MAY 2026
R: 26-05-B

REPORT

THE NITROGEN POLLUTION CRISIS:

HOW FERTILIZER OVERUSE IS POISONING AMERICA'S WATER, AIR AND ECOSYSTEMS

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ACKNOWLEDGMENTS

The authors thank the following reviewers for their helpful input (in alphabetical order): Joy Anderson, Mike Badzmierowski, Steve Fleischli, Laurie Geller, Rebecca Hammer, Andrew Hillman, Carly Griffith, Allison Johnson, Erik Olson, Vero Ramos Kuzuhara, Rebecca Riley, Leah Stecher, Jesse Womack, as well as several anonymous reviewers.

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EXECUTIVE SUMMARY

Fertilizing crops with nitrogen made modern agriculture possible by replenishing nutrients in the soil and increasing crop yields. But this important tool is now routinely overused. In fact, studies across multiple states show that many farmers apply significantly more nitrogen than is recommended by land grant universities while making limited use of practices minimizing nitrogen runoff.[1] As a result, nearly half of the nitrogen fertilizer applied to croplands is not even used by plants; instead it washes into rivers and groundwater or is released into the air. In some places and for certain crops, the proportion rises to more than half.[2]

This lost nitrogen is not harmless. Nitrate-contaminated groundwater has been linked to blue baby syndrome, certain cancers, and thyroid disorders, while gaseous nitrogen emissions contribute to fine-particle air pollution and smog precursors that exacerbate asthma and other respiratory diseases.[3] Excess nitrogen can devastate aquatic ecosystems by fueling harmful algal blooms and creating low-oxygen "dead zones" that suffocate aquatic life. And it contributes to the climate crisis through emissions of nitrous oxide (N_2O), a greenhouse gas roughly 273 times more effective at trapping heat than carbon dioxide.[4]

Nitrogen mismanagement costs the U.S. economy billions of dollars, shouldered predominantly by rural and low-income communities. Nitrogen fertilizer (defined in this report as either synthetic nitrogen fertilizer or manure) can account for a small or large share of a farm's operating budget, depending on the crop grown. But the 40 to 60 percent of applied nitrogen that crops don't use is more than just an unnecessary expense for farmers, especially when it comes to water pollution.[5] Small and rural water systems, which make up the vast majority of U.S. water providers, face disproportionate treatment costs to remove excess nitrogen because they lack the resources to finance filtration upgrades or switch to unpolluted water sources.[6] Nitrogen pollution can require states to spend heavily on interim bottled-water programs, emergency responses to algal blooms, and habitat restoration. Recreational economic losses due to harmful algal blooms caused in part from nitrogen pollution run into the tens of billions of dollars annually when beaches close, boat ramps sit idle, and fisheries falter.[7]

VOLUNTARY NITROGEN REDUCTION PROGRAMS ARE NECESSARY BUT NOT SUFFICIENT

States have leaned heavily on education, technical assistance, and incentives to encourage best management practices to reduce nitrogen pollution in water. For example, California's premier sustainable agriculture grant initiative, the Healthy Soils Program, has awarded more than $162 million to farmers for practices that reduce the potential for nitrogen loss, such as cover cropping, reducing tillage, using hedgerows and windbreaks, rotating diverse crops, and applying compost.[8] While these voluntary efforts have resulted in some practice uptake and increased awareness of nitrogen overuse, they cannot deliver the needed improvements in water quality by themselves. After decades of voluntary efforts, many waters are still impaired, more waters are becoming polluted, more drinking water wells are testing high for nitrate, and treatment costs continue to rise.[9]

STATES MUST SET MEASURABLE LIMITS TO STEM NITROGEN POLLUTION

Successful pollution-control frameworks contain clear, measurable limits that align incentives with outcomes. Where regulators set numeric targets, track performance, and enforce against outliers, progress follows. Where they do not, communities, taxpayers, and ecosystems keep paying the price.

States must set clear goals to address nitrogen over-application and discharge that degrades water quality. They can require robust data collection that enables them to target help where it matters most and to measure progress. They can also pair enforceable, outcome-oriented limits with technical assistance and incentives, ensuring that both small and large farms can comply and thrive. And they can require shared accountability for results so that fertilizer companies and retailers that profit from overapplication are, alongside farmers, part of the solution.

Communities should not be forced to choose between having clean water and growing food. The status quo is inequitable, expensive, and unsustainable. We have the responsibility to change it. The good news is that we also have the tools to do so.

I. INTRODUCTION

Having enough available nitrogen in the soil is crucial to plant growth. Prior to the 20th century, human nitrogen inputs to soil were available only from sources such as manure and crop residue from legumes, which made its presence one of the main determinants of what an acre of farmland could produce.[10] When scientists discovered how to produce synthetic nitrogen fertilizer through the energy-intensive Haber–Bosch process in the early 20th century, farmers finally had a reliable source of nitrogen to scale crop production and harvest unprecedented yields. However, cheap and reliable access to nitrogen fertilizer quickly led to overapplication. Between 1960 and 2000, the amount of nitrogen fertilizer applied to agricultural systems more than tripled and the amount of nitrogen lost to the environment similarly skyrocketed.[11]

Mismanagement of nitrogen fertilizer wreaks havoc on local ecosystems, threatens human health, contributes to the climate crisis, and costs the U.S. economy billions of dollars per year. There is a clear solution: Reduce overapplication and implement practices to minimize nitrogen runoff. The good news is that farmers are proving it's possible and profitable to grow healthy food for communities without polluting water with excess nitrogen. Across the country, they are dramatically cutting nitrogen pollution without sacrificing productivity by reducing overapplication and adopting sustainable farming practices like adaptive nitrogen management, cover cropping, edge-of-field pollution control, and diverse crop rotation. However, current policies create an uneven playing field where industrial agricultural interests face no accountability for continued pollution while sustainable farming practices are not properly rewarded.

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Harmful algal bloom in Lake Okeechobee.

This report explains the scale and sources of the nitrogen pollution crisis, who pays for it, and why current approaches to reduce nitrogen pollution have fallen short. It also proposes practical steps policymakers and stakeholders can take now to turn the tide. It is not intended to be a comprehensive overview of the environmental or economic harms of other agricultural practices.

Nitrogen policy reform is pro-farmer, pro-community, pro-health, and pro-technology. It will reward farmers who are already utilizing effective nitrogen management practices, guide other farmers toward those solutions, and save their communities from pollution. The payoff is cleaner, safer, and more affordable water; healthier rivers, lakes, and coasts; less air pollution; and meaningful climate gains from lower nitrous oxide emissions. Below is an overview of the remainder of this report.

- **Section II** details how the nitrogen pollution crisis is not a niche farm-policy issue but a pervasive problem that endangers human health, damages ecosystems, threatens biodiversity, and fuels climate change.
- **Section III** quantifies the economic burden of the nitrogen pollution crisis, including the costs of drinking water remediation, cleanup of harmful algal blooms, and diminished recreational opportunities.
- **Section IV** evaluates the shortcomings of major existing federal tools that could be used to reduce nitrogen pollution, including the Clean Water Act, Safe Drinking Water Act, and federal conservation programs.
- **Section V** presents case studies of mixed success in nitrogen management from Minnesota and California. Minnesota illustrates how investments in voluntary practices have resulted in only marginal reductions in pollution. California shows how rigorous data collection can form the foundation for smarter, more targeted policy and illustrates the consequences of failing to pair that data with enforceable limits on overapplication and runoff.
- **Section VI** lays out solutions that states can adopt now, including outcome-based monitoring and reporting paired with numeric limits on nitrogen overapplication and runoff.
- **Section VII** highlights the need for better tracking of nitrous oxide, the "forgotten superpollutant"—a primary driver of climate change from excess fertilizer.
- **Section VIII** contains a brief conclusion.
- The **Appendix** addresses frequently asked questions about the nitrogen pollution crisis, offering evidence-based responses.

II. NITROGEN POLLUTION THREATENS COMMUNITIES, ECOSYSTEMS, AND FARMS

The science is unequivocal: Overuse of nitrogen endangers people, degrades ecosystems, and contributes to the climate crisis.[12] This section summarizes decades of research linking nitrogen pollution to these cross-cutting impacts (see figure 1).[13]

TOXIC CONTAMINATION OF DRINKING WATER

Excess nitrogen can leach into water bodies as nitrate, a major contaminant in drinking water. Health risks associated with nitrate contamination were first detected in infants in 1945, when it was observed that some newborns exposed to high levels of nitrates suffered from birth defects or low oxygen levels (also known as blue baby syndrome).[14] In 1991, this connection led the Environmental Protection Agency (EPA) to set a maximum contaminant level (MCL) of 10 milligrams per liter (mg/L) for nitrate in drinking water. However, studies show that this MCL is regularly exceeded in many drinking water sources and is likely surpassed in many groundwater basins across the country (see figure 2).[15] More recent studies reveal that nitrate contamination at levels lower than the MCL may also be harmful to children and adults. Nitrate intake from contaminated water is linked to increased risk of colorectal, ovarian, and kidney cancers at concentrations as low as 5 mg/L.[16] Nitrate intake from both contaminated water and food sources is also linked to thyroid cancers and associated health issues.[17]

FIGURE 1: EXCESS NITROGEN FROM FERTILIZER SPREADS THROUGH THE ENVIRONMENT AND IMPACTS HUMAN AND ENVIRONMENTAL HEALTH

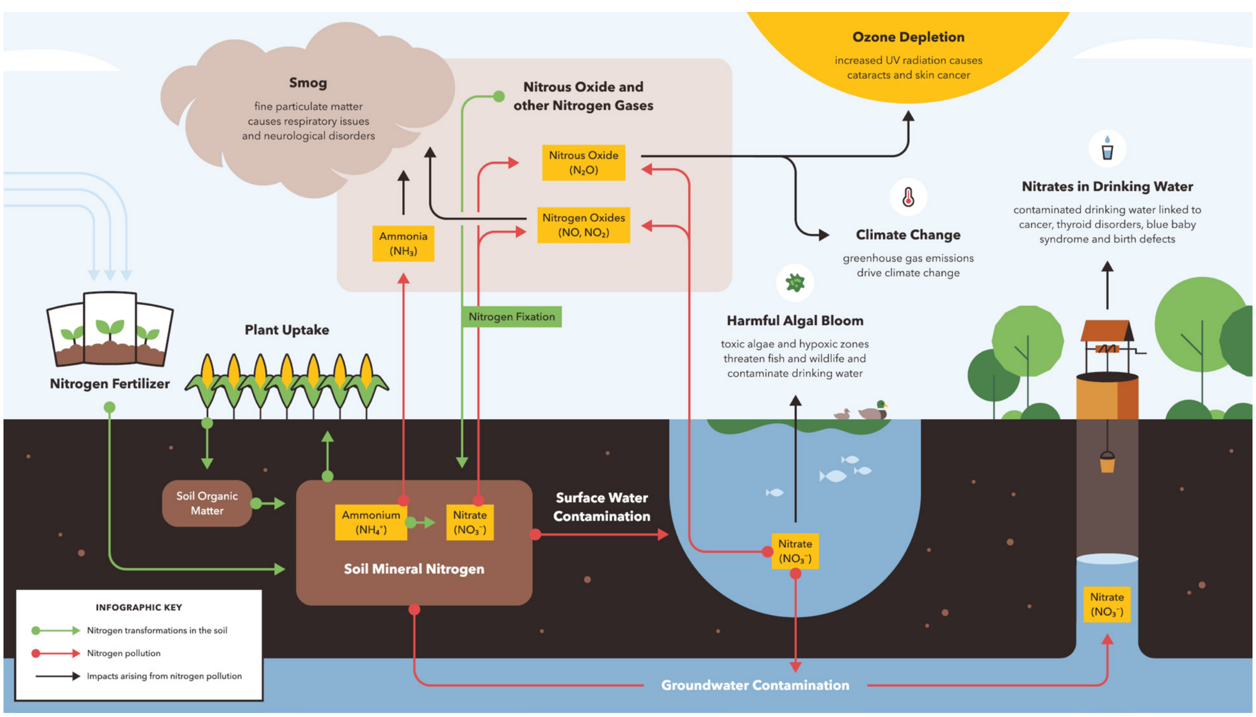


Illustration: Maya Nguyen for NRDC

To provide some perspective on the impact of contaminated drinking water, in areas where the nitrate concentration in drinking water is 10 mg/L, consuming roughly 8 ounces (225 ml) of water exposes a person to as much nitrate as eating a hot dog.[18] Hot dogs and other processed meats have been classified by the World Health Organization as a Group 1 carcinogen (as have tobacco and asbestos) due in part to the amount of evidence linking nitrate/nitrite content in processed meat and cancer risk.[19] If a person drinks the recommended eight glasses of water per day for an entire year, that would be the nitrate-N equivalent of eating 2,920 hot dogs.

The strong link between nitrate intake and colorectal cancer may be one of the factors driving the annual 3 percent increase in colorectal cancer among 20- to 49-year-olds.[20] One recent study estimated that nitrate in drinking water may be responsible for up to 12,594 cases of cancer each year in the United States (at least 54 percent of which are colorectal cancer cases) at an additional cost of up to $1.5 billion a year for medical treatment.[21]

A 2014 study estimated that 5.6 million Americans using community water systems were exposed to unsafe levels of nitrates (above 5 mg/L) despite existing water treatment infrastructure designed to protect people from drinking water contaminants.[22] This estimate is almost certainly an undercount because the study excluded the 44 million Americans who rely on private wells.[23] People who rely on private wells are often at an even higher risk of nitrate contamination in their drinking water due to their proximity to farmland, lack of water treatment infrastructure, and irregular well testing.[24]

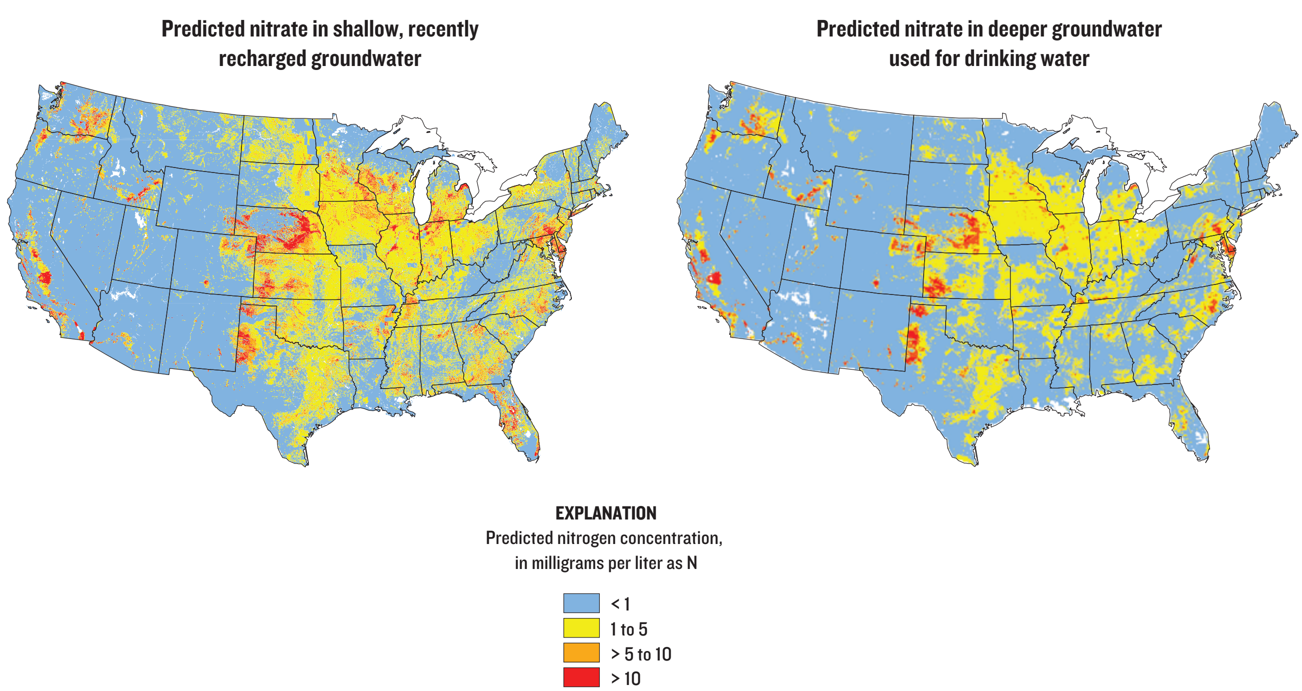
Nitrate contamination in drinking water does not impact Americans equally. Across the country, community water systems serving larger proportions of Latino communities, as in the San Joaquin Valley in California, experience higher nitrate levels in drinking water.[26] In the Midwest, areas with high nitrate levels in drinking water frequently overlap with areas where household income falls below state median income levels.[27] These communities are more likely to be situated in rural, agricultural areas where water quality is poor and water treatment facilities often are not sufficiently maintained or improved.[28]

Unfortunately, nitrogen pollution caused today can continue to contaminate drinking water for decades. It takes time for nitrogen that runs off agricultural land to pollute nearby surface waters, seep into groundwater, and contaminate drinking water supplies. Every year that officials and farmers postpone reducing pollution and runoff can result in increased cleanup costs and potentially millions more Americans drinking nitrate-contaminated water.[29]

DEGRADED ECOSYSTEMS AND LOSS OF BIODIVERSITY

Nitrates degrade ecosystems and kill or sicken birds, fish, and other animals; for instance, they can cause green sea turtles to develop painful and often fatal tumors on their heads, eyes, and flippers.[30] In 2022, high nitrogen concentrations led the EPA to classify roughly 44 percent of rivers and streams and 47 percent of lakes in the United States as being in "poor condition."[31] This pollution can result in harmful algal blooms, in which certain algae grow rapidly and, in the process, create toxins that can sicken both wildlife and

FIGURE 2: NITRATE CONCENTRATIONS GREATER THAN THE MCL OF 10 MG/L AS N ARE PREDICTED TO OCCUR PRIMARILY IN THE HIGH PLAINS, NORTHERN MIDWEST, AND AREAS OF INTENSE AGRICULTURE IN THE EASTERN AND WESTERN UNITED STATES[25]



Nutrient pollution is linked to fibropapillomatosis and skin tumors in sea turtles.

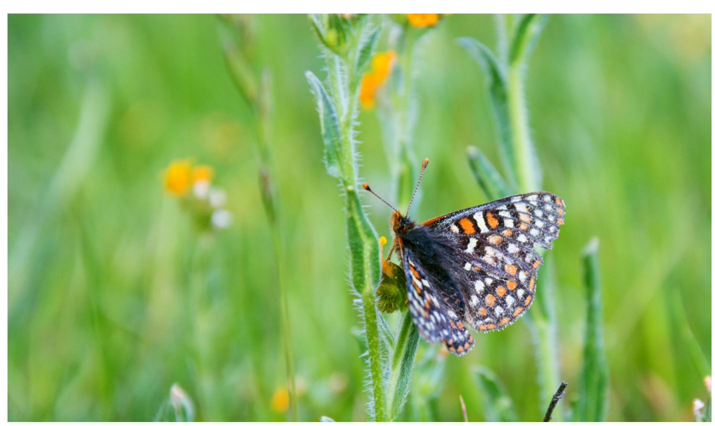
humans.[32] Algae growth may also create "dead zones"—areas with low oxygen levels that are inhospitable to many aquatic species, even resulting in mass death events like fish kills.[33] The largest dead zone in the Western Hemisphere covers 6,500 square miles in the Gulf of Mexico and is in large part fueled by the nutrient pollution flowing down the Mississippi River from farmland in the Midwest.[34]

Nitrogen pollution creates unhealthy habitats that can affect the well-being and food sources of many species of animals beyond the waterways. Within the United States, up to 78 species currently listed under the Endangered Species Act are at risk due in part to nitrogen pollution, including California species like the Bay checkerspot butterfly and arroyo toad.[35] Protecting these species is important to overall ecosystem function; many play essential roles in our food systems, water quality, or even recreational environments by pollinating plants, improving soil health, and cleaning water supplies.

In addition, nitrogen cycles through the atmosphere and can be deposited in nonagricultural landscapes. Increased nitrogen can alter these landscapes by inducing the growth of fast-growing invasive species, which can take over landscapes and suppress other plant species' populations.[36] For example, in the western United States, elevated nitrogen deposition has been linked to increased wildfires due to the spread of dry grasses.[37]

UNSAFE AIR

When nitrogen is broken down by soil microbes, several nitrogen-containing gases are emitted from the soil. These gases include nitrogen oxides—NO and NO_2, often abbreviated together as NO_X—and ammonia (NH_3).[38] Exposure to elevated levels of these gases has been linked to respiratory diseases such as asthma, increased hospital visits due to breathing difficulties, and neurological disorders.[39] While the bulk of nitrogen oxide pollution comes from fossil fuel combustion, recent research suggests that soil NOx emissions may be up to an order of magnitude higher than previously estimated and may account for approximately 20 to 30 percent of annual NOx emissions in some regions of the US.[40]



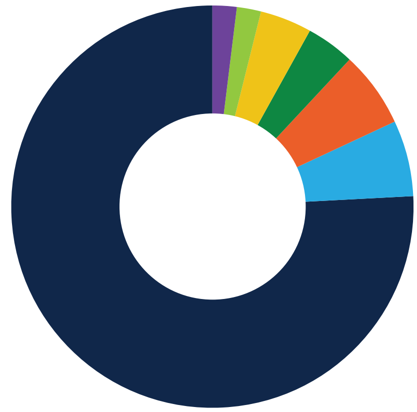
Bay checkerspot butterflies are threatened by nitrogen pollution.

CLIMATE CHANGE IMPACTS

The climate effects of synthetic nitrogen fertilizer begin with production: The Haber-Bosch process relies on fossil fuels and is extremely energy intensive, accounting for roughly 2 percent of global energy consumption.[41] Once either synthetic nitrogen fertilizer or manure is applied to cropland, excess nitrogen can be broken down by soil microbes into the potent greenhouse gas nitrous oxide (N_2O).[42] To date, nitrous oxide represents about 10 percent of total human-caused greenhouse gas emissions.[43] In the United States, agricultural soil management accounts for 75 percent of all nitrous oxide emissions, primarily from the overuse of nitrogen fertilizers (see figure 3).[44] In the atmosphere, nitrous oxide is 273 times more effective than carbon dioxide, per unit, at warming the planet.[45] This gas has long-term impacts: it can persist for more than 100 years in the atmosphere, where it adds to climate change effects such as increased variability of rainfall and extreme weather events, which can reduce crop yield and jeopardize food systems.[46]

Nitrous oxide also contributes to damage of the stratospheric ozone layer.[47] This damage increases UV radiation and is projected to raise the risk of skin cancer and cataracts in the next few decades.[48] The associated health impacts from ozone depletion due to the accumulation of nitrous oxide have the potential to result in 4 million premature deaths in the next 10 years, and 20 million by 2050.[49]

FIGURE 3: U.S. NITROUS OXIDE EMISSIONS FROM 1990 TO 2022, GROUPED BY SOURCE. LULUCF REFERS TO LAND USE, LAND-USE CHANGE, AND FORESTRY[50]



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Harmful algal blooms driven in part by nitrogen pollution can span up to 2000 square miles.

III. NITROGEN POLLUTION DAMAGES THE ECONOMY

Because most programs to reduce nitrogen pollution from fertilizer use are only voluntary, regulators have imposed stricter requirements on other nitrogen dischargers, such as municipal wastewater treatment plants, to meet water quality cleanup targets. Those stricter requirements translate into higher costs for these other nitrogen dischargers and their constituents (e.g., communities, businesses, and local governments) even though agriculture may be a larger contributor to nitrogen pollution in a particular area.

Nitrogen pollution's costs are borne by state and local governments, water districts, and taxpayers who pay for emergency drinking water supplies (e.g., bottled water), remediation of harmful algal blooms, and upgrades of water treatment facilities to remove excess nitrate; they also lose revenue from declines in recreation visits.[51] As a former water executive at the EPA said in 2011, "Nitrogen and phosphorus pollution has the potential to become one of the costliest and most challenging environmental problems we face."[52] According to one estimate, gross economic damages from agricultural nitrogen pollution cost the United States more than $59 billion annually.[53] Another recent analysis estimated that direct nitrous oxide emissions from fertilizer overuse imposes a national economic burden of nearly $12 billion.[54]

Unfortunately, communities served by smaller water districts and communities that rely on groundwater for drinking water (i.e., mostly rural communities) are disproportionately burdened with the costs of nitrate pollution.[55] Research shows that households exposed to nitrate-contaminated water tend to be concentrated in low-income areas with fewer financial resources to remediate contaminated water.[56]

COSTS OF WATER TREATMENT INFRASTRUCTURE

When nitrate levels in drinking water supplies exceed the EPA's MCL of 10 mg/L, public water systems are required to take action to remediate the contamination and provide safe drinking water to their customers. Remediation can include blending freshwater with the nitrate-contaminated water supply, finding new sources of water, or installing and using nitrate removal technologies.[57]

Treating nitrate contamination can be very costly, and these costs are usually born by the affected communities.[58] Columbus, Ohio, spent $35 million on an ion treatment facility to remediate nitrate-contaminated water for roughly 400,000 consumers in 2017.[59] In the highly publicized Des Moines Water Works lawsuit in Iowa, plaintiffs argued that

Drinking water treatment facilities face additional remediation costs from nitrate contamination.

nitrate pollution from agricultural runoff led to repeated violations of the nitrate MCL for the Raccoon River, which, along with the Des Moines River, serves as the region's primary drinking water source. In one winter season in 2012–2013, nitrate removal from the Raccoon River cost Des Moines Water Works around $500,000.[60] These remediation approaches are costly and can struggle to keep up with the levels of ongoing pollution. In 2025, input nitrate levels to the Des Moines drinking water supply tested at 20.55 mg/L from the Raccoon River and 17.15 mg/L from the Des Moines River, putting a massive strain on water treatment capacity and resulting in the first lawn-watering ban ever issued in the country due to high nitrate levels.[61]

Smaller public and community water systems experience more frequent violations of the nitrate MCL because they are more likely to draw water from groundwater sources, where nitrate contamination is more prevalent, and because they cannot afford expensive remediation efforts such as upgrading treatment technology or changing their source water.[62] The cost of remediating nitrate contamination makes water more expensive for communities and fuels the affordability crisis, especially for rural residents served by smaller water systems.[63]

COSTS OF TEMPORARY, INTERIM SOLUTIONS TO STATES AND HOUSEHOLDS

States and local water districts may fund interim solutions such as supplying bottled water or hauled water to communities experiencing nitrate contamination.[64] However, these "temporary" costs will continue to accrue and balloon if the root causes of nitrate contamination are not addressed. Even when fertilizer leaching is reduced from farms, it can take years for nitrate to travel through soil and end up in groundwater aquifers, meaning that affected communities and households could require supplemental water for decades.[65]

For example, nitrate-contaminated drinking water is a significant issue in California's Central Coast and Central Valley regions, especially for disadvantaged communities.[66] In 2019, the California legislature created the Safe and Affordable Funding for Equity and Resilience (SAFER) Program to analyze and monitor drinking water contamination trends and the Safe and Affordable Drinking Water Fund (SADW) to pay for solutions. From 2019 to 2025, the state spent $182.3 million on interim water supplies, including bottled water, for communities served by failing water systems.[67] These costs will continue to accrue until the state reduces nitrogen pollution at the source; as of 2025, 88 water systems in California were failing to meet the nitrate MCL.[68] This estimate does not include the money that families may have paid out of pocket for bottled water. And this can add up: In the Tulare Lake Basin, for instance, households spend an estimated $30 per month for replacement bottled water—in addition to their monthly water bill.[69]

The high cost of purchasing emergency bottled water also imposes a hardship on communities in the Midwest. In southeastern Minnesota, the single largest contributor to drinking water contamination is nitrogen pollution from agriculture.[70] Households that rely on private wells for drinking water may spend anywhere from $530 to $1,590 a year for bottled water due to nitrogen runoff from agriculture.[71] In Toledo, Ohio, in 2014 households spent a total of $828,193 on bottled water over three days due to a harmful algal bloom caused, in part, by agricultural nitrogen pollution.[72]

COSTS TO RECREATIONAL AND FISHING ECONOMIES

The recreational sector stands to lose substantial revenue from nitrogen pollution. According to the EPA's most recent rivers and streams assessment, 44 percent of the nation's rivers and streams are in poor condition due to elevated levels of nitrogen.[73] When water quality is poor, access to recreational sites or activities may be restricted, and even if not, fewer people are likely to pay the access fees. Consistently degraded water quality results in significant economic losses for communities and states that depend on revenue from activities such as swimming, fishing, and boating.[74] According to one recent estimate, the economic damages of nutrient pollution to United States recreation may reach upwards of $45 billion.[75]

States and communities that rely on healthy fisheries for economic security can also suffer financial losses due to nitrogen pollution. The nitrogen pollution that flows down the Mississippi River into the Gulf of Mexico has risen fivefold in the past century and has cost fisheries and marine habitat in the gulf from $552 million to $2.4 billion annually.[76]

COSTS OF ENVIRONMENTAL REMEDIATION

States and communities directly bear the costs of remediating water bodies affected by harmful algal blooms or dead zones. In just 10 years, 85 communities across the United States spent more than $1.15 billion to remediate algal blooms.[77] Cities and towns in Minnesota alone, from 2010 to 2020, spent $3 million to clean up and protect six water bodies from these blooms.[78]

© Mike Hooper/USGS

Harmful algal blooms can result in fish kills.

IV. EXISTING STATUTES AND INFRASTRUCTURE ARE INSUFFICIENT TO REDUCE NITROGEN POLLUTION

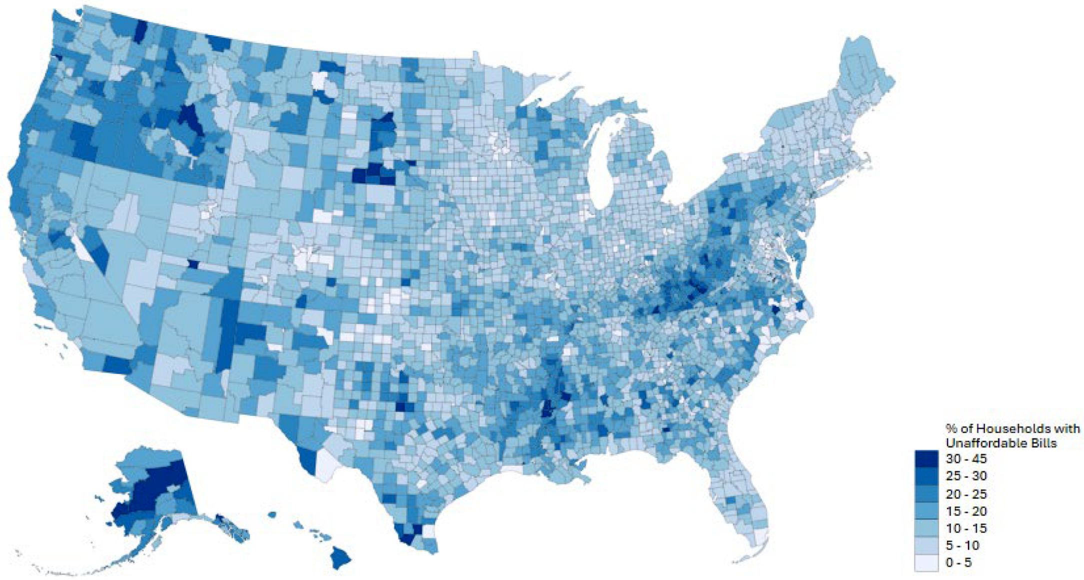
The United States lacks a unified nitrogen reduction strategy. Instead, a variety of statutes, authorities, and programs address different elements of the problem, each with its own limitations. These include two national bedrock statutes, the Clean Water Act (CWA) and the Safe Drinking Water Act (SDWA), which establish standards for protecting surface and drinking water.[79] On the ground, nitrogen management and remediation may be funded by the EPA or the U.S. Department of Agriculture (USDA) through state grants, while the Natural Resources Conservation Service (NRCS), state departments of agriculture, land grant universities, and nongovernmental organizations provide critical information and resources to help farmers limit nitrogen loss at the source.

NITRATES LEACH PAST OUR FEDERAL ENVIRONMENTAL STATUTES

The CWA and SDWA have helped the United States make groundbreaking progress to protect water quality and ensure access to clean drinking water. However, the CWA was originally targeted to address "point source" pollution (i.e., pollution coming from a single, identifiable source), mostly from industrial discharges and municipal wastewater, and has not been effective in limiting water pollution from agriculture.[80] In part, this is because Congress chose not to apply mandatory pollution reduction requirements to most agricultural discharges.[81] The 2023 *Sackett v. EPA* Supreme Court opinion may undermine the CWA's protection of wetlands, which further endangers lakes, rivers, and streams that depend on wetlands to reduce nitrate flows.[82]

The SDWA has been a powerful tool to protect drinking water from both surface water and groundwater contamination.[83] Yet nitrate contamination at the tap continues to threaten Americans from all walks of life. While MCLs exist for all regulated contaminants such as nitrates and are legally required to be reviewed and revised as necessary to protect public health every six years, generally the EPA fails to update the standards. The nitrate standard was supposed to be reevaluated by the EPA during its reviews in 2003, 2010, 2017, and 2024.[84] The agency did not update the nitrate standard in any of those reviews; in fact, the nitrate MCL has not been updated since 1975. This multi-decade delay is especially problematic as new research suggests that the 10 mg/L threshold is too high to protect children and adults from health problems.[85]

FIGURE 4: ESTIMATED PERCENTAGE OF HOUSEHOLDS, BY COUNTY, ACROSS THE UNITED STATES WITH UNAFFORDABLE WATER BILLS, DEFINED AS BILLS EXCEEDING 4.5 PERCENT OF MONTHLY HOUSEHOLD INCOME[86]



Estimated Percent of Households with Unaffordable Bills at the 4.5% Threshold (All Counties)

Even so, some communities across America are employing the SDWA to fight nitrate pollution from agriculture. In Minnesota, Washington, Iowa, and Oregon, communities have used Section 1431 of the SDWA to petition the EPA to make a finding that nitrate levels represent an imminent and substantial danger to the population.[87]

The ability of local and state governments to meet their CWA and SDWA commitments to protect against dangerous drinking water relies in part on stable and healthy flows of federal resources for continued public investments.[88] Rural communities with a strained tax base (see figure 4) are in the worst position to protect their drinking water from nitrates without federal funding.[89] While we have been making progress in protecting clean water as a nation overall, federal clean water infrastructure investments have been declining; as of 2023, state and localities were shouldering 92 percent of the costs of water infrastructure.[90]

EXISTING FEDERAL CONSERVATION PROGRAMS ARE UNDERFUNDED AND UNDERSTAFFED

Another tool for addressing the nitrogen pollution crisis is the suite of voluntary conservation programs funded by the USDA. The Conservation Title of the Farm Bill (Title II) provides cost-share reimbursements to farmers who use practices that improve nutrient management and reduce nitrogen runoff. The Environmental Quality Incentives Program (EQIP) provides cost-share reimbursements to farmers who conserve soil, protect water quality, and implement specific conservation practices such as cover cropping or nutrient management planning.[91] The Conservation Stewardship Program (CSP) pays farmers to maintain and expand their existing conservation practices, for example by continuing to use cover crops but switching to multi-species cover crop mixes or by reducing tillage as part of their cover and cash crop management strategy. These programs offer flexibility for producers to experiment with changes and additions to their in-field conservation practices to reduce the amount of nitrogen applied and lost. Both EQIP and CSP can be used to fund a wide variety of conservation plans that can help producers chart a path to reduced nitrogen use, often with the help of a certified technical service provider. Additionally, the Agricultural Conservation Easement Program (ACEP) helps landowners keep land in farming and preserve wetlands, which function as “nature’s kidneys” and reduce nitrogen pollution from entering water supplies.[92]

These core USDA conservation programs are beneficial for reducing nitrogen pollution and protecting water quality but are consistently oversubscribed and chronically underfunded.[93] The Inflation Reduction Act (IRA) was partly designed to alleviate the voluntary conservation programs’ budget shortfalls with its historic investment of $20 billion for conservation programs. Unfortunately, IRA dollars that had been contractually promised to producers were paused in 2025, leaving many farmers partway through installing conservation practices with major expenses and uncertain prospects for reimbursement.[94] Congress then scrapped the IRA’s dedicated climate funding for conservation agriculture—though it did allocate those dollars to regular farm bill conservation programs. But with the USDA losing almost 21,000 employees in 2025 alone, and with flat funding for technical assistance, farmers trying to implement nitrogen reduction practices face obstacle after obstacle.[95]

Farmers find themselves in a vice grip. While the federal programs designed to help them improve their soil health and decrease nitrogen pollution are underfunded, at the same time they are offered a range of incentives through crop insurance, Title I commodity programs, and other programs to maximize corn and soybean production with *more* nitrogen application, regardless of actual market demand.[96]

TECHNICAL ASSISTANCE IS UNDERVALUED AND UNDERFUNDED

Federal funding for conservation agriculture also has an important gap: These complex grant programs do not provide sufficient funds for technical assistance or support to navigate them. Technical assistance is funded annually and is consistently targeted for budget cuts.[97] Without consistent and predictable public funding for technical assistance, farmers may seek advice from private retailers who are incentivized to sell more products—including more fertilizers—and not to reduce environmental harms. Many farmers stand ready and willing to adopt nitrogen-reducing conservation practices on their own without financial assistance but could benefit from some technical advice on how the practices might work. Stable conservation technical assistance funding from the annual agriculture appropriations bills (and occasionally in mandatory funding like the IRA) is important to ensure that farmers can translate these programs into on-farm success.[98]

Furthermore, federal agencies are lagging dramatically behind the private sector when it comes to compensating professionals with technical qualifications. The low pay for these technical service providers makes recruitment and retention difficult challenges.[99]

In short, federal voluntary agricultural conservation programs are a critical piece of the puzzle because they connect the dots for farmers working to implement practices to reduce nitrogen pollution and lessen the need for inputs. However, they are not sufficient by themselves to significantly reduce nitrogen pollution.

V. MINNESOTA AND CALIFORNIA DEMONSTRATE A NEED FOR MANDATORY, ROBUST STATE MANAGEMENT

As exemplified by the following case studies, states also lack effective nitrogen pollution strategies. Like the federal government, states rely mainly on voluntary programs to manage nitrogen pollution from croplands. But even at the state level, this approach has failed to protect clean water for people and ecosystems for the past 40 years. By setting numeric limits on nitrogen fertilizer applications and discharges while supporting farmers using sustainable nitrogen management practices, states can strengthen existing programs and drive meaningful reductions in nitrogen pollution.

CASE STUDY: MINNESOTA

BACKGROUND

Nitrogen pollution in Minnesota has been a growing problem since the 1980s, when federal and state agencies first identified rising nitrate contamination in Minnesota's surface waters and groundwater.[100] Seventy-two percent of all excess nitrogen in the state's rivers comes from agriculture, specifically from the overapplication of synthetic fertilizer and manure.[101] In fact, synthetic fertilizer accounts for 47 percent of all nitrogen added to cropland in Minnesota, with smaller but notable additions from legume fixation, manure field application, and atmospheric deposition. As a result of this pollution, many Minnesotans are regularly exposed to elevated nitrate levels, with one in eight relying on groundwater-based public water systems that exceed the federal and state limit (10 mg/L) for nitrate.[102] This figure almost certainly increases when the 1.1 million Minnesotans who rely on private drinking wells are included.[103] Across the state, about 1 percent of the 5,000 private wells tested annually have nitrate levels that exceed the MCL; in areas vulnerable to groundwater contamination, this number rises past 10 percent.[104]

Minnesota's southeastern karst region, which sits on top of particularly porous rock prone to quick water infiltration, faces especially alarming levels of nitrate-contaminated groundwater. Many local residents now rely on unhealthy and potentially dangerous drinking water sources due to a combination of this vulnerable geology, a high quantity of animal feeding operations where pollution flows into surrounding waterways, and a transition away from the diverse production of small grains, which may have helped mitigate nitrogen pollution, to nitrogen-intensive corn and

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soybean monocultures.[105] In 2017, 19 percent of the wells in Winona County tested above 10 mg/L, and half of the wells in Fremont Township tested above this limit.[106] As previously mentioned, newer research indicates certain cancers and birth defects are linked to drinking contaminated water with a nitrate level of 5 mg/L or higher.[107]

In a state with more than 10,000 lakes, surface water contamination from nitrogen pollution poses significant risks to biodiversity and fishing economies. Nitrates flowing through the state's northern waterways contribute to severe algal blooms and nutrient overloading in the Lake Winnipeg Basin.[108] The Minnesota Pollution Control Agency concluded that nitrate levels as low as 5 mg/L are unsafe for aquatic life, but it has not adopted a water quality standard based on this conclusion.[109] A report from 2013 indicated that these limits are routinely exceeded in the state, with 41 percent of all tested rivers and streams exceeding 5 mg/L and 27 percent exceeding 10 mg/L.[110]

The damages of nitrogen pollution also extend beyond state boundaries. As noted above, contaminated water flows down the Mississippi River and contributes to the annual dead zone in the Gulf of Mexico, an area the size of Connecticut where low-oxygen conditions make it difficult for marine animals to survive.[111] This hypoxic zone inflicts up to $2.4 billion in damage to fisheries and marine life every year, and efforts to decrease its size have not been successful.[112]

Networks of underground pipes designed to increase water drainage in croplands (known as drainage tile) contribute to the nitrogen pollution crisis in Minnesota. This belowground infrastructure alters the flow of water in soil, results in higher nitrate loads in neighboring streams, and is the largest source of nitrogen pollution to surface waters.[113] Approximately 35 percent of cropland in Minnesota is tile drained, with acreage expanding in the past 15 years.[114] Less than 1 percent of this acreage has implemented controlled drainage management practices designed to slow the flow of water from these heavily drained areas or treat drainage runoff to reduce nutrient load.[115] Use of drainage tile is common in areas that are already prone to groundwater contamination due to geological factors, increasing the likelihood of elevated nitrate levels in drinking water.

Reductions in nitrogen from both manure and synthetic fertilizer are needed to protect water quality in Minnesota.

Overapplication of fertilizer also drives nitrous oxide emissions in Minnesota. In 2023, the overapplication of synthetic fertilizer in the state produced avoidable greenhouse gas emissions equivalent to the output of 400,000 to 700,000 gas-powered cars driven for a year.[116] Nitrous oxide emissions from nitrogen pollution may further increase with the longer growing seasons and potential for extreme weather events under a warming climate.[117]

VOLUNTARY EFFORTS TO MANAGE NITROGEN HAVE NOT WORKED IN MINNESOTA

Minnesota first attempted to address nitrogen pollution with the Groundwater Protection Act in 1989, which directed the Minnesota Department of Agriculture to limit groundwater pollution from synthetic fertilizer overapplication.[118] The law led to voluntary programs focused on instituting best management practices and expanding education and access to private well testing for nitrate contamination.

These interventions had minimal impact. Today, nitrate levels across the state continue to regularly exceed the MCL.[119] In 2014, the Minnesota Pollution Control Agency set a long-term goal of reducing nitrogen pollution in the state by 45 percent by 2040, with a reduction target of 20 percent by 2025.[120] By 2025, statewide nitrogen pollution had decreased by only 6 to 9 percent, depending on the watershed.[121] The majority of these reductions have come from nonagricultural sources like wastewater treatment improvements; almost all remaining reductions will need to come from the agricultural sector.[122]

Data from the state also show that since 2014, more than four million acres of land (roughly 18 percent of total cropland in the state) have voluntarily come under new nitrogen reduction practices adopted through government programs. Yet this limited adoption of best management practices has only resulted in a 4–5 percent reduction in nitrogen loads at the watershed level from the 2014 baseline.[123]

These results show that voluntary efforts alone are insufficient to limit nitrogen pollution, both because most recommended best management practices do not address the issue of overapplication itself, and because they are not being adopted at a scalable level to safeguard water quality.[124] Despite this, Minnesota is continuing to focus narrowly on these voluntary programs as the primary approach to nitrogen pollution reduction.

Meanwhile, at root of the problem, nitrogen fertilizer and manure applied as a nitrogen source to croplands in Minnesota exceed the recommended rates by 18 percent on average.[125] This means that in states like Minnesota, there is significant room to reduce application rates without affecting crop yields. In addition, evidence suggests that smarter fertilizer management combined with best management practices could dramatically reduce nitrogen pollution.[126]

CASE STUDY: CALIFORNIA

BACKGROUND

Excess nitrogen fertilizer has been a major pollutant in California for 70 years.[127] In a 1988 report prepared for the state legislature, the State Water Resources Control Board found that a growing number of drinking water sources were exceeding the MCL for nitrates.[128] The report recommended that the State Water Board centralize nitrate data collection and explore regulatory actions, including limiting fertilizer applications in vulnerable areas to address nitrogen pollution.[129] However, the Water Board did not take any regulatory action and instead continued allowing agricultural operations to unconditionally discharge nitrogen pollution into waterways.[130]

In 1999, the California legislature passed Senate Bill 390 (SB 390), which directed the State Water Board to cease its unconditional permitting and regulate agricultural discharges, including nitrogen pollution.[131] Shortly after passage of SB 390, the board created the Irrigated Lands Regulatory Program (ILRP) to protect water quality by reducing nitrogen pollution from irrigated croplands.[132] However, the regulatory program consists only of data collection and does not set numeric limits or maximums for nitrogen application or discharges.

Unsurprisingly, nitrogen pollution continues to harm communities and ecosystems and is increasing in some parts of the state.[133] In the Central Coast region, 14,039 residents were served water from systems that exceeded the nitrate MCL in 2025.[134] In the San Joaquin Valley, between 2003 and 2017, approximately 1.5 million people received drinking water from systems that tested at or above the MCL.[135]

CALIFORNIA'S DATA COLLECTION EFFORTS

Despite ongoing challenges with reducing nutrient pollution, the ILRP's reporting requirements offer a starting place for nitrogen fertilizer data reporting that can help guide and inform other states. The State Water Board sets baseline requirements for the ILRP that each of nine regional boards can adapt according to each region's growing conditions, hydrology, and crop types.[136] This flexibility has resulted in varying data quality, variable reporting standards, and a fragmented picture of nitrogen pollution across California.

The State Water Board issued a precedential Water Quality Order in 2018 to improve the ILRP, including adding new data reporting requirements.[137] The 2018 order requires farmers to report their fertilizer applications, nitrogen removals, crops grown, projected yields, volume of irrigation water applied, and acreage, among other items. Unfortunately, because of some regional variation in ILRPs, not all the data reported by farmers is shared with the State Water Board or the public, particularly acreage data.

In at least one regional water board's ILRP, field-level acreage values are reported by farmers, but these values are removed before being submitted to the State Water Board and regional water boards, owing to privacy concerns.[138] This undermines the State Water Board's ability to identify farms that are overapplying nitrogen, because it is impossible to know if the overapplications or discharges are happening at rates above the limits without knowing over how many acres the overapplications and discharges are occurring. For example, discharging 50 pounds of nitrogen per acre over 10 acres (potentially 500 pounds of nitrogen lost) has different public health, environmental, and policy implications than that same discharge over 1,000 acres (potentially 50,000 pounds of nitrogen lost).

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If field-level acreage data were made available, the data in these reports could reveal the scale of fertilizer overapplications in California and which cropping systems contribute the most nitrogen pollution. The data could also help resource-strapped regulators efficiently target outreach and education to farmers who are consistently overapplying nitrogen fertilizers. Additionally, the data could allow regulators to design more precise regulations and measure the impact of those regulations, which could help build long-term trust in the program.[139]

THE RISE AND REMAND OF AGRICULTURAL ORDER 4.0

By 2021, one of the regional water boards, the Central Coast Water Quality Control Board, observed that simply requiring farmers to report their nitrogen application was not reducing nitrogen pollution.[140] In fact, water quality in some parts of the region kept getting worse. The Central Coast Board's experience is consistent with the viewpoint that voluntary, nonnumeric efforts to reduce nitrogen pollution are inadequate by themselves to protect water quality.[141]

In response, the Central Coast Board issued Agricultural Order 4.0, a regulation that would have set numeric limits and targets on nitrogen fertilizer applications and discharges. The order was designed to reduce nitrogen pollution over a 28-year period so that, ultimately, nitrogen use would be compatible with safe drinking water quality thresholds.[142] It would have been the first regulation to set numeric limits on general nitrogen applications and discharges in the United States. The order was remanded by the State Water Board before it had a chance to take full effect.

The initial limits in Agricultural Order 4.0 were aimed at growers who were applying nitrogen fertilizer at levels that were orders of magnitude above recommended rates, meaning that most farmers would have already been compliant. According to the Central Coast Board's nitrogen data reporting dashboard, only 3 percent of farmers who reported their nitrogen data in 2021 would have had to change their behavior to meet the first nitrogen discharge target of 500 pounds per acre.[143]

Agriculture Order 4.0 would have also rewarded farmers for using sustainable nitrogen management practices such as planting cover crops or using compost. Interestingly, on the basis of anecdotal evidence from local researchers, the numeric limits in Agriculture Order 4.0 combined with the rewards for sustainable nitrogen management practices prompted more farmers to experiment with cover crops, organic amendments, and compost before the order was remanded.[144] Regulation drove adoption of sustainable nitrogen management practices.

The State Water Board set aside the numeric limits in Agricultural Order 4.0, claiming that the Central Coast Board had violated a previous order issued by the State Water Board.[145] As of 2025, the State Water Board had not implemented any numeric limits on nitrogen application and discharge. Instead, state agencies continue to prioritize reporting, technical assistance, and education, which by themselves have not solved the nitrogen pollution crisis.

A harmful algal bloom in California's San Luis Reservoir.

VI. ENFORCEABLE STANDARDS WILL HELP SOLVE THE NITROGEN POLLUTION CRISIS

The key to solving the nitrogen pollution crisis lies in statewide *enforceable standards* to augment the impact of voluntary compliance. This is true for limiting nitrogen runoff as well as reducing nitrous oxide emissions. The policy framework described below and summarized in table 1 embraces clear, measurable limits that align incentives with outcomes, invests in data and infrastructure that tracks performance, and prioritizes enforcement against outliers to create a level playing field for all farmers.

TABLE 1: A POLICY FRAMEWORK PAIRING CLEAR NUMERIC LIMITS WITH REPORTING TO ACHIEVE REDUCTIONS IN NITROGEN POLLUTION

Set Clear, Measurable Limits	States should establish numeric limits for nitrogen application and discharge designed to protect drinking water and ecosystems. Mandatory limits prevent competitive disadvantages for farmers already employing sustainable farming practices. Clear limits will spur further expansion of sustainable farming practices and development of more advanced fertilizer technologies.
Improve Measurement and Reporting	Progress should be tracked through transparent reporting and monitoring at both the farm and regional levels. Nitrogen management plans should include data on application rates and crop needs with alternative reporting mechanisms that consider the unique circumstances of small and diversified farms. Fertilizer retailers and food companies should share responsibility with farmers in preparing and carrying out plans.
Reward Farmers for Using Sustainable Nitrogen Management Practices	Regulations should drive transitions to more sustainable farming systems. Policies should reward and promote practices such as cover cropping, crop rotations, crop diversification, riparian buffers, and composting, which reduce nitrogen pollution and improve farm productivity.
Pair Enforcement with Support	Regulations should be paired with technical assistance and education to help farmers meet limits without unreasonable burdens while preserving profitability. Enforcement should start with outreach, with penalties reserved for persistent noncompliance.
Establish MMRV for Climate Goals	Build robust systems to measure, monitor, report, and verify nitrous oxide emissions and reductions from farms. This ensures transparency, rewards farmers for improvements, and supports climate goals.

ENFORCEABLE STANDARDS ARE KEY TO REDUCING NITROGEN POLLUTION

It would be great if we could do this voluntarily, but I don't know any society in the history of mankind that has actually protected our natural capital without some level of enforceable regulation.

–An Iowa farmer at an August 2025 water quality event.[146]

State policymakers should establish clear goals ensuring that nitrogen runoff from farms will not contribute to violations of drinking water standards or water quality objectives for surface water or groundwater. Such goals could be implemented through enforceable regulatory limits on overapplication and discharge of nitrogen from croplands, which could require implementation of best management practices and incorporate guidance from land grant universities.

For such goals and limits to be achieved, they must be measurable, reportable, and enforceable. Measurability is critical because governments and industry are unlikely to fix a problem that they are not measuring and not required to measure. Appropriate measurement must include outcome-based monitoring and reporting, including reporting of the nitrogen applied and nitrogen removed as biomass from each acre of cropland.[147] Such reporting allows state officials to work with farmers and fertilizer companies to focus nitrogen management strategies on areas of highest need, including conducting outreach for and increasing enrollment in voluntary and incentive-based programs. Accurate reporting also allows state officials to estimate reductions in nitrogen pollution without solely relying on nitrate concentrations in wells, which can take decades to reflect changes in nitrogen discharge.[148] States should not rely solely on "proxy" systems that simply estimate nitrogen pollution reduction based on the number of acres under best management practices.[149] Instead, reporting should focus on measurable progress toward nitrogen reduction and water quality goals. At the same time, reporting programs should avoid a one-size-fits-all approach and have alternative reporting mechanisms that account for the unique circumstances of small and diversified farms.

As a practical matter, reporting could be achieved through submission of nitrogen or nutrient management plans. Such reporting and associated plans should account for nuances such as soil type and existing nitrogen in the soil, as well as nitrogen applied through non-fertilizer sources such as nitrate-rich irrigation water. Reporting should also include appropriate "ground-truthing" through soil testing or water quality testing of agricultural runoff and adjacent groundwater and surface water. Other ground-truthing and verification approaches could include cross-referencing fertilizer application data information with fertilizer sales data, and certification of data by an independent consultant.

Enforceability is critical because the evidence shows that voluntary programs have not sufficiently addressed the nitrogen pollution crisis given that they do not tackle the core of the problem: overapplication of nitrogen fertilizer and limited use of practices minimizing nitrogen runoff. An effective regulatory system will include numeric limits on both the application and discharge of nitrogen from croplands and provide alternative pathways to compliance that account for crop type, soil conditions, seasonal variations, and farm size. Such limits can be achieved through nitrogen management plans that allow an iterative and collaborative process among farmers, fertilizer companies or consultants, food companies, and state or local officials. California's ILRP, discussed in Section V, provides an example of the kind of information that should be included in such plans. Similar to existing climate pollution directives, regulations could also require food companies to track and mitigate nitrogen pollution in their supply chains.[150] Regulatory limits should be paired with other policies to limit nitrate pollution, such as permitting systems for tile drainage in jurisdictions, like Minnesota, that utilize such infrastructure.[151]

State officials implementing limits on nitrogen overapplication and discharge should avoid punitive enforcement approaches and instead pursue a progressive enforcement approach that begins with clear notice of violations paired with education and outreach. This provides farmers with opportunities to improve their nitrogen management practices without facing significant and immediate financial penalties. Substantial fines or civil penalties should be imposed only if farmers refuse to take steps to improve their nitrogen management practices or incorporate recommended actions.

Enforceable limits on nitrogen application and discharge should also be paired with robust voluntary and incentive-based programs to improve nitrogen management, particularly for small and diversified farms. Programs could encourage crop diversification, cover cropping, or rotation with nitrogen-fixing crops such as legumes. Conservation drainage or edge-of-field practices such as use of riparian buffers, saturated buffers, treatment wetlands, and bioreactors reduce the nitrogen in runoff before it enters streams or groundwater and should be incentivized. This should be paired with a robust nitrous oxide monitoring program to capture potential increases in emissions associated with some types of buffers.[152]

Policy solutions should also recognize that fertilizer companies and other actors along the food supply chain are major drivers of nitrogen overuse; incentives or compliance obligations should be aligned accordingly.[153] As discussed in the appendix to this report, fertilizer retailers are viewed by farmers as a trusted source for nitrogen management information even though they have a financial interest in selling fertilizer and maximizing profits. Policies could require fertilizer retailers, food companies, or their consultants to share responsibility with farmers in developing and implementing nitrogen or nutrient management plans, meeting limits on overapplication and discharge, and ground-truthing the accuracy of information in such plans. In addition, fertilizer and food companies could also be subject to progressive enforcement actions for refusing to meet such requirements.

ENFORCEABLE STANDARDS ARE EQUITABLE

Enforceable standards can help establish a level and equitable playing field for the agriculture industry. Currently, farmers who invest in voluntary best management practices to reduce nitrogen pollution often must compete with farmers who decline to do so. A farmer who employs best management practices might take on higher costs of production that may not be made up in sales. As long as nitrogen reduction is optional, some farmers will continue to face pressure to overapply nitrogen to reduce perceived or real risk and maintain profitability, even if it endangers their communities and degrades their environment. This principle applies in most other industries: a manufacturing facility is subject to the same pollution control regulations as others in the same market. Without consistent regulations, some manufacturers could employ no pollution control technologies and potentially increase sales or profits, even while harming the surrounding community.

Enforceable standards will ensure that all farmers play by the same rules and share responsibility for reducing negative externalities. Enforceable standards are also critical because even if the majority of farmers are investing in strategies to minimize nitrogen pollution, those who don't can still be a major driver of pollution.

ENFORCEABLE STANDARDS INCENTIVIZE TECHNOLOGICAL INNOVATION

Enforceable standards can spur innovation in fertilizer technologies and irrigation practices. Without the demand for advanced technologies that these standards would create, fertilizer companies lack adequate incentives to develop them.

These technologies include enhanced efficiency fertilizers (EEFs), which aim to improve nitrogen use efficiency to minimize nitrogen loss.[154] One possibility is that state officials could require fertilizer retailers to sell an increased percentage of EEFs by a certain date, with that number continuing to increase until the vast majority of fertilizer sales are EEFs, similar to the Corporate Average Fuel Economy standards that increased car fuel efficiency.[155] Other environmental laws have served a technology-forcing role; for instance, the federal Clean Water Act requires the EPA to establish technology-based limitations on discharge and is intended to foster development of new, more efficient, and more effective technologies.[156]

While EEFs have the potential to play an important role in reducing nitrogen pollution, they are not a silver bullet.[157] Currently there are several types of EEF (e.g., nitrification inhibitors, slow-release fertilizers), and it is not clear how well they reduce nitrogen loss in different climates, weather conditions, and cropping systems. EEFs should be designed and appropriately regulated to ensure that they do not have unintended consequences such as delayed release of nitrogen or other chemicals into rivers, streams, or groundwater. Even if EEFs were effective and widely used by farmers, they could still be overapplied like traditional fertilizers. EEFs would also need to be accompanied with robust education programs to ensure that their benefits are realized in actual implementation. Other areas of innovation include the market for edge-of-field practices and technologies to trap nitrogen pollution, such as denitrification reactors and riparian buffers.[158]

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Cover crops such as rye can help trap nitrogen on fields before it runs off.

VII. BETTER TRACKING OF NITROUS OXIDE EMISSIONS FROM FERTILIZER IS KEY TO TACKLING THE CLIMATE CRISIS

Effective measurement, monitoring, reporting, and verification of emissions (MMRV) is the foundation of the United States' attempts to tackle the climate crisis and must be applied to nitrogen emissions from fertilizer. Developing a clearer picture of how nitrous oxide and nitrogen loss is unfolding nationally will benefit both farmers and consumers while clarifying how our atmosphere and ecosystems are transforming.

As discussed in Section II, nitrogen overapplication on croplands is one of the main drivers of nitrous oxide emissions, a major greenhouse gas and the most abundant ozone-depleting substance in the stratosphere. The agricultural sector accounts for 50 to 70 percent of global anthropogenic nitrous oxide emissions, and that number is projected to increase by up to 30 percent by 2050 from agricultural sources alone in a business-as-usual scenario.[159]

MMRV efforts for other greenhouse gases like carbon dioxide and methane are ongoing, but so far efforts have been lacking for nitrous oxide. This lag in infrastructure to measure and track nitrous oxide emissions across the country contributes to nitrous oxide's moniker as the "forgotten superpollutant." Imprecise measurement and monitoring of nitrous oxide results in inaccurate greenhouse gas accounting and increased difficulty in accounting for nitrous oxide when designing interventions. This is particularly important as some efforts to increase soil carbon and soil health in agricultural systems can increase nitrous oxide emissions, a tradeoff that needs to be factored into policy and funding decisions.[160]

WHAT IS MMRV?

MMRV stands for measuring, monitoring, reporting, and verification. In climate mitigation, MMRV refers to the multi-step process that starts with ***measuring*** the amount of greenhouse gas emissions either reduced or removed from the atmosphere by a specific mitigation activity, such as decreasing emissions from fertilizer application. These reductions then need to be ***monitored*** over time to ensure that they are ongoing. Findings are then ***reported*** to a trusted third party, which ***verifies*** the report so that the results can be certified.

The goal of MMRV is to prove that an activity has actually avoided or removed harmful greenhouse gas emissions so that the impacts of this activity can be documented, new activities can be developed or improved, or the activities can be assigned a monetary value.

According to a 2025 estimate, nitrous oxide from nitrogen application accounts for 91 percent of the U.S. agriculture sector's crop-related emissions.[161] As commercial and regulatory incentives for managing these emissions continue to evolve, the importance of understanding and being able to quantify them increases. Without a robust nitrous oxide MMRV framework, it is difficult to measure the impacts of changes in management practices by farmers or to reward their investments in improving their practices. This lack of a clear measurement framework limits economic opportunities for farmers to benefit from nitrous oxide reduction and hinders on-farm decision making for improved operational resilience.

Coordinating research efforts, funding priorities, and funding sequencing between all levels of government and the private sector is critical for improving nitrous oxide MMRV. At the local, state, federal, and international levels, there is a need to build data infrastructure and develop policy to better measure nitrous oxide emissions. Public and private research institutes as well as technology and food companies are important partners in ensuring that MMRV technologies are tested and deployed.[162] This coordination and sequencing of research investments by federal, state, and philanthropic leaders is critical to driving nitrous oxide MMRV innovation and improving our understanding of farm-scale, regional, national, and global nitrogen emissions profiles.

Instruments such as flux chambers are vital for tracking nitrous oxide emissions.

VIII. CONCLUSION

The evidence is clear: Nitrogen pollution is not an isolated agricultural issue but a pervasive environmental and public health crisis with far-reaching economic consequences. Decades of voluntary programs have failed to curb overapplication of synthetic nitrogen fertilizers and manure, leaving communities with unsafe drinking water, ecosystems in decline, and taxpayers footing the bill for costly remediation. The science shows that improving nitrogen management by reducing fertilizer overapplication and minimizing nitrogen discharge is both feasible and effective, and doing so would deliver cleaner water, healthier ecosystems, and significant climate benefits without sacrificing agricultural productivity. For far too long communities have been presented with a false choice between clean water and food production.

To achieve these outcomes, states must move beyond education and incentives and adopt enforceable, outcome-based standards that align nitrogen fertilizer application with crop requirements and mandate implementation of practices to reduce nitrogen runoff. Paired with robust technical assistance, targeted financial support, and shared accountability on the part of fertilizer and food companies, these measures can create a level playing field for farmers and drive innovation and expansion in sustainable farming practices. Now is the time for policymakers, industry leaders, and farmers to work together to implement solutions that support thriving farming economies while protecting our water, our health, and our future.

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APPENDIX: FREQUENTLY ASKED QUESTIONS ABOUT THE NITROGEN POLLUTION CRISIS

WHAT IS THE PRIMARY SOURCE OF NITROGEN POLLUTION IN THE UNITED STATES?

Excess nitrogen from agricultural systems is the primary source of nitrogen pollution in the atmosphere, and in many watersheds across the United States.

Nitrogen runoff from agriculture is the primary source of nitrogen pollution in the atmosphere as well as in many of the watersheds experiencing degraded water quality across the United States. In the atmosphere, agricultural nitrogen inputs account for 50 to 70 percent of anthropogenic nitrous oxide emissions globally.[163] These agricultural nitrous oxide emissions are a major reason why nitrous oxide is currently the most abundant stratospheric-ozone-depleting substance.[164]

There are many potential sources of aquatic nitrogen pollution—synthetic and organic fertilizers, municipal wastewater, biological nitrogen fixation, and atmospheric nitrogen deposition—and the specific mix of sources that impact a particular watershed will often depend on the location of that watershed. Studies using both modeling and stable isotopes to track the sources of nitrogen in ground and surface water confirm that agricultural nitrogen inputs are the main source of nitrate in groundwater in watersheds across the globe.[165] In ground and surface water, agricultural systems can contribute 56 to 88 percent of nitrogen pollution, depending on the watershed, largely through the runoff of nitrogen from synthetic fertilizers and manure.[166] Even small increases in fertilizer application can have an impact, with a 10 percent increase in the use of nitrogen fertilizer (kg) across a watershed estimated to lead to a 1.525 percent increase in the concentration of nitrogen (mg/L) in surface water.[167] Across the United States, synthetic nitrogen fertilizer is the largest nitrogen source in 41 percent of watersheds, and agriculture is the dominant source of runoff to coastal estuaries on the East Coast and the eastern Gulf of Mexico.[168]

IS FERTILIZER OVERAPPLICATION REALLY OCCURRING?

Yes. Numerous studies demonstrate that more nitrogen fertilizer is applied to agricultural fields than plants can use, particularly in hot spot areas, with actual overapplication amounts varying by location and crop type.

Fertilizer overapplication has been recognized as a global problem for decades.[169] An estimated 40 to 60 percent of the nitrogen applied to U.S. fields is not used by crops and instead runs off into the environment.[170] Many studies have shown that a significant number of farmers in the United States apply nitrogen in excess of recommendations from land grant universities. In 2006, one USDA study found that 64 percent of U.S. fertilized crop acres did not meet nitrogen management criteria, including rate, timing, and placement of nitrogen fertilizer. Of those, approximately 32 percent were applying more nitrogen than recommended.[171]

However, not all agricultural land contributes to nitrogen runoff equally. A 2021 study found that nitrogen hot spots in only about 24 percent of U.S. cropland area, most of which was dominated by animal feed crops, collectively account for approximately 63 percent of total surplus nitrogen balance.[172] Another 2021 study found that approximately 2 to 8 percent of the land area within the contiguous United States accounted for 75 percent of the estimated nitrogen pollution to rivers and lakes.[173] These studies highlight how the lack of accurate fertilizer application data can make it difficult to understand the full scope of nitrogen pollution in the United States and also underscore how most agricultural nitrogen pollution in this country originates in nitrogen hot spots.

There is a documented history of nitrogen overapplication occurring within U.S. nitrogen hot spot areas. In 2014, a study of three midwestern states found that an estimated 37 percent of the 134 farmers interviewed overapplied nitrogen by five pounds per acre or more.[174] The average farm size was 1,615 acres, translating to an estimated overapplication of at least 400,000 pounds of nitrogen per year, just for that study area. A 2020 study of Illinois corn acres showed that 67 percent of sampled acres were applying nitrogen above the maximum return to nitrogen value, with 33 percent of fields applying at least 20 pounds of nitrogen per acre over the recommended rate.[175] Finally, in a 2014 study of Iowa farmers, more than half of those surveyed agreed that "farmers apply too much nitrogen to ensure yield."[176]

Overapplication is likely to continue. Applying more nitrogen fertilizer is one of the documented farmer responses to the increased potential for irregular rainfall patterns and extreme weather events linked to climate change.[177] The idea is that extra nitrogen will be left behind to support crop growth after a rain event diminishes nitrogen levels in the soil. While this response is seen as a quick fix, it can actually exacerbate climate change and nitrogen pollution issues and is projected to be a key factor in increased nitrogen runoff from susceptible agricultural fields in the next few decades.[178]

WHY DO FARMERS OVERAPPLY NITROGEN FERTILIZER?

Farmers often apply more nitrogen fertilizer than plants need to manage risk, maximize yields, and take advantage of insurance policies and supply contracts that incentivize overapplication.

There are two major reasons why farmers may be motivated to overapply nitrogen fertilizers: boosting yields and reducing risk. Higher nitrogen application is assumed to result in greater yields, and greater yields help farmers maintain their crop insurance rates, obtain bank loans, and secure contracts with larger-scale industrial buyers.[179]

Crop yield increases with the amount of nitrogen applied, up to an optimum point ("B" in figure A1). Past this point, farmers see only marginal improvements to yield with increased nitrogen applied, but this increase still creates a perverse incentive to overapply nitrogen fertilizers past what is economically optimum, to avoid falling short of the maximum.[180] Past the optimum rate, a greater proportion of the nitrogen applied is not being used by the crop and is wasted. However, the combination of operating on small profit margins and the low cost of nitrogen fertilizers (relative to other farm costs) mean that farmers still opt for reaping the marginal profits associated with diminished yields.[181]

Overapplication also doubles as a risk management strategy.[182] Some farmers apply excess nitrogen to provide a buffer against yield losses that might occur or to reap benefits from ideal weather conditions. Ironically, climate change driven in part by emissions from cropland nitrogen increases unpredictable weather patterns and may make those ideal growing conditions less likely.[183] The practice of overapplication to mitigate risk has become so commonplace that many farmers believe that any reduction in their nitrogen applications will lead to yield or profit losses.[184] However, studies show that in some situations nitrogen use can be cut by up to half without reducing agricultural productivity, and that overapplication is driven largely by perceptions of risk.[185]

Insurance policies can incentivize overapplication of fertilizer.[186] To receive crop insurance payments, the U.S. Federal Crop Insurance Program requires farmers to prove that they were not at fault for crop failures by demonstrating they were following "good farming practices."[187] Farmers can be denied insurance payouts for under-fertilizing their crops, which encourages them to err on the side of overapplying nitrogen fertilizer. Crop insurance coverage is also often a prerequisite for farmers to apply for bank loans.[188] Farm insurance coverage depends on actual production history (APH), which is calculated using the average of a farmer's previous 4- to 10-year yield records.[189] Higher APHs can improve a farmer's crop insurance coverage and encourage farmers to overapply nitrogen fertilizers to achieve higher yields. In 2023, the USDA took an important step to address the mismatch between crop insurance and sustainable farming practices, aligning crop insurance rules with the NRCS guidelines for practices like cover cropping.[190]

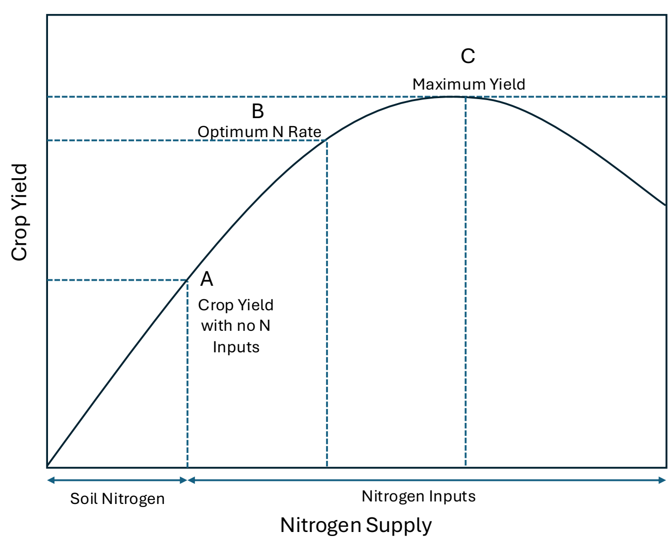
Supply contracts between corporations and farmers also incentivize overapplication of nitrogen fertilizer. Two types of contracts dominate the agricultural sector: tournament and fixed-rate. Tournament contracts pit growers against each other and pay on the basis of farmers' rankings. This rewards farmers who produce the highest yields and penalizes those who do not, sometimes with cancelled contracts.[191] Tournament contracts, which are common for corn seed production, introduce an extreme incentive to overapply nitrogen fertilizer in the hopes of maximizing yield. In one study, farmers who produce seed for both corn seed and commercial corn reported applying four times as much nitrogen per acre on their corn seed acreage as they did on their commercial corn acres.[192]

Fixed-rate contracts, which are used predominantly for fruit and vegetable production, directly influence farmers' fertilizer decisions because of fertilization and quality control practices that are written into the contracts.[193] Under some very specific fixed-rate production contracts, large-scale buyers mandate fertilizer application rates, leaving farmers without any control over their fertilizer practices.[194]

Fertilizer retailers also influence nitrogen fertilizer practices implemented by farmers. Studies reveal that fertilizer retailers are consistently ranked as the most trusted source of nitrogen management information, marking a significant shift away from public sector academics toward private sector sources.[195] Farmers believe that a fertilizer retailer's interest in protecting farmers' output closely aligns with their own profit motives.[196] Unfortunately, fertilizer retailers also have a vested financial interest in selling as much fertilizer as possible.

FIGURE A1

Nitrogen fertilizer can be economically beneficial and improve yield, but only up to a certain point.



Finally, government pressure has pushed nitrogen application amounts to higher and higher levels. Today's nitrogen pollution crisis sits atop a policy decision the United States made in the 1970s when the secretary of the USDA, Earl Butz, set a goal to dramatically increase corn and soybean production and pushed farmers and ranchers across the country to "get big or get out" of agriculture.[197] Farmers now operate in an environment where generations of policy have made consolidation and growth among the few survival strategies available to them.

WILL REDUCING NITROGEN FERTILIZER APPLICATION RESULT IN CROPS NOT GETTING ENOUGH NITROGEN?

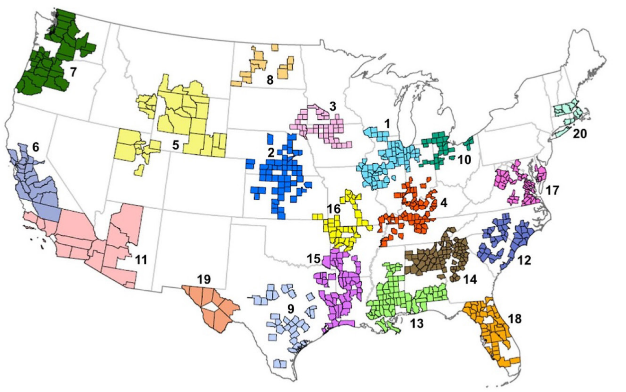
No. Given that 40 to 60 percent of the nitrogen applied to fields is not taken up by crops, nitrogen use, particularly in hotspots, can be reduced without significant impacts on yield.

As discussed earlier in this section, nitrogen hot spots account for a majority of the nitrogen surplus and overapplication across the United States. This means that nitrogen reduction efforts targeted to specific areas and cropping systems (particularly less efficient cropping systems producing animal feed) can have an outsize impact on reducing nitrogen waste with minimal impact on yield.[198]

Studies show that both nitrogen inputs and nitrogen losses from agricultural fields can be significantly reduced without a loss of agricultural productivity, particularly in low-yielding areas.[199] Maintaining productivity under nitrogen rates lower than many farmers currently use is possible both because overapplication is occurring and because the majority of the nitrogen that plants use during the cropping season actually comes from soil organic matter.[200] This is why soil nitrogen tests—which measure the soil nitrogen pool—are important. Increasing nitrogen stored in soil organic matter helps reduce loss, since nitrogen trapped in soil organic matter is less susceptible to leaching.[201] The legacy of nitrogen overapplication in the United States means that soils may contain significant nitrogen reserves that can be used to supply crops and reduce the need for application. However, even though an increasing number of farmers perform soil nitrogen tests, it is not clear whether those test results inform or influence fertilizer management decisions.[202] Neglecting to consider soil nitrogen may be one of the reasons why less profitable farms spend 30 percent more on fertilizer than the most profitable farms.[203]

Farm productivity can also be maintained by increasing the efficiency of nitrogen use via practices that trap nitrogen on fields. Cover cropping can reduce incidences of both nitrogen leaching and soil erosion while trapping nitrogen in crop residues to be released over the subsequent growing season. Riparian buffers and field border strips can trap nitrogen before it runs off to surface water bodies. Crop diversification can ensure that different compartments of the soil are scavenged for nitrogen, and using legumes can improve nitrogen fixation. Setting clear limits on nitrogen application and discharge from fields can accelerate adoption of these practices.[204] Accounting for the nitrogen supplied by the soil and crop residues when planning fertilizer applications is a practice adopted in several other countries. Nitrogen budgets in Germany and Denmark estimate the amount of nitrogen provided by cover crop residue and soil mineralization and reduce recommended nitrogen rates by that amount.[205]

FIGURE A2: A MAP OF N SURPLUS HOT SPOTS ACROSS THE UNITED STATES WHERE BETTER N MANAGEMENT COULD REDUCE LOSSES WITHOUT SIGNIFICANT YIELD IMPACTS. NUMBERS CORRESPOND TO RANKINGS BY TOTAL N SURPLUS (METRIC TONS N YR^{-1}), GREATEST TO SMALLEST[206]



CAN'T WE SOLVE THE NITROGEN POLLUTION CRISIS WITH NEW TECHNOLOGIES?

No. While new technologies and innovations will play an important role, they will not solve the nitrogen pollution crisis by themselves because they can be misused.

While technological solutions will continue to play an important role in reducing nitrogen pollution, relying solely on technology to increase nitrogen use efficiency may not actually reduce nitrogen overapplication. In fact, increasing the efficiency of resource use may actually increase overall resource use. This idea, called Jevon's Paradox, has been observed in other fields such as alternative energy and irrigation technology.[207] A nitrogen-specific example is split application of fertilizer—a practice intended to apply smaller amounts of fertilizer at times when it can be better taken up by plants—which has been found to actually increase overall nitrogen application.[208]

Incremental technical approaches to address agricultural nutrient pollution may not be sufficient on their own because farm nitrogen application decisions are driven not solely by economic concerns, but also by risk management and structural incentives such as crop insurance. Because of this, there is a need to alter the structural, social, and ecological conditions of the modern agricultural system to ensure that food is produced without compromising the natural resources that production depends on. This involves combining technological advances with wider systemic changes, such as limits on overapplication of nitrogen fertilizer and nitrogen runoff, wider food system accountability for nitrogen pollution, accounting for soil nitrogen mineralization, increased crop diversification, insurance and incentive reform, and improved reporting.[209]

There are already promising technologies that could significantly reduce nitrogen pollution when combined with practice changes. Enhanced-efficiency fertilizers (EEFs) and the introduction of new cultivars as well as irrigation and tillage technologies can be combined with organic carbon amendments, crop legume rotation, and buffer zones to great effect.[210]

However, as discussed above in Section VI, technological advances are not a one-size-fits-all approach. For instance, some EEFs are designed to reduce the amount of nitrogen that is lost from fields through coatings that slow the rate at which that nitrogen is released. Slowing nitrogen losses with EEFs can give farmers more time to use any excess nitrogen in a second crop or post-harvest cover crop. These benefits can be lost by fertilizer timing and rate mismanagement. Enhanced efficiency fertilizers currently available also are not necessarily effective in all conditions, including in some humid wheat and corn systems. To create an enabling environment where these technological advances can deliver on their promise, the need to reduce nitrogen fertilizer application rates and nitrogen runoff must be clearly established; the need plainly exists in an environmental sense, but not in an economic or regulatory sense under the current system.

COULDN'T A TAX ON FERTILIZER RESULT IN LESS USE OF NITROGEN FERTILIZER?

No. A tax that increases fertilizer prices will not necessarily reduce nitrogen application but can increase farmer costs because overapplication is also driven by other factors.

A proposed solution to the nitrogen pollution crisis is the institution of taxes or additional fees on nitrogen fertilizer. The logic is that if fertilizer costs more, farmers will need to reduce their application rates to keep input costs stable. However, this would not necessarily bear out in practice, as the drivers of fertilizer application are not purely economic; crop prices matter more than fertilizer prices, and nitrogen costs represent only a fraction of the total cost of running a farm.

As discussed above, farmers often apply more nitrogen than plants need to manage potential risks or to maximize yield. The current market is set up to incentivize yield above all else, which is reflected in the design of producer contracts, crop insurance premiums, and other factors that drive farmer fertilizer choices apart from the price of fertilizer. In cases where crop prices are high, there is a high potential return on investment, making it more economically feasible to apply more fertilizer during the season to maximize potential yield, even if some of it is wasted. Fertilizer expenditure relative to potential income can also be small—often only about 1 to 2 percent of a farm budget in the case of some high-value crops.

For instance, fertilizer costs for lettuce grown in California's Central Coast region are still typically less than 1 percent of gross revenue even under extremely high fertilizer rate scenarios. Because fertilizer costs are such a small fraction of gross revenue, reducing fertilizer application rates by 70 to 100 pounds of nitrogen per an acre does not result in meaningful cost savings for growers—less than $50 per an acre in most years. However, lettuce prices can command up to $21,000 per acre, meaning that the economic cost to farmers from applying an excessive rate can be low while the perceived benefits can be quite high.

Moreover, the presence of subsidies and crop insurance can warp the impact of fertilizer prices. At the average Minnesota corn yield observed over the past five years (184 bushels per acre), the breakeven price of corn ranged from $3.68 to $4.94 per bushel. In 2025 the USDA estimated production costs at $897 per an acre, which would make the breakeven price at average Minnesota yields $4.88 per bushel, well above the August price of $3.72 per bushel or even the September price of approximately $4 per bushel. Even excluding all fertilizer, production costs are approximately $3.97 per acre, making it impossible to raise profitable average-yield corn in Minnesota even if fertilizer were free, given the low corn prices. In this case, fertilizer application would be driven by the yields needed to fulfill contracts or meet crop insurance requirements.

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