched with ammonium nitrate allow the crops that we eat to be grown at an unnaturally rapid speed, as they have to be in order for farmers and corporations to maximize their profit. Fertilizer use in the food production industry exemplifies how humans have dramatically altered our environment with technologies and chemicals meant for our immediate benefit, even if they contribute to our impending environmental destruction.

Conclusion

Agricultural fertilizers have evolved over time into the synthetic fertilizers that the industrialized world most commonly utilizes today. From manure, to guano, to the first synthetic fertilizers, soil additives have always been an important part of farming productivity and efficacy. While synthetic fertilizers are revolutionary in agriculture and crucial to maintaining the crop yields necessary to support our global population, they must be managed responsibly in order to avoid harming our commons—such as our drinking water, lakes, and ecosystems. It is apparent that many decisions that farmers make about synthetic fertilizers are unfair transactions between humans and the environment, which cannot continue to be the norm. While policies and regulations exist to institutionalize fertilizer use, there is still a long road towards properly holding agricultural systems accountable.

In the future, agricultural industries must prioritize protecting nature instead of producing the most products possible. It is important to recognize that the commodification of synthetic fertilizers for capitalistic benefit is detrimental to a human-environment relationship that encourages

[12] Synthetic fertilizers will likely continue causing greenhouse gas emissions and competition-fueled overproduction resulting in food waste. If this becomes too costly for small farmers, they may go out of business.

environmental longevity and protection rather than wealth-driven greed. Overall, our relationship with synthetic fertilizers as humans displays the importance of maintaining balance in nature to ensure that our wildlife, ecosystems, and human societies remain healthy in the future. While synthetic fertilizers offer humans instant gratification in the form of plentiful crop yields and profits, the long-term effects of the agricultural industry's capitalism-fueled interests can already be seen today in the destruction of our largest common resource: our planet.

References

Brookside Laboratories (n.d.). "The Role of Nitrogen Fertilizer on Soil Ph." *The Role of Nitrogen Fertilizer on Soil pH | Brookside Labs*, www.blinc.com/role-nitrogen-fertilizer-soil-ph#:~:text=As%20the%20ammonium%2DN%20in,be%20increased%2C%20thus%20reducing%20pH. Accessed 10 Dec. 2023.

Center for Biodiversity (2019). Food waste is trashing the planet. *Take Extinction Off Your Plate* https://www.biologicaldiversity.org/takeextinctionoffyourplate/waste/index.html#:~:text=Not%20only%20do%20we%20waste,faster%20rate%20than%20our%20population.

Codamon, A. & Blaustein-Rejto, D. (6 May 2019). "The Environmental Case for Synthetic Fertilizer." *The Breakthrough Institute*. thebreakthrough.org/issues/food-agriculture-environment/synthetic-fertilizer-infographic#:~:text=Nitrogen%20pollution%20is%20a%20pressing,contribute%20to%20greenhouse%20gas%20emissions.l.

Entine, J. (2022, August 19). Fritz Haber and Carl Bosch: The chemists who revolutionized fertilizer production and "changed the world for the better." *Genetic Literacy Project.* https://geneticliteracyproject.org/2021/01/29/fritz-haber-and-carl-bosch-the-chemists-who-revolutionized-fertilizer-production-changing-agriculture-forever/

Gach, J. (n.d). "Understanding Synthetic vs Organic Fertilizers." *Hortitech Direct*, https://www.enviroingenuity.com/articles/synthetic-vs-organic-fertilizers.html, expert.hortitechdirect.com/article/115-synthetic-vs-organic-fertilizers.

Goodrich, K (2012). "Pasture Fertilization" *Natural Resources Conservation Service*. https://www.nrcs.usda.gov › https › ContentStream

Hergert, G., Neilsen, R., & Margheim, J. (2015, March 15). *Fertilizer history Part 1*. CropWatch. University of Nebraska at Lincoln Institute of Agriculture and Natural Resources. https://cropwatch.unl.edu/fertilizer-history-p1

Hergert, G., Neilsen, R., & Margheim, J. (2015, March 27). *Fertilizer history Part 2*. CropWatch. University of Nebraska at Lincoln Institute of Agriculture and Natural Resources. https://cropwatch.unl.edu/fertilizer-history-p2

Huber, B. (2021, November 1). *Report: Fertilizer responsible for more than 20 percent of total agricultural emissions.* Food and Environment Reporting Network. https://thefern.org/ag_insider/report-fertilizer-responsible-for-more-than-20-percent-of-total-agricultural-emissions/#:~:text=The%20amount%20of%20synthetic%20nitrogen,United%20Nations%20(FAO)%20estimates.

Merrigan, K. (2023, June 14). *Fertilizer prices are soaring – and that's an opportunity to promote more sustainable ways of growing crops.* The Conversation. https://theconversation.com/fertilizer-prices-are-soaring-and-thats-an-opportunity-to-promote-more-sustainable-ways-of-growing-crops-183418

Minnesota Department of Health (2023, April 25). "Heavy Metals in Fertilizers." *Heavy Metals in Fertilizers - MN Dept. of Health*, www.health.state.mn.us/communities/environment/risk/studies/

metals.html#:~:text=Analytical%20testing%20of%20a%20wide,nitrogen%2C%20potash%2C%20gypsum). Accessed 10 Dec. 2023.

No Kid Hungry by Share Our Strength. (2023, February 10). *Childhood Hunger in Colorado*. https://bestpractices.nokidhungry.org/sites/default/files/breakfast-nudges_0.pdf

Nobel Prize Outreach. (n.d.). The Nobel Prize in Chemistry 1918: Fritz Haber Nobel Diploma. https://www.nobelprize.org/prizes/chemistry/1918/haber/facts/

Robbins, P., Hintz, J. G., & Moore, S. A. (2022). Environment and Society. Retrieved from https://platform.virdocs.com/read/2156464/32/#/4/2/4[b2-dl-0001]/2/50/2/2/2[rgl-13],/1:0,/1:0

Schiffman, R. (2017, May 3). *Why it's time to stop punishing our soils with fertilizers*. Yale E360. https://e360.yale.edu/features/why-its-time-to-stop-punishing-our-soils-with-fertilizers-and-chemicals

Schlesinger, William H. (2015, June 3). "The Downside of Nitrogen Fertilizer". *Cary Institute of Ecosystem Studies*. www.caryinstitute.org/news-insights/podcast/downside-nitrogen-fertilizer.

Schnug, E., Jacobs, F., & Stöven, K., (2018). Guano: The White Gold of the Seabirds. InTech. doi: 10.5772/intechopen.79501

UNAcademy (2022, March 14). *Artificial fertilisers-harmful effects of artificial fertilisers*. https://unacademy.com/content/nda/study-material/chemistry/artificial-fertilisers-harmful-effects-of-artificial-fertilisers/#:~:text=Waterway%20pollution%2C%20chemical%20burn%20to,problems%20that%20chemical%20fertilisers%20problems.&text=Synthetic%20fertilisers%20are%20said%20to,microbes%2C%20according%20to%20some%20sources

UN Environmental Programme (n.d). *Four reasons why the world needs to limit nitrogen pollution*. https://www.unep.org/news-and-stories/story/four-reasons-why-world-needs-limit-nitrogen-pollution#:~:text=Nitrogen%20is%20a%20key%20contributor,the%20atmosphere%20than%20carbon%20dioxide.

US Environmental Protection Agency (2022, December 30). Clean Air Act standards and Guidelines for Mineral Processing. https://www.epa.gov/stationary-sources-air-pollution/clean-air-act-standards-and-guidelines-mineral-processing

US Environmental Protection Agency (2017, January 19). *Fact Sheet Agriculture - US EPA*, https://19january2017snapshot.epa.gov/nutrientpollution/sources-and-solutions_.html#:~:text=The%20primary%20sources%20of%20nutrient,phosphorus%20pollution%20in%20the%20country.

US Environmental Protection Agency (2023, June 26). Fertilizer Manufacturing Effluent Guidelines | US EPA. https://www.epa.gov/eg/fertilizer-manufacturing-effluent-guidelines

US Environmental Protection Agency (2023, February 16). Potential well water contaminants and their impacts | US EPA. https://www.epa.gov/privatewells/potential-well-water-contaminants-and-their-impacts

USDA Press. (2023, May 4). *Fact sheet: USDA is fighting for fair, competitive, and transparent markets.* https://www.usda.gov/media/press-releases/2023/05/04/fact-sheet-usda-fighting-fair-competitive-and-transparent-markets

Water Resources Mission Area (2019, March 3). "Nutrients and Eutrophication Active." *Nutrients and Eutrophication | U.S. Geological Survey*, www.usgs.gov/mission-areas/water-resources/science/nutrients-and-eutrophication#overview.

Wills, M. (2016, May 4). Are we entering a new Golden Age of Guano? - JSTOR DAILY. https://daily.jstor.org/golden-age-of-guano/

Weisenhorn, A. J. (2021, March 23). *Ask extension: Do fertilizers help or hurt plants?*. University of Minnesota Extension. https://extension.umn.edu/yard-and-garden-news/ask-extension-do-fertilizers-help-or-hurt-plants

Zalewski, A. (2020, May 7). *Petroleum in real life: Food, fertilizer and Fuel*. Context Magazine by CAPP. https://context.capp.ca/articles/2020/pirl-fertilizers/