SASTA OLIPHANT SCIENCE AWARDS

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Science Writing

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How do nitrogen-based fertilisers affect global warming and the environment?

Introduction

Nitrogen is a key element that contributes to the facilitation of life on earth. All living organisms require nitrogen. To maintain and support the current and growing human population of the earth there needs to be a steady supply of nitrogen to humans through things like food. To support the ever-increasing food demands over time, farming practices have evolved to increase the production and yield of crops. One of these practices that was implemented to increase food production is the introduction of nitrogen-based fertilisers.

Nitrogen based fertilisers serve to rejuvenate the soil from previous crop harvests by reintroducing nitrogen directly into the soil through the application of fertiliser. The widespread adoption of nitrogen-based fertilisers eliminated the need to rotate crops seasonally to allow the soil to revitalise, which increased the number of crops that can be farmed at any one time and opened the door to more industrial farming processes to farm even larger numbers of crops.

The drawback of nitrogen-based fertilisers is their negative effects on the environment through the release of NOx gases and nitrous oxide which is a highly potent greenhouse gas that increases the rate of global warming when present in the atmosphere. Global warming is caused by an increased concentration of greenhouse gases in the atmosphere that absorb infrared light travelling into space and keep it in the atmosphere, causing the atmosphere to warm.

Nitrogen based fertilisers have been revolutionary for the world because it opened the door for consistent and large-scale farming practices that produce more crop and can support populations more readily. Society has become highly dependent on nitrogen-based fertilisers to ensure adequate food production, but the effects that the fertilisers have on the environment are too grave. The only realistic way to reduce the effects that nitrogen-based fertilisers have on the environment is to research solutions and alter current practices to reduce harmful emissions that aid in global warming and the creation of photochemical smog.

Relevant Science

Nitrogen is critical to plant growth and reproduction. Giving soil nitrogen-rich fertiliser increases crop yield and harvest size year-round. Nitrogen is vital to plants as it is a large component of the amino acids within the plants, and it is an important part of chlorophyll. During times of low oxygen concentration, many types of bacteria will use nitrate in an anaerobic reaction for energy which can create nitrous oxide and NOx gases.

$$\mathrm{NO_{3\,(aq)}^{-}} \rightarrow \mathrm{NO_{2\,(aq)}^{-}} \rightarrow \mathrm{NO_{(g)}} + \mathrm{N_2O_{(g)}} \rightarrow \mathrm{N_{2\,(g)}}$$

$$\text{Nitrate} \rightarrow \text{Nitrite} \rightarrow \text{Nitric oxide} + \text{Nitrous oxide} \rightarrow \text{Nitrogen gas}$$

Equation 1: Denitrification, where soil bound nitrogen converts to gaseous nitrogen

This process is denitrification in which nitrogen bound to the soil is released into the atmosphere in a gaseous state.

NOx gases released from denitrification, when present in the troposphere, are the precursors to the formation of photochemical smog and the formation of tropospheric ozone.

During the day when the UV radiation emitted from the sun is the strongest, NOx gases undergo photodissociation.

$$NO_{2\,(g)} + hv \rightarrow NO_{(g)} + O_{(g)}$$

$$\text{Nitrogen dioxide} + \text{hv} \rightarrow \text{Nitric oxide} + \text{Oxygen radical}$$

Equation 2: The process of photodissociation of nitrogen dioxide

When a nitrogen dioxide molecule undergoes photolysis, a highly reactive oxygen radical is released which reacts with a nearby oxygen molecule to create an ozone molecule.

$$O_{(g)} + O_{2\,(g)} \rightarrow O_{3\,(g)}$$

$$Oxygen\ radical + Oxygen \rightarrow Ozone$$

Equation 3: The formation of ozone

Nitrous oxide, one of the gases released in microbial denitrification processes, has three hundred times more global warming potential than methane or carbon dioxide. Nitrous oxide stays in the atmosphere for an average of 114 years (Brind'Amour & Lee 2022) and roughly 40% of the nitrous oxide in the atmosphere is from anthropogenic sources (Brind'Amour & Lee 2022). Greenhouse gases are gases that don't absorb the short wavelength radiation emitted from the sun but do absorb the long wavelength infrared radiation released by the earth.

Nitrous oxide is much less abundant in the atmosphere than carbon dioxide, but it has 300 times the global warming potential (Brind'Amour & Lee 2022). This phenomenon traps heat in the atmosphere and causes a thermal imbalance since less heat is being released than is being absorbed. So, the earth and its atmosphere will continue to warm until a new thermal equilibrium is established.

Nitrous oxide is stable in the troposphere but in the stratosphere, it undergoes photolysis due to the increased UV radiation. This creates NOx gases which are major contributors to stratospheric ozone depletion as nitric oxide can catalytically react with ozone to produce oxygen molecules. Since the ozone molecules in the stratosphere are in constant equilibrium due to being broken down by the sun and reformed at lower levels in the stratosphere, the addition of NOx gases, which break down ozone, disrupt the equilibrium. This leads to a new equilibrium to be established with a lower concentration of ozone.

The nitrogen in fertilisers is present as nitrate, ammonium or urea. To allow for the mass production of these substances, the Haber process is used. The Haber process is an industrial process that has a significant effect on global warming as the high temperatures and pressure needed to form the ammonia require a large amount of energy. This energy is most often acquired from the burning of fossil fuels. The burning of fossil fuels also has significant effects on global warming.

SHE paragraph

- **Scientific knowledge, understanding, and inquiry can enable scientists to develop solutions, make discoveries, design action for sustainability, evaluate economic, social, cultural, and environmental impacts, offer valid explanations, and make reliable predictions.**

Nitrogen-based fertilisers are an indispensable tool in the agricultural industry due to the immense benefits to crop yield and harvest size that they provide. These fertilisers, directly and indirectly, cause harm to the environment however the negative effects of abandoning this practice worldwide would be unimaginable. Anthropogenic nitrous oxide accounts for approximately 5-7% of global emissions and 90% are derived from agricultural practices (Agriculture Victoria 2024). The key causes are nitrogen-based fertilisers and livestock manure. This reveals a concerning problem because the threat of global warming is increasingly large. The large-scale emissions of something as harmful as nitrous oxide cannot go unattended for too long. Nitrogen-based fertilisers are too valuable to be abandoned as it would have severe social and economic consequences due to the steep drop in food production. The only option to reduce the emission of nitrous oxide and other harmful substances from the agricultural industry is to use current knowledge and research to implement new strategies which optimise the application of fertiliser.

It is estimated that 40-60% of the nitrogen implemented into cropping systems is lost to the environment on average (Agriculture Victoria 2024). This can be reduced by using the four Rs, right product, right rate, right time and right place (Agriculture Victoria 2024). This is a method that has been derived from current research on nitrogen application in soil and its effect on the crops grown and harvested. The aim is to reduce harmful emissions, streamline costs by requiring less fertiliser and modify or implement new processes to reduce the amount of nitrogen lost to ammonia volatilisation, leaching and denitrification. The implementation of the four Rs slows down the rate of global warming from the reduced nitrous oxide emissions. It also aids in reducing ozone depletion and the production of photochemical smog because of the reduction in NOx emissions. This results in a positive solution for both farmers and society as the more efficient applications of fertilisers reduce costs for farmers. This allows for more food production and a significantly reduced risk of large-scale effects on the environment from the emission of nitrogenic gases.

The four Rs involve choosing the right type of fertiliser for the type of crop or its stage of growth, as crops tend to require more nitrogen in stages of rapid growth such as tillering. Right rate refers to the type of fertiliser and the quantity at which it is applied, which is largely dependent on the crop and the existing nitrogen in the soil. Ammonium and urea-based fertilisers are more optimal and result in less nitrous oxide emissions as the conversion to nitrate is slowed and when applied right, they can effectively match the needs of plants without a large surplus of nitrogen. Right time refers to the stages of growth of the crop to maximise crop nitrogen uptake and it refers to soil conditions. Fertiliser should not be applied to soil while it is waterlogged or soon to be as that would significantly increase nitrogen emissions and increase economic expenses. The correct location to apply fertiliser is close to the active root zones of the crops to maximise crop nitrogen uptake and reduce the chances of ammonia volatilisation.

Conclusion

Nitrogen-based fertilisers are essential to society because of the social and economic benefits created from the efficient generation of food. To reduce the negative effects that they have on the environment, while still utilising their efficiency in the agricultural industry, it is crucial to implement the four Rs. The four Rs are a crop farming strategy created from current scientific knowledge and research to optimise the application of nitrogen-based fertilisers. By implementing the four Rs, nitrous oxide emissions can be massively reduced, crop nitrogen uptake efficiency can be improved, and the agricultural industry can be more cost effective and less harmful to the environment. As the agricultural industry accounts for roughly 90% of anthropogenic nitrous oxide emissions, widespread adoption of the four Rs would have a very significant impact on the rate of global warming.

1464 words

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