Science Societies

Climate-smart fertilizers in 4R nutrient stewardship

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The nitrogen industry seeks to reduce its carbon footprint. Photo courtesy of The Fertilizer Institute.

Climate-smart fertilizers will play an increasingly important role. They fit well into the 4R Nutrient Stewardship concept, which provides an excellent

framework for recognizing and rewarding the farmers that adopt their use. Programs, protocols, and policies aimed at reducing the carbon footprint of agriculture need to recognize climate-smart fertilizer use in a 4R framework.

Public commitments toward reducing greenhouse gas emissions have driven considerable recent interest in the emissions associated with fertilizer. The Scientific Panel on Responsible Plant Nutrition recently published an article on "Furthering 4R Nutrient Stewardship" (SPRPN, **2022**) to update the 4R framework and principles originally spelled out in 2012. The update added new principles to those that defined right source in the original framework. One of those new principles is to use climate-smart forms. What attributes make a fertilizer product climate smart?

The concept central to responsible plant nutrition is a holistic view of the full chain of outcomes arising from decisions influencing the flow of nutrients, both within agriculture and within the whole of the agricultural value chain. Responsible plant nutrition, therefore, involves many players who may not be directly involved on the farm.

On the other hand, 4R Nutrient Stewardship focuses on the decisions in the field for applying the right source at the right rate, right time, and in the right place (Figure **1**). While its focus is on a smaller subset of decisions, those decisions need to consider and support the decisions made elsewhere, both for the effective functioning of the agricultural system as a whole as well as for its improvement in terms of sustainability.

Agricultural emissions of greenhouse gases are considered among the Scope 3 emissions of the companies that supply inputs to farmers and those that purchase the commodities farmers produce. So farmers, fertilizer companies, grain buyers, and food companies are all in this together.

Climate-smart forms of fertilizer need to generate less emission of greenhouse gases, both in their manufacture and post-application (SPRPN, **2022**). Farmers can't control manufacturing emissions, but they can ask their fertilizer supplier for information on the carbon footprint of each manufactured product and choose the products with that footprint as one of their considerations.

Ammonia, in fact, may play a role in an envisioned carbon-free hydrogen economy. Fertilizer production technology conferences in 2022 feature topics like decarbonization and revamping options for the production of green and blue ammonia and urea—forms produced with zero or low emissions of carbon dioxide and other greenhouse gases (Driver et al., **2019**). Over the past two years, many nitrogen producers in Europe and North America have announced investments toward producing ammonia with a lower carbon footprint. It will take a lot more investment and technological development, however, to make such production methods into cost-effective replacements for a substantial part of the volume of fertilizer nitrogen used today.

A low embedded carbon footprint constitutes the first attribute of a climate-smart fertilizer. Two more attributes contribute toward the reduction of post-application emissions. First, the product needs to contribute to improved use efficiency of the applied nitrogen. By using less nitrogen per unit of crop produced, the nitrogen surplus and the nitrous oxide emissions footprint of the commodity are reduced. Second, certain products can directly reduce the nitrous oxide emissions per unit of nitrogen

applied. Both of these mechanisms make sense in terms of the overall nitrogen cycle (Figure 2).

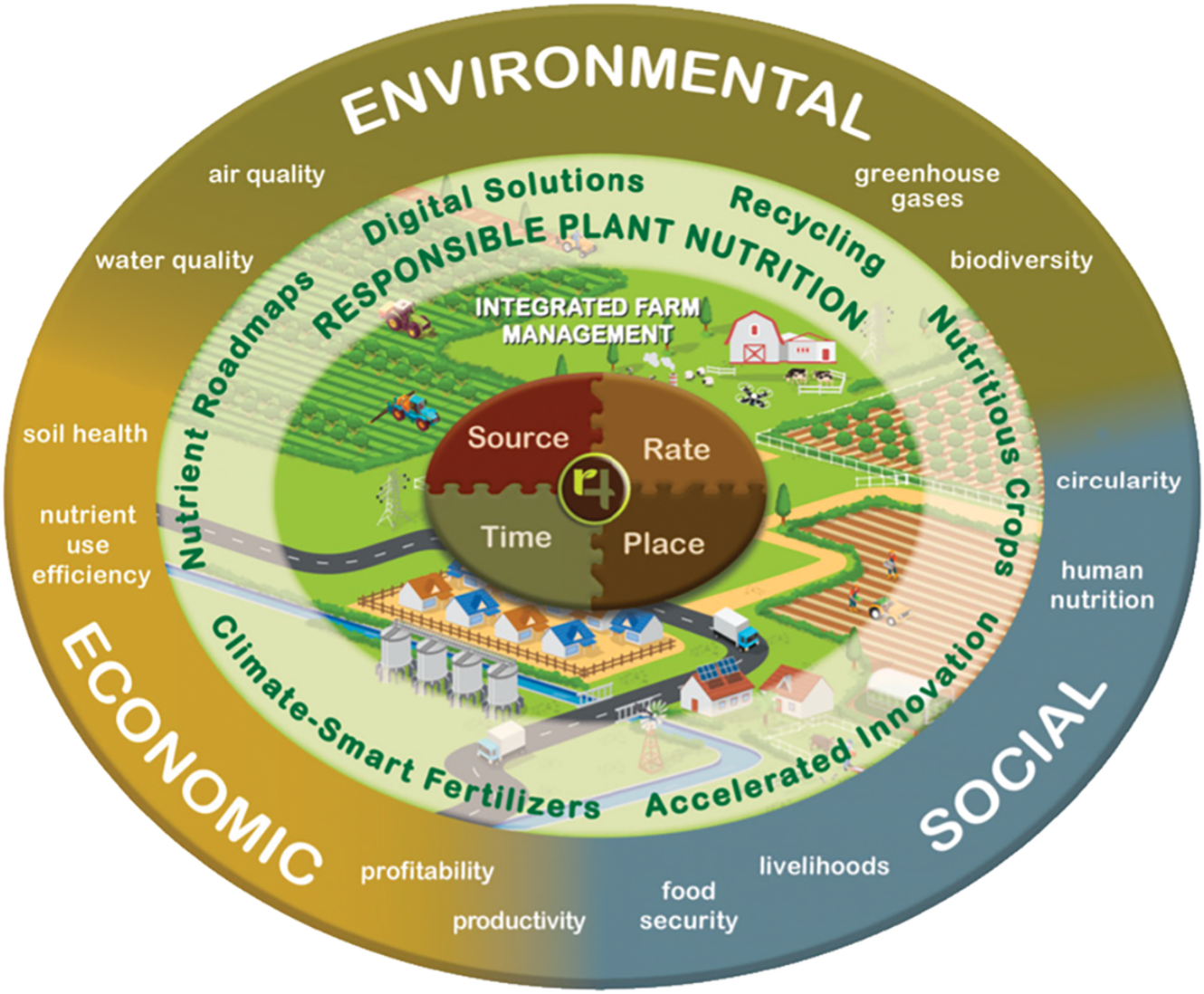


Figure 1, *Responsible Plant Nutrition requires action to develop climate-smart fertilizers. 4R Nutrient Stewardship supports their adoption (SPRPN, **2022**).*

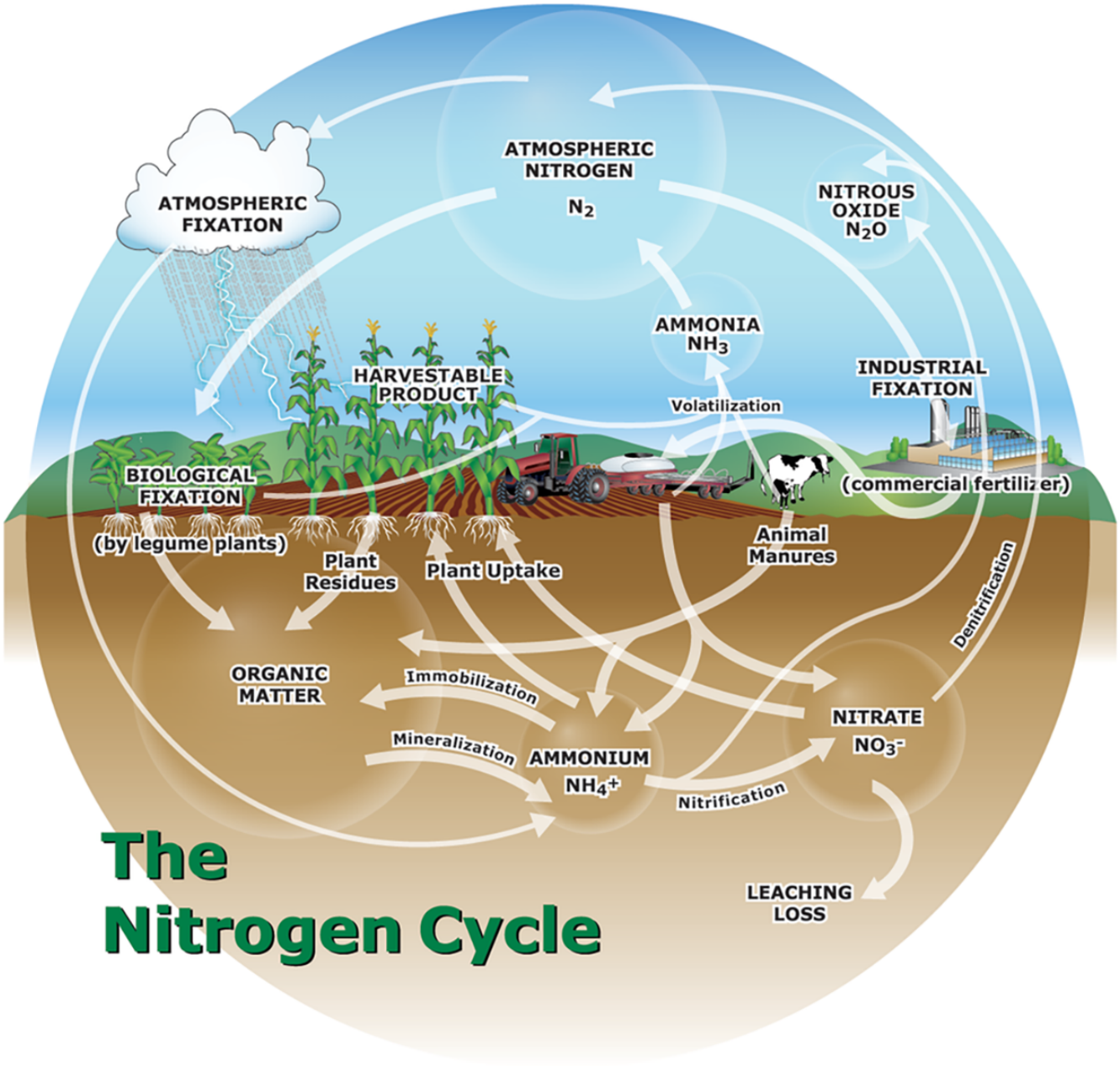


Figure 2, *Nitrous oxide is emitted in small amounts during the processes of nitrification and denitrification. © The Fertilizer Institute.*

Nitrogen Use Efficiency

Let's first discuss nitrogen use efficiency. Choosing the product most appropriate for the specific soil and crop enhances the nutrient use efficiency of the cropping system. For example, when choosing a source for topdressing winter wheat, the options for "right place" are limited since incorporation into the soil would disturb the crop. But

broadcasting urea or urea ammonium nitrate on the soil surface, particularly on soils with higher pH, entails a risk of losing a substantial fraction of the nitrogen if it volatilizes as ammonia (Figure 2). The climate-smart choice in this instance may be a product designed to lower the rate of urea hydrolysis and thus reduce the risk of ammonia loss. Such a product might include urea treated with urease inhibitors or polymer coatings. These products may or may not have an additional direct effect on nitrous oxide emissions as well, but already by increasing nutrient use efficiency, if applied at the optimum rate specific to the protected product, they contribute to reduced nitrous oxide emissions. Higher nitrogen use efficiency means more crop yield per unit of fertilizer applied, and since nitrous oxide emissions are proportional to either the amount applied or to its surplus in relation to crop uptake and removal, the greenhouse gas footprint per unit of crop yield decreases.

The term “smart fertilizer” is used to describe fertilizers that are responsive to plant needs. Sparingly soluble struvite, for example, dissolves and releases its ammonium, phosphate, and magnesium when a plant root exudes organic acids near a granule of it in the soil (do Nascimento et al., **2018**). Possible future innovations include nanoparticulate forms of nutrients, aptamers, and other coatings sensitive to plant signals, releasing nutrients in response to microbial activity and plant demand (Monreal et al., **2016**). The potential benefits of a fertilizer granule coating that allows release only in response to the presence of specific protein or nucleic acid signals from the target crop are huge, but of course, much work remains to be done in adapting such technology to the field environment. Smart fertilizers could become an important subset of climate-smart fertilizers.

Inhibition of Nitrous Oxide Emission

Now let's discuss specific inhibition of nitrous oxide emission. Several products have been demonstrated in global meta-analyses to reduce nitrous oxide emissions, on average, per unit of nitrogen applied. This reduction is larger than their effect on crop yield or nutrient use efficiency. The specific products demonstrated to have such efficacy are nitrification inhibitors and polymer coatings applied to urea. Across a wide range of soils and cropping systems globally, measured nitrous oxide emissions in more than 60 comparisons averaged to a reduction of 30 to 38% for nitrification inhibitors and 19% for polymer-coated urea (Thapa et al., **2016**). These reductions in nitrous oxide emissions are larger than the reported effects of these products on crop yield or nitrogen use efficiency (7.5 and 12.9%, respectively (Abalos et al., **2014**).

What about urease inhibitors? While their direct effect on nitrous oxide is less consistent, much of the research supporting the emissions reduction by nitrification inhibitors applied to urea was conducted with them co-applied with urease inhibitors ("dual inhibitors"). It makes sense to use a urease inhibitor with a nitrification inhibitor in any situation where ammonia volatilization may be a concern. Suppressing nitrification could increase volatile losses of ammonia from urea (Lam et al., **2017**). This risk is reduced by the use of a urease inhibitor.

The findings above are supported by numerous published meta-analyses and have important implications for programs designed to reduce the greenhouse gas footprint of crop production. Adoption of nitrification inhibitors and polymer coatings currently sits at about 10 to 20% of the nitrogen fertilizers sold in North America and has been driven mainly by the benefits of the small increases in yield and nitrogen use efficiency.

The reduction in nitrous oxide emissions, while proportionally larger than the increase in yield or use efficiency, applies only to the rather small percentage of fertilizer lost in

the form of nitrous oxide (Figure 2). While it's a "mighty molecule" in terms of its greenhouse gas effect, direct loss of nitrous oxide typically represents less than 2% of the nitrogen applied as fertilizer. Compare that to the potential loss of ammonia from urea left on a bare soil surface, which averages 18% (Pan et al., **2016**).

The decision to use a product that acts specifically on nitrous oxide emissions benefits society more than the farmer who pays for the product. There is thus a sound basis for the public to provide some form of incentive payment for farmers to adopt these technologies to achieve a societal optimum in their use.

Summary

Climate-smart fertilizers will play an increasingly important role. They fit well into the 4R Nutrient Stewardship concept, which provides an excellent framework for recognizing and rewarding the farmers that adopt their use. Programs, protocols, and policies aimed at reducing the carbon footprint of agriculture need to recognize climate-smart fertilizer use in a 4R framework.

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