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Jack Miklaucic April 10, 2023

Going Beyond Carbon: Mitigating Nitrogen Pollution from Agriculture in the U.S.

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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
of the requirements of the degree of
Bachelor of Science with Honors

Environmental Sciences

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Abstract

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Nitrogen overloading impacts human and environmental health across the globe, presenting serious challenges to planetary systems and exacerbating key problems like climate change. Yet synthetic nitrogen fertilizers have transformed modern agriculture, facilitating rapid population growth and supporting economies around the world. These fertilizers are the primary cause of nitrogen overloading, yet their use has continued to increase in recent decades, even in wealthy nations with access to funding for conservation agriculture incentives and alternative management practices. Better understanding the federal and state policy that influences nitrogen pollution in the United States is critical to mitigating its impacts and securing a sustainable future. This paper examines federal nitrogen management policies as well as four state contexts—Iowa, California, Maryland, and Georgia—to better understand what types of policy interventions may have the most potential to deliver transformative reductions in N loading. Three potential leverage points for effective action to reduce N pollution from fertilizer use are: 1) innovative legal approaches to and interpretations of existing environmental laws; 2) targeted educational and regulatory policies that address location-specific concerns and incentivize the simultaneous adoption of multiple conservation practices; and 3) efforts to shift humanity away from current exploitative agricultural systems towards sustainable and just farming.

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Acknowledgements

First and foremost, thank you so much to my wonderful adviser Eri Saikawa for all of the support and kindness you have shown me throughout my four years at Emory. The opportunity to collaborate with you on this thesis has been the icing on the cake of a fantastic lab experience. You are an amazing mentor, professor, and researcher, and it has been an honor to learn from and work with you. Thank you also to my terrific committee members, Dr. Burchfield and Dr. Rich—I have benefited so much from your guidance and ideas throughout my writing process. Your feedback and encouragement have greatly improved my experience writing this thesis, and I am so grateful for all of your time and effort. I am also incredibly appreciative of the great community the Saikawa Lab has provided me with at Emory. Finally, I wish to extend my heartfelt thanks to my wonderful family and friends, who are always there for me and have put up with far too many rants about nitrogen pollution throughout the years. You all are the best!

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Chapter I: Introduction

The rapid global industrialization of the past few centuries has vastly changed the ways in which we live our lives. It has seen the global population increase from around one billion in 1800 to nearly eight billion today and fueled unprecedented advances in technology, global prosperity, and life expectancy (Klein Goldewijk et al., 2010; UNFPA, 2022). With these markers of progress, however, have come new and growing environmental challenges. The new report released by the Intergovernmental Panel on Climate Change (IPCC) this year warns that climate change has already caused “irreversible changes” in ecosystem health globally along with significant direct effects on human life through extreme heat, challenges to food security, public health impacts, and many more obstacles (2022). They warn that without drastic actions toward greenhouse gas emissions reductions—reaching a peak in global emissions by 2025 and net-zero emissions by 2050—limiting warming to 1.5°C above pre-industrial levels, as outlined in the 2016 Paris Agreement, will be out of reach.

Climate change, however, is just one of numerous “planetary boundaries” the world has crossed in the past century. Many others, including biochemical flows (like phosphorus and nitrogen) and “biosphere integrity” (encompassing both functional and genetic diversity), demand our attention (Steffen et al., 2015). One common element of these crises that is often overlooked is nitrogen (N) pollution, which significantly reduces biodiversity through the loss of N-sensitive native species and is responsible for other environmental issues, including eutrophication and water pollution (Davidson et al., 2011; Guthrie et al., 2018; Vitousek et al., 1997). While the vast majority of policymakers’ attention to environmental issues is paid to the role of carbon emissions in climate change, it is also critical to also consider the role of N. Agriculture is responsible for three-quarters of nitrous oxide (N_2O) emissions, a “forgotten” greenhouse gas that nevertheless has the power to result in more than 3℃ of warming above pre-industrial levels before 2100 if current trends continue (Lynch et al., 2021; Tian et al., 2020). While carbon dioxide is responsible for around ten times more warming than nitrous oxide to date, N_2O is approximately 300 times more potent than CO_2 and typically persists in the atmosphere slightly longer, an average of 116 years (Tian et al., 2020). Thus, an emphasis on net-zero CO_2 emissions that forgets the impacts of N_2O would be disastrous.

Despite these clear signs that human alterations to the global N cycle are dangerous and critical to major environmental issues, environmental policies related to both air pollution and climate change have focused overwhelmingly on carbon. The Biden administration has proposed an expansion of existing carbon markets into agriculture, paying farmers that implement regenerative agriculture practices for the carbon they sequester (Newberger 2021). Regardless of other possible problems with such a proposal, namely the lack of evidence supporting the long-term efficacy of agricultural carbon sequestration and the lack of consideration for agricultural effects on biodiversity, water, and other areas, it is important that such policies address the N pollution crisis (Maixner and Brasher 2020). The lack of holistic and national/global action against N pollution is contributing to a problem that is potentially already worse than carbon, with impacts throughout the environment. Furthermore, "even proposed mitigation options for problems such as climate change could exacerbate N pollution," necessitating an integrated and carefully considered approach to solving the multifaceted environmental issues we face (Kanter et al. 2020). The N policy vacuum is further exacerbated by the fact that one-quarter of major N policies worldwide, and over two-thirds of agricultural N policies, actively incentivize additional N production or consumption (Kanter et al. 2020).

Despite the lack of a concerted effort to reduce N emissions, many U.S. states are taking action to mitigate N emissions, which will be explored in detail below. Because agriculture accounts for a majority of anthropogenic N pollution globally, making up 73 percent of N_2O emissions, 84 percent of NH_3 emissions, and 54 percent of nitrate (NO_3^-) emissions in the U.S., the vast majority of policies directed towards N mitigation focus on agriculture (Fowler et al., 2013; Ribaudo, 2011). This footprint is so vast because only one-third of the reactive N applied to soils remains there (Billen et al., 2013; Lassaletta et al., 2014). State policies on N mitigation include financial incentives for sustainable fertilizer application, cover cropping, and more, as well as voluntary targets for pollution reduction.

However, there are many additional policies designed to reduce agricultural N emissions beyond those that have been implemented in the U.S. Potential solutions include the use of remote sensing to understand N content in the soil and thus more efficiently apply fertilizers and use nitrification inhibitors. These policies together could reduce N_2O emissions 26 percent from their current trajectory by 2030, representing a significant reduction in cumulative greenhouse gas emissions (Winiwarter et al., 2018). No-till agriculture might have the potential to also help reduce N loss from soils long-term despite an increase in emissions over the first decade of implementation due to increased aeration providing a higher-oxygen environment for microbes (van Kessel et al., 2012). More direct regulatory approaches such as nitrogen taxes are also potentially effective, with the gradual inducement of enhanced efficiency fertilizer use being a policy that could generate net $5-8 billion by 2030 through avoiding environmental damages, mostly from nitrate leaching (Kanter and Searchinger 2018). This fertilizer-focused approach is key, since even 24 years ago, “probably the most important” of fixed N losses in food systems were those “associated with suboptimal application of fertilizer,” and fertilizer application rates—unlike some other drivers of N loss—have continued to rise throughout the 21st century (Socolow, 1999; Houlton et al., 2019).

N pollution is also a severe and unmitigated cause of particulate matter ($PM_{2.5}$) pollution, a particularly dangerous form of air pollution that causes numerous diseases and health impacts (Fuller et al., 2022; Nansai et al., 2021). Like other forms of environmental pollution, the health impacts from N overuse disproportionately impact low-income and minority residents in the United States, contributing to pervasive environmental injustices (Liu et al., 2021). These consequences reflect a steady increase in N pollution worldwide in recent decades despite growing knowledge of its impacts (Chang et al., 2021).

N is such a critical element in human society due to its role in ameliorating another serious global problem: food security (Leip et al., 2021). The Nobel Prize-winning Haber-Bosch process, allowing mass production of ammonia (NH_3) from atmospheric nitrogen (N_2), provided for the large-scale production of cheap N fertilizer. Together with a set of other technological innovations, the associated Green Revolution greatly increased crop yields (Erisman et al., 2008; Follett et al., 2010). N fertilizer use is a central element of modern agriculture—it is estimated that 40% of people today are alive because of fertilizers produced by the Haber-Bosch process (Smil, 2004). Because of this utility in large-scale agriculture, synthetic N use worldwide has risen drastically from 10.8 Mt N per year in 1960 to 118.8 Mt N per year in 2019 (FAO, 2019). This trend shows no sign of stopping as N fertilizer use is projected to increase significantly by 2030, particularly in the global South, and it will continue to play a dominant role in agriculture worldwide (Heffer and Prud’homme, 2016). Unfortunately, N fertilizer use is also a primary factor in human transgression of numerous planetary boundaries beyond biodiversity, including drinking water quality, air quality (through smog, particulate matter [PM], and tropospheric ozone), freshwater ecosystem health (due to eutrophication), coastal ecosystem health, stratospheric ozone depletion, and climate change (Erisman et al., 2013).

These impacts arise from the excess of N introduced to the Earth system: nearly two-thirds of the N applied to crops each year are not used and thus become a serious pollutant (Lassaletta et al., 2014). Additionally, 90% of global NH_3 pollution results from agriculture, combining with industrial emissions to produce secondary inorganic aerosols (SIAs) and thus $PM_{2.5}$ pollution (Aneja et al., 2008; Backes et al., 2016). Exposure to $PM_{2.5}$ is associated with many health impacts, including Chronic Obstructive Pulmonary Disease (COPD), diabetes, respiratory illness, cardiovascular problems, and birth defects (Feng et al., 2016). These diseases can be deadly, with Nansai et al. (2021) estimating that $PM_{2.5}$ pollution worldwide causes over four million premature deaths per year—20% of which result from agriculture (Lelieveld et al., 2015). In fact, $PM_{2.5}$ pollution from U.S. maize production is so impactful (with total yearly damages summing $39 billion) that in 40% of maize-growing states, the costs outweigh the profits (Hill et al., 2019). These impacts are why reducing N fertilizer use is vital to mitigating climate change and air, water, and soil pollution (Horowitz and Gottlieb, 2010).

One potential method of reducing the quantity of N fertilizer applied to crops is through the use of N-fixing cover crops, which “fix” or convert atmospheric N into organic compounds that remain in the soil. Cover cropping is the practice of planting a non-commodity crop along with or ahead of a commodity crop with the purpose of improving soil health (Wallander et al., 2021). Throughout most of the country and nearly all of the largest agricultural producer states, cover crop adoption is at or below ten percent, representing a vast area for improving N use efficiency (NUE). Cover crops have the potential to reduce farmer expenditures on soil health amendments, fertilizers, and related farm equipment, but there are many potential practical and sociopolitical challenges to their use. Cover crops are a critical area of intervention that will be discussed in detail in this thesis.

Because N fertilizer use is increasing even in wealthy nations, understanding obstacles to progress on this issue and rapidly developing effective policy solutions is necessary to protect human and ecosystem health. This paper will seek to answer the following questions:

1. What does the federal agricultural N management policy landscape look like, and how does it impact regulation in select important agricultural states: Iowa, California, Maryland, and Georgia?
2. How do agricultural N management policies differ in these states, and which are/have been most effective at mitigating pollution and/or increasing cover crop adoption?
3. What factors have the potential to influence the efficacy of agricultural N management policies at the federal and state levels?
4. What lessons can be learned from effective N management policies on the state level that can be implemented in other states or countries?

Chapter II: Methods

To address the importance of federal policy and law in agricultural N management, a thorough literature review was conducted to assist in identifying key policies and court cases as well as inform an analysis of their relevance/potential future developments. Queries of the Web of Science database and Emory Libraries main catalog were entered with the following search terms: “federal agricultural nitrogen management policy,” “federal agricultural nitrogen management law,” “agricultural nitrogen pollution policy,” “nitrogen pollution court cases United States,” and “agricultural nitrogen pollution law.” Results from these searches were then surveyed to determine their applicability to the above research question. When sources with information about federal policy and law influencing N pollution were found, their citations and references were reviewed to identify any additional sources. Furthermore, briefs and memos from nonprofits influencing law and policy related to agricultural N, including the Chesapeake Bay Foundation and the Northwest Environmental Advocates, were consulted to identify important court cases involving N pollution and water/air quality. The results from these searches yielded seven important pieces of legislation that were chosen for further inquiry: Farm Bills; the Clean Air Act; the Clean Water Act; the Comprehensive Environmental Response, Compensation, and Liability Act; the Safe Drinking Water Act; the Endangered Species Act; and the Inflation Reduction Act.

After these laws were chosen, they were used to search for important legal proceedings along with the following search terms: “agricultural nitrogen,” “nitrogen pollution,” and “nitrogen fertilizer runoff.” Searches were also run to identify significant court cases addressing the EPA and other federal agencies’ ability to regulate polluters and other key issues that affect agricultural N management policy. These queries used search terms such as “notable environment court cases" and "notable environmental court cases nitrogen." They also yielded sources such as Earthjustice's "50 Landmark Legal Cases," which provided useful context for identifying key decisions (2022a). From a large list of resulting cases, four key D.C. District Court and Supreme Court decisions were chosen to maintain brevity: *West Virginia v. EPA*, *American Farm Bureau Federation et al. v. EPA, C. Bernard Fowler et al. v. EPA et al.*, and *County of Maui v. Hawaii Wildlife Fund*. These cases, along with the above pieces of legislation, were each the subject of additional research encompassing academic publications, legal scholarship, and more to identify their pertinence in agricultural N management policy and to suggest possible pathways forward to strengthen regulation.

Unique agricultural and policy contexts in different regions, though, merit an investigation of notable states to holistically understand influences on agricultural N. Past research supports the increased impact of incentive programs for sustainable agricultural practices when these programs are targeted based on climate, existing sustainable agricultural practices, dominant crops, and other factors, underscoring the importance of state-level analysis (Piñeiro et al., 2020; Sorice and Donlan, 2015; Feldmann et al., 2019; Claassen and Ribaudo, 2016). In addition, there are a plethora of state-level incentive programs, often offering more dollars in total to farmers than federal ones (Feldmann et al., 2019). Many of these programs are carried out in partnership with the federal government, but these partnerships can only occur with willing state governments. Even when federal funding is involved in agronomic policies, it is often through initiatives targeted at states where agriculture is prominent and where there is demonstrated interest in adoption, as well as a large potential impact. For example, the USDA announced in January 2022 that its Natural Resources Conservation Service (NRCS) was investing $38 million into a targeted Cover Crop Initiative in 11 key states, including Iowa, California, and Georgia, which will be analyzed in this paper (USDA Press, 2022). The other state chosen for analysis, Maryland, was likely absent from this program due to its already-high cover crop adoption, which in turn results from very strong incentive programs. Thus, combining federal and state analyses is appropriate to ascertain the full picture of conservation incentives in the United States.

States to conduct a detailed policy analysis for were chosen by a variety of criteria. One main aim was to achieve diversity—in geographic location, climate, conservation practice adoption, common crops grown, etc.—since, as established above, these factors play an important role in agricultural management (Piñeiro et al., 2020; Sorice and Donlan, 2015; Feldmann et al., 2019; Claassen and Ribaudo, 2016). The four states chosen were Iowa, California, Maryland, and Georgia. These states are first and foremost geographically and climatically distinct, providing useful cases to understand how these differences might affect agricultural N pollution and related policy. They also grow different crops, with Iowa and Maryland growing mostly corn and soybeans (and Maryland winter wheat), California growing large amounts of fruits and vegetables like grapes and avocados, and Georgia growing primarily cotton and peanuts (USDA NASS, 2023). These states also represent nearly the full range of cover crop adoption: Maryland is far and away the highest adopter at 31.8% of harvested cropland acres, Georgia is in the top 10 states for cover crop adoption at 14.6%, and California and Iowa both lag behind at 4.5% and 4.0% respectively (USDA NASS, 2017).

The four selected states also fulfill a number of other requirements that heighten their utility to this analysis. California and Iowa were the two states with the largest value of cash receipts for their agricultural production in 2021, indicating the importance of the agricultural industry in these locations (USDA ERS, 2022). Georgia ranks 16th on this metric, with agriculture still being a key industry in the state, while Maryland ranks 35th, representing a state with less than half the acres in Georgia, and far fewer acres than California and Iowa, dedicated to agricultural production (USDA ERS, 2022). Maryland, though, is a key state to include in this analysis due to its Cover Crop Plus incentive program, which offers payments between $115-160 per acre to encourage cover crop adoption contingent on a three-year commitment (Maryland Department of Agriculture, *Cover Crop Plus*). This amount is potentially more than double comparable median state payments through federal programs, which range from $62.33 to $92.27 (Wallander et al., 2021). Additionally, Maryland's Agricultural Water Quality Cost-Share program, which originated in 2009, covers 100% of the cost of incorporating cover crops—between $30-75 an acre—unlike similar programs in other states, which often pay only $5-20 an acre (Maryland Department of Agriculture, *MACS Program*; Wallander et al., 2021). In 2017, Maryland's cover crop incentive programs also enrolled more harvested cropland acres than other initiatives even in states like Iowa, which has over twenty times more potential acreage (Wallander et al., 2021). Clearly, Maryland's emphasis on economic incentives to encourage cover crop adoption is distinctive, meriting the state's inclusion in this analysis.

Finally, the four states chosen for investigation in this paper have diverse policy landscapes regarding agricultural N management, while all being places where agricultural N pollution is severe and must be addressed. These states are all areas with significant potential to mitigate agricultural N pollution, each having "hotspots" with large emissions/N input levels yet other favorable characteristics, like the ability to reduce N use with a minimal impact on crop yields and other standards of achievability (Roy et al., 2021). Yet Iowa, California, Georgia, and Maryland are all distinct and complex political environments, with differing amounts of power in the hands of the agricultural lobby and with unique approaches to agricultural policy. Choosing states representing various climates, political contexts, conservation practice adoption rates, crop portfolios, levels of agricultural importance, and pollution hotspots is key to understanding how N policy does, and perhaps should, differ around the U.S. This diversity will be explored further below, but it is a critical part of the application of this case study.

Notable policies and dynamics in each state were identified through a similar methodology to the one described above for federal policies. Search terms included “agricultural nitrogen pollution policy X” and “agricultural nitrogen management policy X,” where X represents the state being analyzed. Specific searches were also conducted to identify cover crop-related research and incentive programs in addition to regulatory solutions. Terms for cover crop searches included “cover crop incentive program X” and “nutrient management incentive program X.” For regulatory approaches, terms varied widely; policy and law-focused searches included “water pollution statute X,” “air pollution statute X,” and “agricultural nitrogen pollution policy X.” The author’s prior knowledge was also used to inform a selection of key points of analysis, as were the suggestions of the author’s internship supervisor Dr. Alison Eagle and the members of his Thesis Committee: Drs. Eri Saikawa, Emily Burchfield, and Michael Rich. Similar to the approach used to identify federal policy sources described above, results from these state-specific searches were analyzed to determine their applicability to the above research question. When sources addressing state-level N policy were found, their citations and references were reviewed to identify other potential sources, and any relevant policies or statutes they mentioned but did not adequately discuss were also identified and became the subject of additional searches. Information from the United States Census of Agriculture for years 2012 and 2017 and the United States Department of Agriculture website was also used extensively to inform the state selection and analysis process as well as the description of state-level EQIP and CSP initiatives.

To analyze cover crop adoption trends across the United States and in the four states central to this paper, data from the Census of Agriculture was aggregated, cleaned, and visualized using R version 4.2.1. The category “PRACTICES, LAND USE, CROPLAND, COVER CROP PLANTED, (EXCL CRP) - ACRES” was filtered out and compared with the total number of harvested cropland acres in each state to determine overall adoption rate, and changes in adoption over time were calculated by comparing this category’s value between the 2012 and 2017 editions of the Census.

Chapter III: Federal Policy

Background

N pollution's serious effect on social, environmental, and economic systems in the United States suggests the importance of policy and law, at both the federal and state levels, addressing this issue. While there is a lack of federal policy in recent years specifically addressing the N overuse crisis, numerous non-governmental organizations have explored applications of existing law and policy to agricultural regulation. In addition, federal government entities such as the United States Department of Agriculture (USDA) have developed new initiatives and reallocated existing funding towards sustainable agricultural practices. The recently passed Inflation Reduction Act (IRA) represents the largest infusion of money into agricultural pollution mitigation in decades (Inflation Reduction Act of 2022). The Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP), the two most well-funded and widespread working lands conservation initiatives, account for 43% ($8.45 billion) and 17% ($3.25 billion), respectively, of the new IRA appropriation for agricultural conservation (Du et al., 2022). Additional funds are badly needed since demand for funding through EQIP and CSP is not being met, with only 31% and 42% of applications respectively being accepted from 2010-2020 (Happ, 2021). Another $4.95 billion in IRA funding will go towards the Regional Conservation Partnership Program (RCPP), which fosters federal-state partnerships (Du et al., 2022). This rare increase in resources represents an important opportunity for the United States to finally achieve meaningful increases in the adoption of practices like cover cropping and "nutrient management," reversing a trend of increasing N emissions that has persisted since the mid-20th-century.

Despite this exciting development, there are still many obstacles to circumvent when attempting to manage agricultural N pollution. Slow increases in the adoption of cover cropping and conservation tillage, two potential N management strategies, suggest that additional funding for incentive programs like EQIP and CSP may not translate into the transformational change necessary to address the N overuse crisis. In addition, the power of the agricultural lobby has yielded many legal victories, creating precedents that will be difficult to overcome. The agriculture sector is explicitly excused from numerous requirements and regulations outlined in the Clean Air Act and Clean Water Act as well as other landmark federal legislation, severely limiting the power of entities like the Environmental Protection Agency (EPA) to reduce emissions (Clean Air Act of 1970; Clean Water Act of 1972; Kulkarni, 2020).

One key issue impeding the effective regulation of agribusinesses is preemption, a term that refers to the supremacy of federal legislation over state laws. This doctrine means that when state laws conflict with federal laws that limit the extent of regulation of farmers, the federal laws take precedence and invalidate the state laws. For example, the state of California was forced to rescind a set of regulations it imposed on federally inspected slaughterhouses due to the primacy of the Federal Meat Inspection Act of 1906 (National Agricultural Law Center, 2022). Preemption thus prevents certain states from expanding upon insufficient federal policies, while other states less keen on regulating the agriculture sector have only to meet the bare minimum standards outlined by the federal government. Federal legislation is important to provide a baseline standard of regulations on polluters, since without it, some states might not control N pollution at all. Nevertheless, preemption is a victory for agricultural lobbyists—because of the weakness of federal legislation on the issue (discussed in more detail below), farm operators are largely free to manage their lands in ways that maximize efficiency and profits at the expense of the environment and public health. Because the N pollution crisis is often overshadowed by pressing climate and biodiversity concerns, there is currently an insufficient body of literature analyzing these obstacles and suggesting a path forward to mitigate agricultural N emissions.

Nevertheless, federal policy and law are incredibly important in shaping agricultural practices and achieving long-term sustainability. In particular, many court cases in recent years have explored the application of decades-old statutes to modern environmental problems, with mixed results. Analyzing these legal battles and better understanding the federal policy landscape related to agricultural emissions is critical to achieving sustainable agricultural systems—without a resilient foundation of federal statutes, only a small handful of states currently attempt to meaningfully regulate agribusinesses, despite existing federal-state partnerships. This paper will identify key successes and areas for improvement in federal agricultural N management policy, focusing on relevant legislation and court cases dating back to the environmental movement of the late 1960s and 1970s. After this exploration, it will be clear that transitioning from a voluntary and incentive-based regulatory framework to more traditional forms of federal oversight, as well as adopting a holistic and multimedia approach that prioritizes the health of soils, the hydrosphere, and the atmosphere all at once, are critical steps forward in reducing agricultural N pollution.

Farm Bill

One key set of legislation that outlines the authority of the federal government to regulate agricultural pollution is the Farm Bill. Around every five years dating back to the Agricultural Adjustment Act of 1938, the United States Congress has debated on and passed an omnibus bill relating to agricultural operations within its borders. Farm Bills are omnibus legislation, meaning that they address multiple diverse issues all at once, and they have totaled more than 600 pages per bill in recent years (Agriculture Improvement Act of 2018). This size is due to the breadth of their scope, covering everything from the pricing and trade of agricultural commodities to the everyday on-farm practices conducted by farmers. As discussed earlier in this chapter, the extreme power of the agricultural lobby has led to favorable terms for the industry being enacted in recent Farm Bills. The agricultural lobby spends $150 million to influence Congress each year in order to achieve unique exemptions from important regulations and the suppression of relevant conservation spending (OpenSecrets, 2022). In fact, one book assessing agricultural policy noted that "the policy inertia is so great, and the vested interest of the farm community in the policy status-quo usually so significant, that the impetus for reform must come from the outside" (Moyer and Josling, 2018). Farm Bills do not currently incorporate the kind of community governance that some researchers posit is necessary for a transition to sustainable food systems (Clapp, 2021).

One highly important aspect of Farm Bills is their provisions concerning the applications of numerous other bills listed above to the agriculture sector. For example, the 2018 Farm Bill (like the others before it) exempts farms from providing data on greenhouse gas emissions that nearly every other industry, big or small, is required to record (Agriculture Improvement Act of 2018). This concession both precludes the EPA and other federal government agencies from holding agricultural polluters accountable and limits the availability of important emissions data, inhibiting effective climate regulation. In the context of N, it means that the large N_2O and NH_3 footprint of the agriculture industry is largely untraceable. Even if farms were not explicitly excused from Clean Air Act regulations, this lack of point source data would make it incredibly difficult to pinpoint major emissions sources and enforce existing regulations. Thus, even states that wish to reduce agricultural N_2O emissions are largely unable to do so.

The other significant provision in Farm Bills that is most relevant to this paper is the allocation of funding towards conservation programs implemented by the USDA. The power of the agriculture lobby, especially when compared to the minimal resources available to conservation advocacy groups, has meant that major nutrient management and cover cropping programs that could reduce N emissions are profoundly under-resourced. These programs are also created and enforced in ways that maximize agricultural production at the expense of human and environmental health and prosperity. In particular, federal subsidies and incentive programs provided to farmers that practice monocropping or simple corn-soybean-wheat rotations without sustainable practice modifications continue to be vastly larger than similar funding for these conservation practices. Subsidies for specific crops, called "commodity programs," represented 79% of U.S. farm subsidy spending in 2020, dwarfing conservation programs, disaster programs, and crop insurance subsidies (Environmental Working Group, 2023). Even worse, research suggests that "US farm subsidy programs provide no measurable economic benefits for the rural poor … Nor do [they] lower overall food purchasing costs for consumers" (Smith, 2018). Without a change in this incentive structure, agrichemical corporations and farmers will continue to take advantage of incentives that encourage unsustainable management without providing commensurate increases in yield. Thus, changes to future Farm Bills that require greenhouse gas and other pollution inventories from large farms and alter a flawed incentive structure in favor of sustainable policies are critical to solving the N pollution crisis.

Clean Air Act

Farm Bills' special treatment of agricultural enterprises is intertwined with numerous provisions in the Clean Air Act (CAA), most notably the greenhouse gas reporting requirements referenced above. The EPA has used its CAA authority to outline National Ambient Air Quality Standards (NAAQS) for six "criteria" air pollutants: "sulfur dioxide (SO_2), particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone, and lead" (National Agricultural Law Center, 2021). The operative language in the act is its emphasis on providing jurisdiction to the EPA to regulate "major" sources of air pollution (Clean Air Act of 1970). By this definition, most farms are not subject to regulation, since the majority of them do not exceed the threshold outline for nitrogen dioxide (NO_2) or $PM_{2.5}$. In particular, regulating $PM_{2.5}$ that arises from agricultural emissions of ammonia (NH_3) is challenging, since emissions from farms may indirectly violate NAAQS through contributing to $PM_{2.5}$ production without being a direct source. It is nevertheless important to explore new legal methods to use existing $PM_{2.5}$ standards in the CAA to more effectively regulate polluters, since agriculture alone is responsible for 29% of $PM_{2.5}$ pollution and the associated mortality in the United States (Pan et al., 2022).

Despite the regulation of NH_3 under the CAA, emissions from agricultural sources continue to grow (Liu et al., 2022), pointing also towards the importance of more robust enforcement. The inclusion of NH_3 as a criteria pollutant like the six mentioned above is a critical step towards bolstering the authority of the EPA and other federal government agencies to secure emissions reductions. Adding this designation for NH_3 would provide for the establishment of associated NAAQS, a critical first step for stopping the rapid intensification of pollution. Especially given progress mitigating other sources of N pollution such as large industrial facilities and power plants, applying the power of the CAA to agriculture, and to NH_3

specifically, is integral to achieving progress (Solyst, 2022). One potential avenue for better enforcing the existing provisions of the CAA in light of the difficulty of creating new regulations is an increase in monitoring efforts of large fertilizer producers. The EPA's settlement with Terra Industries in 2012 is one of many examples of an important victory made possible by oversight of errant corporations, who are frequently fined so little and caught so seldomly that breaking the law is profitable (EPA, 2011; Atkinson, 2020). More stringent oversight and enforcement of the CAA, when combined with harsher penalties, have the potential to achieve badly needed N emissions reductions in the agricultural sector.

One highly important court case limiting the application of the CAA, however, was decided in June 2022 by the U.S. Supreme Court. The case, *West Virginia v. EPA,* targeted the EPA's regulatory authority under section 111(d) of the CAA, which provides for the regulation of pollutants from existing point sources and was interpreted by the EPA to allow for the implementation of "best system of emissions reduction" (BSER) standards (Legal Information Institute, 2022). The Supreme Court reaffirmed the case as representing a "major question," requiring the court to find a clear Congressional delegation of sweeping responsibility to regulate as large a sector of economy as the power sector (Legal Information Institute, 2022). The Court thus held that the EPA did not have the authority to regulate greenhouse gas emissions beyond setting standards, since outlining the BSER and thus mandating specific types of actions on the part of power plants was beyond its stated responsibility in section 111(d) (*West Virginia v. EPA*, 2022). While this case addressed the federal government's authority to implement the Clean Power Plan and not agricultural regulations, the decision limiting federal powers sets a troubling precedent for those seeking to increase the regulation of agricultural runoff.

Clean Water Act

The “companion” of the CAA, the Clean Water Act (the CWA), also has an important role to play in agricultural N regulation. Leaching from excess N in soils is a significant contributor to water pollution that causes serious environmental and public health impacts, demanding a commensurate response (Davidson et al., 2011). The most notable section of the CWA is Section 319, which was added in amendments made to the bill in 1987 and establishes grant funding mechanisms for states, territories, and tribes to more effectively address nonpoint source pollution (Clean Water Act of 1972). Because the CAA and CWA are geared towards addressing pollution that comes from point sources, discrete origins of measurable emissions, nonpoint sources of pollutants that coalesce in the soil, waterways, and the air such as most of the agriculture sector are difficult to regulate. The result is a large number of voluntary regulations and incentive programs like EQIP and CSP, which have not been effective at mitigating water pollution from agricultural runoff (Guthrie et al., 2018). Clearly, a more robust application of these laws towards agricultural emissions is of paramount importance.

One way to achieve this goal is to bolster enforcement mechanisms for existing CWA provisions. The CWA charges states with establishing numeric nutrient standards for particular bodies of water based on their “designated uses” that would guide the allotment of permits and facilitate the creation of pollution limits from specific industries as well as enable more efficient cleanup of badly polluted waters (Devine, 2019). However, despite acknowledgement from the EPA’s Inspector General in 2010 that states were abdicating this responsibility and the agency should take charge, it has instead taken to the courts to continue dodging this task and maintain a status quo of severely polluted waters (Devine, 2019). The weakness of the CWA when it comes to agricultural runoff makes enforcing the development and maintenance of these numeric nutrient standards all the more important, since other potential solutions are likely to encounter serious legal challenges.

Despite the aforementioned weakness of the CWA—largely characterized by the exemption of farming operations from most of the act's permitting requirements—there are important paths forward to use the existing bill text to regulate agricultural N pollution (Clean Air Act of 1972). One significant area for improvement relates to the CWA's Total Maximum Daily Load (TMDL) standards for the cleanup of "impaired" waters. The chronic lack of enforcement and legal backing behind these standards necessitates the EPA revisiting its revocation of a set of rules to strengthen these standards (Devine, 2019). All too often, instead of being a powerful force in favor of water cleanup and pollution mitigation, the EPA has supported corporations and states in shirking their responsibilities under the law—this phenomenon must end if agricultural runoff into waterways is to be reduced (Sweeney, 2021). Luckily, the EPA's 2022 Nutrient Reduction Memorandum includes an entire strategy devoted to CWA authorities, including "urging more robust adoption of numeric nutrient criteria … into Water Quality Standards," assisting states more robustly in developing TMDL standards, and "providing strong support of innovative permitting approaches that can drive deeper, sustained nutrient reductions" (EPA, 2022a). These steps, if they are carried out, will mark important progress in the decades-long struggle to adequately regulate agricultural runoff.

The permitting system outlined in the CWA has been the subject of much legal dispute, leading to a large number of important court decisions under the Act. One important lawsuit that upheld important CWA provisions came in *C. Bernard Fowler et al. v. EPA et al.*, a case in the D.C. District Court brought by a number of environmental NGOs with an interest in reducing pollution in the Chesapeake Bay. In this case, the Chesapeake Bay Foundation and other regional nonprofits settled a case with the EPA requiring the agency to take sufficient actions to remove the Chesapeake Bay from the federally impaired waters list under the CWA (Chesapeake Bay Foundation, 2022). The settlement also stated that the EPA would consider concrete consequences if states did not meet the subsequent TMDL standards, an important safety mechanism given the incentive for all states not around the Chesapeake Bay to continue polluting (Chesapeake Bay Foundation, 2022). This case was so important since it set a precedent for groups seeking to hold the EPA accountable in areas it fails to regulate adequately.

The *Fowler* decision paved the way for another key case that was decided in April 2016, also by the D.C. District Court. In this case, the American Farm Bureau Federation, the “face” of the agricultural lobby, sued the EPA (along with numerous other industry claimants) after it implemented a TMDL standard for excess N, phosphorus, and sediment pollution in the entire Chesapeake Bay watershed (Chesapeake Bay Foundation, 2022). They alleged a lack of authority, issues with the public commenting process on the agency’s recent regulatory action, and faulty scientific backing for the action despite more than twenty-five years of negotiation and precedent moving towards Chesapeake Bay protections (Chesapeake Bay Foundation, 2022). After numerous appeals and a nationwide battle, with amicus briefs from around the country filed on both sides at every step of the way, the Court ruled that EPA’s decision to implement a TMDL was an entirely “reasonable” policy decision given the powers outlined for them in the CWA (*American Farm Bureau Foundation et al. v. EPA et al.*, 2016). This case upheld the EPA’s power to implement these standards in highly polluted areas, a crucial victory for ameliorating water quality.

One key provision of the CWA is the nature of its permitting requirements for point source polluters like wastewater treatment plants. A final relevant court case and a critical environmental victory, which the environmental law nonprofit Earthjustice referred to as the "clean water case of the century," came in *County of Maui v. Hawaii Wildlife Fund*, which was decided in the U.S. Supreme Court (2020). In this case, the County of Maui was knowingly releasing liquid waste into federal waters through discharging it into groundwater first, where it then eventually flowed into nearby rivers and eventually ended up in the ocean (Earthjustice, 2022b). The Supreme Court, when deciding in favor of the Hawaii Wildlife Fund, upheld the requirement that if point source pollution that would end up in federal waters, no matter if it arrived in those waters through a "nonpoint source" like groundwater, it would be subject to permitting requirements under the CWA (*County of Maui v. Hawaii Wildlife Fund*, 2020). Even though there are still many weaknesses with the enforcement of permitting under the CWA, the strength of point source pollution regulation is key to protecting water quality nationwide.

Comprehensive Environmental Response, Compensation, and Liability Act

Another act that would benefit from additional enforcement measures is the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). CERCLA includes a requirement to notify authorities when more than a “reportable quantity” of a specific pollutant or “hazardous substance” is released (Comprehensive Environmental Response, Compensation, and Liability Act of 1980). Both NO_2 and nitric oxide (NO) are on the list of regulated compounds, but CERCLA suffers from the same problem as the CAA and the CWA—regulating nonpoint source pollution is much more difficult, and specific powers are not clearly provided to the federal government to do so. However, increased monitoring of large fertilizer producers and farms could increase compliance with CERCLA’s reporting requirement and facilitate a reduction in large releases of hazardous substances into the environment. Without additional oversight, polluters are likely to continue evaluating the economic benefit of pollution as higher than the potential cost of legal action and fines.

Safe Drinking Water Act

One form of N pollution that the above laws do not strongly address is nitrate (NO_3^-) pollution in waterways from agricultural runoff. Luckily, the Safe Drinking Water Act (SDWA) includes nitrates in its suite of pollution standards to protect drinking water (Safe Drinking Water Act of 1974). Like numerous other environmental laws, though, the initial provisions laid out in the SDWA were woefully inadequate at preventing contamination of public waterways, with numerous instances of eutrophication in drinking water sources (Clean Water Action, 2018). Thus, the Drinking Water Protection Act, an amendment to the SDWA, was passed to bolster the assessment and management of "algal toxins" in drinking water (Safe Drinking Water Act of 1974). The SDWA is not sufficiently protecting Americans from nitrate pollution in their drinking water, with the EPA standard of 10 mg/L being above the level determined by the CDC to reflect external contamination, which is 3 mg/L. More than 20 million Americans face levels of nitrates in their water that are above the EPA standard, with millions more drinking water above the CDC threshold for nitrate contamination.

However, a recent review of published literature on the health risks of drinking water nitrate found that increased risk of colorectal cancer, thyroid disease, and numerous other ailments occurred even in water with nitrate levels below the EPA threshold (Ward et al., 2018). There is little recourse for affected citizens unless a stronger standard is implemented (Environmental Working Group, 2020). A persistent challenge in the implementation of the SDWA and related environmental laws has been battles to update standards when new evidence of health risks or other issues is presented. Pollutants like lead and nitrates may have no safe threshold of exposure, complicating regulation further. With significant pressure from the agriculture lobby to avoid strengthening clean water and air protections, the public faces an uphill battle securing the right to a clean environment. In *Federalism and Environmental Policy*, Denise Scheberle (2004) concludes that “the safe drinking water program provides a perfect illustration of what happens in a one-size-fits-all regulatory environment when the target group is anything but one size,” reflecting the consensus that this law needs an overhaul to adequately protect Americans from drinking water pollution.

Endangered Species Act

The limitations of these bedrock environmental laws geared towards assessing pollution have inspired scholarship and legal action exploring the applications of other environmental legislation to the problem of N pollution. One such law is the Endangered Species Act, which has the potential to address N pollution that represents a direct threat to biodiversity (Endangered Species Act of 1973). Fortunately, there is a growing body of research that addresses the problem of N pollution for federally protected species. Hernández et al. (2016) found that 78 of the 1400 federally listed species they surveyed experienced direct impacts from N pollution for which impact pathways could be traced, potentially providing enough evidence for legal challenges to polluters. Assigning liability to either individual nonpoint source polluters or state regulators for a dereliction of their responsibility to conduct business and/or regulate effectively is an important potential benefit of using the ESA, since few other environmental laws allow citizen suits on behalf of endangered species (Tzankova, 2013). Because studies of particular species can be much more granular than assessments of overall ecosystem health, the ESA allows NGOs and other actors to present a convincing science-based argument for assigning liability. This smaller scale of action allows suits under the EPA to isolate target regions for improvement where point sources are difficult to identify and place that onus on local and state regulators.

The ESA is also notoriously strong, one of the few environmental laws (or laws in general) that places sweeping powers in the hands of the federal government (Tzankova, 2013). Perhaps an increase in ESA-based litigation would make polluters think twice before potentially harming endangered species, providing a much stronger disincentive than the paltry fines assigned under many other laws. Even though the ESA badly needs new legal interpretations in light of indiscrete causes of endangerment like climate change, this room for growth under a law that already grants strong authority to the federal government could pave the way for critical 21st century applications of the law to numerous important environmental crises.

Incentive Programs and the Inflation Reduction Act

Another important area for improvement outside of heightening enforcement of pollution regulations and standards is a more effective allocation of the $424 billion of federal funds that went towards crop insurance payments alone from 1995-2020 (Burchfield et al., 2022). The U.S. federal government, in addition to providing funds to numerous state-level incentive programs, runs two important initiatives of its own: the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP). In recent decades, the funding provided by both of these programs has significantly increased. Between 2006 and 2016, the acreage covered by cover crop EQIP payments increased more than fourfold, and a similar increase (from 7 to 30 million) was observed for CSP payments relating to soil health practices (Hellerstein, Vilorio, and Ribaudo, 2020; USDA NPAD, 2020a; USDA NPAD, 2020b). Cover cropping has benefited the most from changes to the makeup of EQIP funding in recent years—most notably an increase in funding from $19 million to $800 million between 1998 and 2015—becoming a plurality of awarded dollars (Hellerstein, Vilorio, and Ribaudo, 2020; Figure 7). However, increases in CSP funding have primarily addressed soil health improvements other than cover cropping and conservation tillage, and there is still much room for improvement in supporting farmers' adoption of conservation practices. EQIP "funded roughly 3.7 million acres of no-till/strip-till, 6.5 million acres of nutrient management, and 1.7 million acres of cover crops" between 2009 and 2012, still a small fraction of the more than 300 million acres of cropland in the U.S. (Wade, Claassen, and Wallander, 2015). EQIP's strong growth in acreage enrollment, though, is quite positive, particularly given its focus on only no- and strip-till, nutrient management, and cover crops.

Especially in light of the additional dollars granted to EQIP and CSP under the IRA, ensuring that valuable federal funds produce the greatest emissions reductions possible is paramount. The USDA's Natural Resources Conservation Service (NRCS) identifies both nutrient management and cover cropping as "climate-smart practices," meaning that they will receive even more support from IRA funding (Du et al., 2022). There are multiple ways in which the USDA and other important agencies could improve the efficiency of conservation programs. One key aspect of funding dispersal is the importance of supporting agricultural practices that are profitable while reducing pollution across the system, not just of one pollutant or in one reservoir. For example, reducing N emissions can reduce carbon sequestration and vice versa, demanding caution when implementing new policies (Li, Frolking, and Butterbach-Bahl, 2005). In combination with supporting practices that protect the environment in numerous ways, the federal government should also expand programs that support the adoption of a suite of conservation agriculture practices on farms, as opposed to a single-practice approach. Doing so would maximize the financial and soil health benefits that come from the adoption of multiple conservation practices, such as cover cropping, nutrient management, and conservation tillage, at once—these management decisions can each address potential limitations of the others and maximize efficiency (Monast, Sands, and Grafton, 2018). Another major concern is location: as can be seen in Figure 1, adoption of cover crops in Southeastern states is mostly at least twice that in major agricultural producers like Iowa and Illinois, where adoption is still below five percent. Figure 1 also illustrates that rates of cover crop adoption in high-cover crop states like Maryland, Pennsylvania, Virginia, and Georgia far outstrip those in the Corn Belt and along the West Coast. Allocating EQIP and CSP funds, as well as dollars given to states to support local conservation programs, more thoughtfully to states that are experiencing low rates of adoption and low total cover crop usage is a critical step towards increasing N fixation in agricultural soils. Part of this regulation could be to incentivize the use of N-fixing cover crops, which maximize soil health benefits.

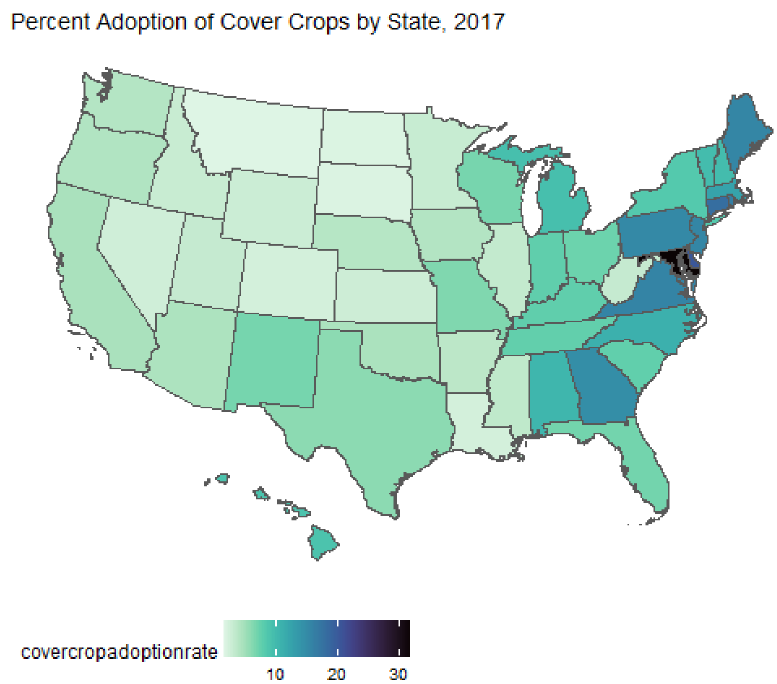

Figure 1: Percent of State-Level Harvested Cropland Acreage with Cover Crops, 2017 (data from USDA NASS, 2017).

Another key concern in federal conservation funding is additionality, which refers to the ability of an investment to "cause a change in practice(s) that lead(s) to improved environmental quality" (Claassen et al., 2014). If a practice would not be adopted without such investment and/or the use of the practice would halt without that investment, then high additionality is present. This metric is lower for conservation tillage than numerous other conservation practices, and there is evidence that the same holds true for cover cropping (Claassen et al., 2014; Sawadgo, Plastina, and Liu, 2019; Lichtenberg, Wang, and Newburn, 2018; Gonzalez-Ramirez, Kling, and Arbuckle, 2016). Low additionality for these practices may occur due to their long-term profitability in many cases, as well as the co-benefits they provide. Therefore, while conservation finance can be a critical component of a successful push to increase practice adoption, it must be supported by shifts that can address non-financial barriers (which are discussed further below) and ensure that the benefits of investments in sustainable agriculture reach all farmers, particularly low-income, minority, and rural farmers.

Despite concerns about the additionality of incentive programs, these programs' presence is clearly responsible for a meaningful portion of cover crop and conservation tillage adoption in recent years. In 2018, "about one-third of the acreage planted with a cover crop received a financial assistance payment from either Federal, State, or other programs that support cover crop adoption," representing a large increase in farmers supported by funding largely due to increased government investment at the federal and state levels (Wallander et al., 2021). This low total level of support, though, indicates that there are other soil health and economic benefits motivating farmers who do not receive financial compensation to use cover crops. There is significant variance in the amount awarded per cover crop acre, which can help us understand trends in certain states. Excluding CSP, cover crop assistance in 2018 varied from $12 to $92 per acre among both federal and state programs, with varying results (Wallander et al., 2021). This variation occurred due to available funding, bonuses awarded for the adoption of multiple conservation practices simultaneously/desired implementation strategies for practices like cover crops, differing levels of support from state governments, and more. Despite the relatively smaller number of acres supported by at least 22 state programs, which covered more than 1 million cover crop acres in 2018, these initiatives are having large impacts on cover crop trends (Wallander et al., 2021). Maryland, which Figures 1 and 2 demonstrate has both a high overall adoption rate (32% in 2017) and a high percent change in total acres using cover crops (6%), is achieving this commendable growth through a robust state program covering nearly half of the state's 1.28 million cropland acres with payments of up to $90 per acre (Wade, Claassen, and Wallander, 2015). This trend of states with already high growth continuing to achieve significant increases in adoption holds true for many other states for cover crops but not for conservation tillage, likely because of its already much-higher adoption. Nevertheless, this pattern reflects the importance of observability in conservation practice adoption, as farmers in states with strong funding programs continue to share the existence of these mechanisms with neighboring operators. Another important trend is influenced by the presence of strong new state incentive programs and collaborations with federal agencies in states like Iowa and Indiana, which are seeing commensurate increases in cover crop adoption despite a low baseline adoption level (Wallander et al., 2021; Wade, Claassen, and Wallander, 2015).

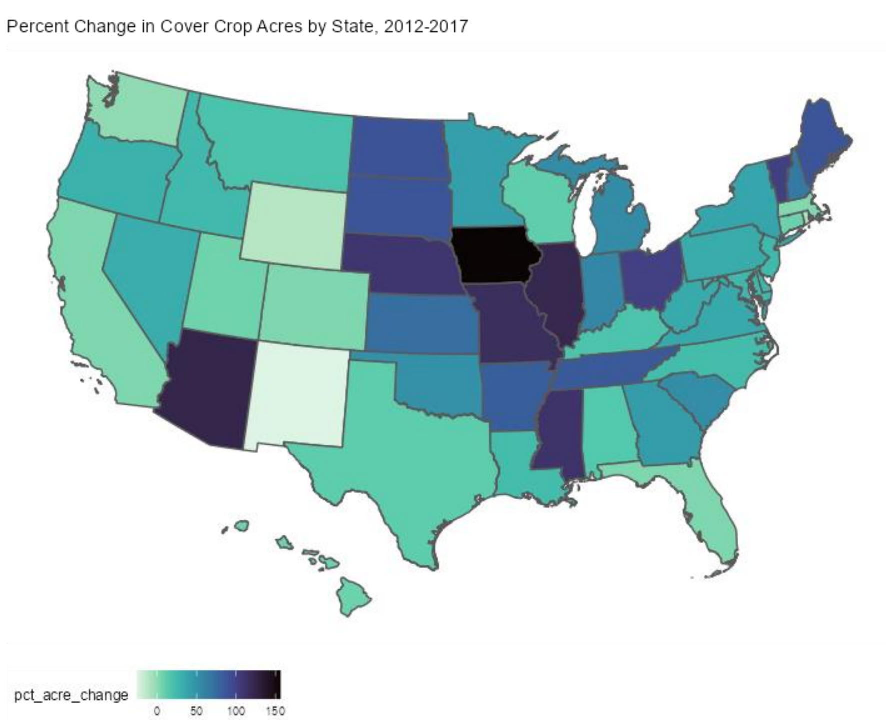

Figure 2: Percent Change in Cover Crop Acres by State, 2012-2017 (data from USDA NASS, 2012/2017).

Finally, legislation like Farm Bills and the IRA that impacts funding allotments to agricultural activities must be made with these equity concerns in mind. The status quo of agricultural subsidies disproportionately benefits large farms, incentivizing consolidation: insurance indemnity payments and crop subsidies totaled over $424 billion from 1995 to 2020, 78% of which went to the top 10% of recipients (Burchfield et al., 2022). The USDA's own website reveals that their $3.1 billion contribution to partnerships with corporations and large-scale nonprofits such as PepsiCo, Cargill, Target, and the National Fish and Wildlife Foundation is much greater than the $325 million devoted to smaller projects and minority farmers (USDA, 2022). Large farms are much less likely to be implementing sustainable agricultural practices on their lands, which ought to be a top priority of federal and state governments when distributing funding (USDA NASS, 2017). Valuable federal dollars must be used in ways that advance environmental protection, equity, and farmer livelihoods all at once to maximize impact.

Combining Mandatory and Voluntary Approaches

The analysis of key legislation and court cases presented above yields important lessons for parties interested in more effectively regulating agricultural N pollution. Perhaps most important is the conclusion that the framework in U.S. environmental policy and law to address nonpoint source pollution, comprising only voluntary regulations and incentive programs, is woefully inadequate. Countering decades-long patterns of increasing water contamination and heightened fertilizer use and achieving reductions in N pollution will require the federal government to carefully monitor and enforce binding regulations and standards on agricultural entities, like those that have been successful in reducing power plant emissions in the CAA (EPA, 2022b). Even if emissions per farm begin to decrease, the world's continuous population growth will drive an increase in N fertilizer use for at least this decade, necessitating drastic and system-wide change in the agriculture sector if the impacts of agricultural N pollution are to be significantly abated (Heffer and Prud'homme, 2016). Choosing which mandatory regulations to implement is also critical, since without a multimedia regulatory approach—one that considers the impact of agricultural pollution on soils, waterways, and the air—federal and state government agencies might inadvertently incentivize farmers to choose practices that mitigate one form of pollution only at the cost of exacerbating another. For example, some manure application patterns that reduce atmospheric ammonia emissions also increase nutrient runoff into waterways, making them a poor choice for federal and state government subsidization (Li, Frolking, and Butterbach-Bahl, 2005). By setting stringent pollution standards for multiple N compounds simultaneously and addressing these different reservoirs of excess nutrients, regulators could begin to bring about the profound change necessary to reach sustainable agricultural production.

In combination with enacting and enforcing mandatory regulations, enhancing the effectiveness of existing voluntary regulations and incentive programs is key to achieving the fastest possible emissions reductions. Maximizing the value of funding allocated to programs like EQIP and CSP in the IRA and Farm Bills is an easy way to tip the balance of federal government subsidization in favor of sustainable agricultural practices. Numerous state programs for cover cropping and conservation tillage, many of them partially funded with federal dollars, in states like Maryland and Pennsylvania have yielded rapid increases in adoption even as total adoption climbs above the majority of other states (Wallander et al., 2021). Even with the influx of new IRA funding, there is still not enough funding for EQIP and CSP to outcompete existing subsidies in many states, but optimizing these incentive programs can support efforts made in other areas. Furthermore, new funding will not change the fundamental process behind EQIP and CSP funding allocation, an incredibly time-intensive and bureaucratic process that is very inefficient for small farmers. The federal government can also provide support to key states in funding their own programs as well as increasing monitoring and enforcement of pollution standards, helping circumvent the difficulty of changing state budgets due to the influence of agribusiness.

These recommendations, although they arise from only a tiny fraction of the countless critical laws and legal proceedings that influence agricultural regulation in the United States, reflect the highest-profile lessons learned from core environmental laws. Future work should inquire into the application of additional federal policy and law, such as the Resource Conservation and Recovery Act and the wide body of cases involving federal and state government and NGO challenges against fertilizer-producing corporations, to agricultural N pollution regulation. In addition, exploring where federal-state collaborations on this issue can be most effective is another excellent way to achieve emissions reductions. Nevertheless, learning from the successes and failures in the implementation of complicated and oft-used legislation like the Clean Air Act and the Clean Water Act is a great first step towards achieving a cleaner and more sustainable future for people and for the environment we inhabit.

Chapter IV: State Policy

Background

The ineffectiveness of federal regulations in reducing N emissions from agriculture suggests the importance of other approaches towards this issue. Some states have experienced success limiting the impacts of N pollution and incentivizing sustainable agricultural practices like cover cropping, meriting further attention. Scaling up these state-level policies to the federal level could be an important tool in addressing the N pollution crisis. Due to their reduced scope, state-level initiatives can more effectively target existing obstacles to sustainable agricultural practices and seek to overcome them with location-specific support. Understanding the N policy landscape and relevant successes/failures in Iowa, California, Maryland, and Georgia, which were selected to be as representative as possible of various policymaking contexts across the nation (see Methods), is critical to reducing agricultural N pollution across the country. Table 1 provides relevant crop agriculture statistics for each state, while Table 2 summarizes N application dynamics for each state.

Table 1: Summary statistics for cropland agriculture in Iowa, California, Maryland, and Georgia (USDA NASS, 2023; USDA NASS, 2017).

	Total Number of Farms (2017)	**Total Harvested Cropland Acres (2017)**	**Median Size of Farm, Acres (2017)**	**Most Common Crops (2022)**	**Total Value of Crops Produced, Millions of $ (2017)**
Iowa	86,104	24,347,862	142	Corn, soybeans	25,948.0
California	70,521	7,857,512	20	Rice, tomatoes, lettuce	14,665.6
Maryland	12,429	1,290,212	40	Corn, soybeans,	904.3

				winter wheat	
Georgia	42,439	3,628,707	67	Cotton, peanuts, pecans	3,430.9

Table 2: Summary statistics for N application in Iowa, California, Maryland, and Georgia (USDA NASS, 2017).

	Cropland Treated with Commercial Fertilizer, Acres (2017)	**Cropland Treated with Manure, Acres (2017)**	**Cropland Treated with Organic Fertilizer, Acres (2017)**	**Fertilizer, Lime, and Soil Conditioners Purchased, Millions of $ (2017)**	**Cropland Planted to a Cover Crop, Acres (2017)**
Iowa	18,760,579	2,762,414	192,333	1,845,469	973,112
California	6,513,329	656,688	336,701	2,082,908	350,436
Maryland	962,612	204,028	16,497	121,447	410,849
Georgia	2,975,950	627,178	73,098	452,329	530,888

Iowa

Iowa is the state with the most harvested cropland in the country, notable for its extensive corn-soybean rotations and entrenched agricultural economy. In 2021, Iowa received more federal subsidies—to the tune of $1.656 billion—than any other state except for Texas and North Dakota (Environmental Working Group, 2023). The impacts of widespread N pollution resulting from the vast amounts of fertilizer applied in the state drove the creation of the EPA's 2008 Gulf Hypoxia Action Plan. This initiative called upon states in the Mississippi River watershed, including many large polluters like Iowa, to strengthen their nutrient management efforts with the aim of reducing nutrient loading in the Gulf of Mexico (Arbuckle and Rosman, 2014). As a result, the Iowa Nutrient Reduction Strategy (INRS) was created by the state of Iowa in 2013 (Nowatzke and Benning, 2020). The INRS set a goal of reducing N loss from agricultural nonpoint sources by 41%, an ambitious target that would go a long way towards lessening the impacts of N pollution (Nowatzke and Benning, 2020).

The scale of this 41% reduction target caused the authors of the INRS Science Assessment to include in-field practices like cover crops, erosion control practices, and land use change as potential strategies for reducing N loss (Iowa Department of Agriculture and Land Stewardship, 2017). While there has been some progress in these areas—particularly in cover crop acreage, which increased from 379,000 to 973,000 from 2012 to 2017—changes in adoption over the past ten years are much too slow to reach the INRS's goal in the coming decades (Nowatzke and Benning, 2020). As the INRS's 2018-19 summary report explained:

> Meeting the goals of the INRS requires changes on every acre of Iowa farmland. One scenario calls for an estimated 10.5 million acres of no-till and strip-till, 12.5 million acres of cover crops, 7,600 nutrient removal wetlands, and 120,000 bioreactors and saturated buffers. In comparing these numbers to the 2019 assessment of practices, we have a lot of work ahead of us to reach the goals (Nowatzke et al., 2020).

Reaching the practice adoption outlined in this scenario would likely require significant changes to existing conservation programs, which have not generally achieved such transformative results to date. There are many state-scale initiatives to support conservation agriculture in Iowa and in other agriculture-intensive states. The strengths and weaknesses of such programs are important to understand to achieve broad improvements in N pollution; thus, a comparison of their impact in each of this study's selected states follows.

Despite slow historical adoption of conservation agriculture practices, Iowa's Soil Health EQIP initiative (conducted in partnership with the USDA) requires farmers to implement a minimum of three of the following four practices: no-till, cover cropping, nutrient management, and conservation crop rotations (Iowa NRCS, 2020). This program, which offers federal financial assistance above normal EQIP payment rates (between $35-63 an acre depending on cover crop type), has played a large part in Iowa's 156% increase in cover crop acreage between 2012 and 2017 (Iowa NRCS, 2020; USDA NASS, 2012/2017). Iowa's EQIP initiative also takes action to prevent partial or short-term adoption of tillage by requiring that enrolled farmers practice continuous no-till (Iowa NRCS, 2020). These interruptions in conservation tillage have the potential to reverse nearly all of the benefits of no-till, underscoring the value of carefully designed incentive programs (VandenBygaart, 2015). A commonality among states like Iowa that have strong positive trends in conservation practice adoption is the implementation of innovative funding mechanisms beyond federal baselines. These ingenuous approaches can circumvent common barriers to successful financing programs, including the delay between investments and financial returns, the presence of existing funding favoring conventional agriculture, and a lack of pricing for environmental benefits (Feldmann et al., 2019; Pike et al., 2020). Thus, they address the barrier of compatibility, ensuring that cover cropping and conservation tillage mesh with the needs of farmers to turn a profit given the severe financial hardship they face. With national median net farm income, which includes crop insurance and indemnity payments, being more than $1,000 below zero, bringing in enough money to pay for basic expenses is a serious challenge (Burchfield et al., 2022). Farmers in households with small or negative net on-farm income often have other jobs or sources of capital, but limiting profitability to large farming corporations has negative impacts on farming practices, diversity and inclusion, and the environment. Addressing N pollution in states like Iowa where agriculture is a central part of the economy requires understanding this financial reality.

In addition to EQIP, Iowa also participates in other key federal programs like the Mississippi River Basin Healthy Watersheds Initiative (MRBWHI), the Agricultural Conservation Easement Program (ACEP), the Regional Conservation Partnership Program (RCPP), and the Water Quality Initiative Program (WQIP). These conversation measures all operate in similar fashions, relying on voluntary farmer participation through financial incentives that require a sign-up process and agreement to certain stipulations (USDA NRCS, 2023a). They are currently achieving emissions reductions on a small scale. For instance, a 2022 RCPP project received nearly half of its $669,400 budget from USDA contributions, targeting the adoption of cover cropping and no-till in Allamakee County (USDA NRCS, 2023b). The impact of these targeted programs, though, is relatively small-scale due to the limited resources allocated to them by the federal government. Increased participation from states like Iowa, dedicating portions of their annual budget to conservation practices and collaborations with the USDA and other entities, will be key to reducing N emissions from cropland.

Some of Iowa's state-level programs have limited scope due to competition with existing agricultural subsidies. In order to incentivize cover crop adoption, Iowa's cost-share program through the WQIP offers $25 per acre for first-time cover crop farmers and $15 per acre for farmers who have used cover crops previously to switch over to this management practice (Nowatzke and Benning, 2020). One key issue with this program is its limited scope—with funds only available for 160 acres per farmer or landowner, such initiatives are unlikely to reach the large farms that produce most agricultural N emissions (Nowatzke and Benning, 2020). These incentives are also on the low end of the $12 to $92 range for per-acre cover crop payments in numerous other states, reducing the cost-effectiveness of participation when compared to current funding sources and making the process of receiving funding a poor time investment for small farmers (Wallander et al., 2021). Despite these limitations, such cost-share programs target smaller farms that receive less support from federal programs like EQIP and CSP and can help bridge the gap in funding and demand experienced by these initiatives. Iowa faces unique challenges in mitigating agricultural N pollution due to the size of its agricultural industry, since any large per-acre payment would quickly overwhelm limited program budgets.

The large impact of Iowa's agricultural industry on U.S. waterways has inspired numerous federal and nonprofit-run education and outreach programs aimed at encouraging conservation practice adoption amongst Iowa farmers. These initiatives often run into two main problems: opposition from the agricultural lobby and difficulty reaching the full population of farmers in the state. To understand the power of agricultural interest groups, the example of the Maximum Return to Nitrogen (MRTN) calculator is appropriate. This calculator was developed in 2006 by a team of scientists in Corn Belt states seeking to provide a tool for farmers to optimize their N fertilizer use. With variables including location, soil characteristics, the price of corn, and the price of fertilizer, the calculator was able to provide farmers in these states an estimate of the ideal amount of fertilizer to apply to their fields—one that maximizes profits by saving money usually spent on excess fertilizer (Iowa Sierra Club, 2022). Despite numerous studies concluding that Corn Belt farmers in various watersheds were applying more than double the necessary amount of fertilizer (Sainju et al., 2020; Donner and Kucharik, 2003; Houser, 2022), agricultural interest groups maintained that the MRTN calculator was overly simplistic and did not constitute a good indicator for N fertilizer decision-making (Iowa Sierra Club, 2022). These organizations, including the Iowa Farm Bureau, advocated for yield-based management—in other words, applying as much fertilizer as needed to maximize yields without considering the marginal utility of each additional pound as compared to environmental and health impacts (Iowa Sierra Club, 2022). Because of federal commodity subsidies, much of the financial cost of fertilizer is not felt by farmers, not to mention the externalities of N overuse like ecosystem degradation and reduced water quality. Thus, a yield-based fertilizer application paradigm has persisted despite its long-term impracticality.

The opposition from notable organizations in the agricultural industry is a significant obstacle to progress in reducing N emissions because of the status of these organizations in farmers' decision-making processes. The Iowa Farm and Rural Life Poll found that of Iowa farmers who planted corn or soybeans in 2011, only 11% used the MRTN calculator (Arbuckle and Rosman, 2014). Instead, the farmers surveyed were overwhelmingly likely to use either "crop nutrient requirements based upon yield goals" (71%), recommendations from their fertilizer supplier (62%), or their prior experience (58%) when deciding how to apply fertilizer (Arbuckle and Rosman, 2014). Without a concerted effort to reach out to Iowan farmers about tools like the MRTN calculator, prior knowledge/connections and the financial hardships of farming will continue to be the driving factor of N pollution from fertilizer in the state.

California

California, now the world’s fourth-largest economy, has a unique agricultural landscape. Instead of the corn, soybeans, and wheat that dominate much of American cropland, California produces much of the country’s fruits and vegetables. The state produces almost all of many key crops, including 99% of both the pomegranates and almonds grown in the U.S. (Tolomeo, 2017). California also harvests crops worth 57% of the value of Iowan crop yields despite having only 32% of Iowa's large cropland acreage (Table 1). Yet a thriving agricultural economy has come at the cost of severe N pollution. Furthermore, unlike other pollutants for which the state has had success regulating, N emissions from fertilizer have consistently increased for many decades (Tomich et al., 2016). The California Nitrogen Assessment (CNA), which was published in 2016 by the University of California-Davis, found that inorganic N fertilizer application rates increased 25% from 1973–2005 and that “the majority of California crops recover well below half of applied N, with some crops capturing as little as 30%” (Tomich et al., 2016). N leaching from cropland is the cause of 88% of the state’s N input to groundwater, thus being responsible for the associated health outcomes of contaminated drinking water (Tomich et al., 2016). The Assessment found that due to the long-lasting nature of N in environmental systems, none of the four future scenarios they projected for California agriculture would “lead to sufficient improvement in groundwater quality to fully address human health concerns by 2030” (Tomich et al., 2016). Because “nitrogen flows in California are unlikely to decrease and indeed are likely to continue to grow,” it is critical that the state tackles this nitrogen use efficiency (NUE) problem before the human health impacts become much more severe (Tomich et al., 2016).

California’s liberal politics do mean that unlike a conservative state such as Iowa, strong regulations and government oversight powers are a possibility. In fact, the CNA states that “voluntary participation in best management practice (BMP) programs typically cannot achieve significant reductions in nitrogen pollution from agriculture,” invalidating the predominate method by which that N pollution is currently addressed (Tomich et al., 2016). Because BMP programs are so common, there is a concerning absence of research on other types of policy to regulate N pollution: “The general lack of evidence, rigorous experimentation, comparative study, or integrated assessment of the impact of alternative policy instruments for controlling nitrogen pollution from agriculture is a major barrier to development of sound policy” (Tomich et al., 2016). Nevertheless, the authors of the Assessment recommend “five types of policy instruments” that merit additional research: “emission standards, emission charges, tradable emission permits, abatement subsidies, and auction-based abatement contracts,” which are discussed further below (Tomich et al., 2016).

One challenge with developing these policy instruments is the lack of available data about N fertilizer use, which is often not tracked at appropriate scales for state policymaking or is evaluated inconsistently across different data sources (Rosenstock et al., 2013). For example, statewide N fertilizer sales data often have unexplained variability that limits their plausibility, and county-level data is often unrepresentative due to the complicated transport of fertilizer across the state. For example, one study found that more than 20% of the state’s N sales were reported to take place in San Joaquin County, an unlikely figure that can only be explained by the prominence of the Port of Stockton (Rosenstock et al., 2013). Much of the N delivered to this port was likely not used in the county, but it is incredibly difficult to track its travel and eventual use. California, like Iowa, does have state-level guidelines for the application of N fertilizer that are designed to incorporate local variability. Yet in 31% of California cropping systems, “either the research underestimates nitrogen requirements for on-farm cropping conditions or the producers, on average, overapply nitrogen fertilizer" (Rosenstock et al., 2013). In other words, there is still a significant portion of California agriculture for which additional research would be useful. Better understanding the exact amount of the potential N surplus applied on this cropland, or to certain crops that are often oversaturated with N fertilizer, is critical to identify leverage points to balance N emissions reduction with crop yields and economic benefits (Rosenstock et al., 2013). However, the data necessary to calculate this surplus, including "data on yield, N and moisture content of harvested products, and nitrogen application," is not available in an easily accessible or comprehensive manner (Rosenstock et al., 2013). Innovative policy tools will require better information access, likely from mandatory reporting schemes, which are currently quite uncommon.

In addition to its consideration of these regulatory approaches, California is unique for its mandatory information-based approaches, which constitute some of the only mandatory agricultural policies in the United States (Wood et al., 2022). Under the state's Irrigated Lands Regulatory Program (ILRP), farmers are required to register for regulatory coverage either individually or under a coalition in order to "prepare and implement mandatory regional water quality management and monitoring plans" (State of California, 2020). To fulfill this requirement, farmers learn about the impacts of N pollution on regional waterways and submit detailed information about their N application rates to state authorities (Wood et al., 2022). When evaluating the effectiveness of this program, Liza Wood and a team of researchers from various California universities found that "accepting agriculture's role in nitrogen pollution is an important precursor to any kind of learning," supporting the efficacy of mandatory programming in reducing N emissions (2022). This acceptance/awareness was a "significant, positive predictor of all learning stages," meaning that it helped farmers with various levels of experience reduce their N emissions (Wood et al., 2022). Given the external nature of many problems caused by N pollution, supporting farmer awareness through mandatory reporting programs is wise both to facilitate more effective regulations and to foster self-motivated management changes. Mandatory programming is also key to reach demographics of farmers who are not typically early adopters of sustainable management practices. In a "reversal" of what prior research has found, Wood and her team concluded that "the farmers benefiting from mandatory plan-writing do not fit the typical innovator profile" (2022). Because the ILRP is mandatory but also allows for flexible plan-writing, it is the perfect type of program to reap the benefits of increased participation while extending them to populations that are typically neglected in agricultural policymaking (Wood et al., 2022). Reaching these demographics also has the very important benefit of increasing data collection, a key challenge in non-point source N pollution. Adequate data is key to enforcing pollution control policies, but the diffuse nature of N pollution has been a significant obstacle to the few mandatory regulations that exist (Wood et al., 2022). Facilitating "the transition of nitrogen from a non-point source problem to a more manageable point source problem" is critical to meeting California's lofty N management goals, improving human and ecosystem health in the process (Wood et al., 2022).

The creation of the CNA was meant to address these issues by providing farmers with an extensive summary of existing science. One of the Assessment's goals was to "effectively link science with action and to produce information that informs both policy and field-level practice" (Tomich et al., 2016). However, the lack of reliable access to useful information about N fertilizer use is largely due to an absence of available information, not a gap in the synthesis of existing research. The CNA did help position the goals of California's N pollution management, emphasizing the unique nature of N pollution in the state. California, compared to other locations in which comprehensive mass balances are available, has low N flows through surface water, but high amounts of N storage in groundwater and urban land (Tomich et al., 2016). This unique situation ought to inspire specific N management policies that can mitigate groundwater contamination and protect human health. Of the nine “critical control points” identified in the CNA, three are particularly relevant to N pollution from fertilizer: agriculture N use efficiency, nitrate leaching from croplands, and greenhouse gas emissions from fertilizer use (Tomich et al., 2016). Future research on N pollution reduction policy in California ought to focus on these three metrics, particularly from a groundwater pollution perspective.

What the CNA does effectively, though, is to identify the potential of policy and technology changes to achieving the state’s N emissions mitigation goals. For example, the study quantifies a 283,000-pound reduction in leaching necessary to stop groundwater nitrate accumulation, noting that soil management practices can only contribute around 40,000 pounds of this change (Tomich et al., 2016). This finding indicates that in California and other states where groundwater pollution is a key issue, conservation practices like cover cropping, even if widely adopted, are only one part of the solution. The CNA evaluated additional policies to close this gap based upon six criteria that are outlined in Table 3 below. The five types of policy instruments evaluated in the CNA are also listed in Table 4.

Table 3: Descriptions of the six criteria adopted in the California Nitrogen Assessment to evaluate potential N pollution management policies (Tomich et al., 2016).

Criterion	**Description**
Adaptability	Flexibility to accommodate changing conditions
Institutional Compatibility	Implementation does not conflict with larger institutional frameworks

Distributional Effects	How both costs and benefits are distributed across stakeholder groups
Cost Effectiveness	Total economic cost of implementation compared across policy alternatives
Technological Feasibility	Are currently available technologies and practices suitable?
Environmental Effectiveness	A likelihood of achieving the desired environmental goal, without major side effects.

Table 4: Descriptions of the six five policy instruments evaluated in the California Nitrogen Assessment (Tomich et al., 2016).

Policy Instrument	**Description**
Emission Standards	Specifications that emissions cannot exceed a set limit. These standards allow producers to identify the most cost-effective ways to reduce emissions, but also involve high monitoring costs to ensure compliance and can disproportionately impact small producers.
Emission Charges	Set prices/taxes on N emissions. Emission charges encourage producer innovation and provide valuable revenue that can account for monitoring and enforcement costs, yet cost increases for producers can lead to reduced yields and potential industry collapse.
Tradable Emission Permits	Fix the “supply” of N pollution and allow the price of emissions to be set in the market. These permits have similar advantages to emission charges but may be ill-suited to addressing groundwater pollution due to its hyper-local nature and can concentrate power in the hands of a few large producers.
Abatement Subsidies	Financial incentives for achieving greater N abatement. Under abatement subsidies, producers are encouraged to innovate and are compensated fairly for the large health costs that they avoid incurring through abatement. However, regional characteristics may lead to undesirable differences in abatement targets across the state, and subsidies can encourage additional entries into the industry, offsetting abatement.

Auction-based Abatement Contracts	Regulators choose to purchase contracts from a variety of producers submitting them, deciding based upon the cost-effectiveness of the proposals and the total emissions reductions to be achieved. This decision-making process can allow federal or state government officials to coordinate abatement strategies and foster collaboration, yet they entail particularly high administrative costs.

Despite the promise of many of these policies, there are significant roadblocks to progress in mitigating N pollution. First and foremost comes the costs of these policies, most of which would require additional federal or state government revenues to implement. N pollution is also a worsening problem with lasting and serious effects, necessitating immediate action to protect frontline communities experiencing unsafe drinking water (Tomich et al., 2016). If there are sufficient measures to ensure the quality and immediacy of emissions reductions caused by tradable permits, though, market solutions have the potential to begin the steep mitigation necessary for planetary stability. One study of N permitting in Denmark found that the policy led to a 21.5% reduction from baseline N load, resulting in cost savings of 56% (36.6 million pounds) compared to uniform regulation and supporting participating farms through a mean net benefit of 97 pounds per hectare (Hasan et al., 2022). However, the application of such policy in the United States demands careful consideration of potential obstacles. For example, in a study of the Chesapeake Bay area (the largest Total Maximum Daily Load standard area in the country), multiple roadblocks were identified. Firstly, past programs that have successfully raised farmer participation in trading programs “rely heavily on existing embedded ties with farmers and intensive personal interactions,” forms of social capital that are not necessarily scalable (Ribaudo et al., 2013). Furthermore, uncertainty in the efficacy of best management practices and in the long-term consistency of farmer participation “impedes the development of viable markets" because reducing that uncertainty—additional point source trading compared to nonpoint sources, inspections, monitoring, and more— "are expensive and make markets inefficient" (Ribaudo et al., 2013). Existing subsidies also mean that these market-based solutions "cannot be expected" to achieve emissions reduction goals on their own, or even to be a primary contributor to those reductions (Ribaudo et al., 2013). Like other policies, the effectiveness of agricultural market-based solutions is dependent on the small choices made in their implementation. Efforts like the CNA will go a long way towards identifying the specific choices that will make such policies effective in California, but these solutions need to be implemented with haste if emissions reduction goals are to be met.

Maryland

Maryland is a state with a much smaller focus on agriculture than Iowa or California, leading to a very different regulatory environment. Its location in the Chesapeake Bay watershed has led to significant attention from the federal government, with organizations like the Chesapeake Bay Foundation continuing to litigate extensively to mitigate pollution in the area (Chesapeake Bay Foundation, 2022). Like Iowa, however, Maryland grows primarily corn and soybeans, homogeneity which makes introducing uniform N management policies easier. The state's relatively smaller acreage has allowed for much higher per-acre incentive payments at the state level for the adoption of cover crops and nutrient management systems, facilitating Maryland's status as the state with the highest use of cover crops in the United States. Maryland is a potential model for states seeking to double down on a voluntary best management practice (BMP) approach, achieving impressive results from these large payments.

One key policy that has facilitated these benefits is Maryland's state-level Agricultural Water Quality Cost-Share (MACS) Program, which supports farmers in installing a wide variety of BMPs. The key aspect of this Program is that almost all its benefits have their implementation costs covered 100%, allowing farmers to avoid making a potentially risky investment (State of Maryland, 2022). Because short-term profit is the dominant factor in farm management practice adoption, grants funding the implementation cost and supporting farmers through their first years navigating new practices is critical to increasing cover cropping and sustainable nutrient management (Prokopy et al., 2019). The MACS Program's expansive list of available practices also provides for the future of land after agricultural production (State of Maryland, 2022). This inclusion is key, since practices like cover cropping are important tools in the land use change that will be necessary to realize N emissions reduction goals.

Maryland, like California, also requires farmers of a certain size (making gross revenues of $2,500 a year or more) to follow a nutrient management plan submitted to the state government when fertilizing crops. Maryland's requirement that farmers become certified to create their own plans, or work with private consultants or University of Maryland experts, ensures that all farmers are consistently exposed to the impacts of nutrient runoff (State of Maryland, 2023). These plans are incredibly detailed, requiring farmers to account for all aspects of their contributions to nutrient cycling (Aiken, 2019). As mentioned above, this awareness is a prerequisite to maximizing conservation practice adoption, perhaps contributing to Maryland's high cover crop use (Wood et al., 2022). Maryland's Program also requires farmers who apply N to 10 or more acres a year "to attend a two-hour nutrient applicator course" and take soil samples every three years as well as submit Annual Implementation Reports each year (State of Maryland, 2023). These requirements, while they may seem onerous, are critical to the state's excellent data on N pollution as well as farmer knowledge. As in Iowa, Maryland's government collaborates extensively with the University of Maryland's extension program to support farmers and increase information access. Maryland's Agricultural Nutrient Management Program, which is responsible for the implementation of these policies, exemplifies multifaceted state policy that is achieving tangible results.

The primary factor in Maryland's high cover crop adoption rate and the associated mitigation of agricultural N pollution, though, is the state's Cover Crop Program (CCP). This initiative reaches the state's cropland acres that are not already supported by federal programs like EQIP and CSP, ensuring that there is enough funding to come much closer to matching the demand for cover crop incentives in Maryland than in other states (State of Maryland, 2022). The CCP's base rate of $55/acre is already more than federal or state programs provide in much of the country, including key agricultural states like Iowa and Illinois, and it is provided to farmers in addition to any federal funding (Wallander et al., 2021). Yet Maryland's Program also adds incentives to encourage the most effective adoption of cover crops, providing extra support to farmers who plant cover crops early in the growing season, plant a multi-species cover crop, and/or wait until late in the growing season to terminate their cover crop (State of Maryland, 2022). The combination of these management decisions can earn Maryland farmers payments of up to $90/acre for their cover crops, a level of support unmatched by any other federal or state cover crop incentive system. Maryland's ability to provide such generous grants comes from the support the CCP receives from the Chesapeake Bay Restoration Fund and the Chesapeake and Atlantic Coastal Bays Trust Fund, which significantly reduces the need for state investment (State of Maryland, 2022). Other states in key watersheds might consider collaborating with funds and programs aligned with those locations to bolster their own sustainable agriculture incentives.

Despite the success of Maryland's Cover Crop Program, there are other farm management practices that the state ought to support similarly to maximize reductions. From 2010 to 2018, the state reduced N pollution from agriculture (including N entering the air and waterways) by 1.6 million pounds, an impressive reduction in a relatively short period of time (Metcalf, 2020). However, Maryland's Chesapeake Bay cleanup goals aim for the agriculture sector to achieve a 4.2-million-pound reduction by 2025, necessitating additional action (Metcalf, 2020). One key practice that the Chesapeake Bay Foundation is seeking state support for is the bolstering of natural filters, which are plants or organisms capable of cleaning air and water of nutrients like N and phosphorus (Metcalf, 2023). Interspersing trees, wetlands, and grass pastures in agricultural lands is an effective strategy in reducing N runoff to waterways, but the practice has received little support compared to cover cropping in Maryland (Metcalf, 2020). Legislation to extend support for natural filters did not pass in Maryland’s state legislature in 2020, but the Chesapeake Bay Foundation is supporting a suite of legislation during the 2023 session that would go a long way towards reducing N emissions (Metcalf, 2023). Even in a state as successful in reducing N pollution as Maryland, it is critical to implement a variety of N emissions reduction policies to achieve lofty goals that will greatly improve human and ecosystem health.

Georgia

Georgia's agriculture sector is an important one in the state's economy, employing nearly 360,000 people in predominately rural areas (Knox et al., 2022). Its high production of cotton, peanuts, and pecans, crops that are uncommon outside the Southeast, drives additional N pollution in the state, since these crops are often fertilized at rates higher than staples like wheat and soybeans (Shirley, 2021). However, the smaller amount of corn production in Georgia mitigates N pollution somewhat, since corn is the crop that requires the most N per acre (Ribaudo, 2011). Despite having only 15.1% of Iowa's cropland acreage, Georgia has 49.3% of Iowa's total number of farms, reflecting a lower proportion of large agribusiness conglomerates (Table 1). In fact, 88% of Georgia's farms are considered to be small businesses by the metric of their annual sales, contributing to a higher diversity of farm management practices and crop outputs than other states (Wolf, 2017). This large dispersal of agricultural activity across the state and different actors makes Georgia a useful case study in agricultural regulation outside of the larger and less diverse agriculture of the Midwest.

Like other states, Georgia has sought to counter the prevailing conception among farmers that cover cropping would negatively affect their yields or lead to other costs. The Georgia Association of Conservation Districts (GACD), in partnership with the Lower Chattahoochee River Conservation District and the USDA's NRCS, developed the Lower Chattahoochee River Cover Crop Project to address educational concerns (Wilson, 2017). Through cover crop demonstration sites implemented in collaboration with Southwest Georgia farmers, the GACD is quantifying in a local and trustworthy setting potential benefits to soil erosion, water quality, energy savings, and more (Wilson, 2017). These demonstration sites, in combination with the

GACD's targeted farmer outreach programs and work with the University of Georgia extension, are providing the information access that is so key to increasing conservation practice adoption. Georgia, like Iowa and California, is also the beneficiary of a new targeted program led by the NRCS. The Cover Crop Initiative (or CCI, which is being run through EQIP) was launched in 2022 to assist eleven key states that expressed a demand for additional cover cropping support to "mitigate climate change through the widespread adoption of cover crops" (USDA NRCS, 2022). The CCI will provide additional funding to help meet the demand for EQIP support in these eleven states. These cover crops will not only potentially lead to climate mitigation through reduced nitrous oxide emissions, but also provide numerous co-benefits including reducing N runoff. While the CCI is not a state-run program, its focus on states where additional cover crop adoption is both most likely (measured by farmer demand) and most important to meeting existing N pollution reduction goals is critical to reaching the cover crop target adopted by the NRCS and partner organization Farmers for Soil Health: 30 million acres by 2030 (USDA NRCS, 2022).

Due to lacking state-level N pollution reduction initiatives, Georgia has received large amounts of funding from federal programs designed to bolster cover crop adoption. In addition to the CCI, Georgia farmers have benefited from the Pandemic Cover Crop Program (PCCP), which sought to support the agricultural industry during the 2021 crop year. The state received more than four times the funding per acre that agricultural powerhouses like Iowa and Illinois received due to its higher cover crop adoption (as funds only went to farmers who planted cover crops the prior year), money that went a long way towards keeping Georgia farmers in business during the height of the economic shock (American Farmland Trust, 2022). This trend may continue for PCCP's 2022 crop year, for which data is not yet available. Certain states may be hard-pressed to implement potentially expensive N pollution mitigation measures due to their politics or to other financial burdens. In these locations, targeted federal funding is key to achieving conservation practice adoption goals.

One useful lesson from Georgia state policy, though it has not led to large changes in N emissions, is the controversy over a 2021 soil amendment rule. Soil amendments are additives meant to improve the "texture and water retention" of soils, as well as providing them key nutrients like N (Mecke, 2022). The Georgia Environmental Protection Division (EPD), when writing the guidelines allowing the use of soil amendments, neglected to provide specific details important for upholding their regulatory authority (Mecke, 2022). For example, one rule stated that soil amendments should be added "at a rate which leaves no significant amount of material on the surface within one hour following injection" without defining what a "significant amount of material" constituted (Montoya, 2022). Following a series of complaints from residents and environmental advocates, the EPD and the Georgia Department of Agriculture wrote updates to their rules which specify appropriate application methods and testing requirements and set specific guidelines which are subject to monitoring (Mecke, 2022). This example reinforces the importance of tackling N pollution in a holistic manner—focusing only on cover crops or on fertilizer use efficiency could bring unintended consequences, like increases in soil amendment application, which negate any existing abatement. Considering factors like Georgia's climate and its lack of corn-soybean dominance when constructing N management policy is critical to reducing N pollution across the entire country, not just in traditional agricultural environments.

Contexts of State Policymaking

Iowa, California, Maryland, and Georgia are states with different political leanings, regulatory contexts, agricultural interests, and numerous other factors that affect N policy. Understanding the characteristics of states that influence policy outcomes is critical to choosing the right types of policy interventions to address N pollution across the United States. Table 5 below includes information about a number of key variables with the potential to alter the N policy portfolios chosen by states for the four states analyzed above.

One important aspect of state N policies is each state's current level of N pollution and depth of policies seeking to counteract it, including the extent to which it has incentivized conservation practices on farms and the severity of ecosystem impacts it faces. The table below presents rankings developed by the Union of Conservation Scientists for two categories: conservation practices and reduced ecosystem impacts (Union of Conservation Scientists, 2018). The conservation practices rank prioritizes cover crop usage but also includes no-till and conservation tillage, rotational or management-intensive grazing, organic practices, conservation easements, and alley cropping/silvopasture. The reduced ecosystem impacts rank features climate impacts from agriculture as well as erosion rates, nutrient loss, impaired waters, and low water quality due to high nitrate levels. These two rankings are valuable assessments of where states are in terms of achieving the adoption of conservation practices and in reducing agricultural impacts on ecosystems.

As might be expected given the dominance of agricultural interests in the state, Iowa ranks near the bottom of the 50 United States in both conservation practices and reduced ecosystem impacts. A very low cover crop adoption rate, high quantity of fertilizer application, and the large proportion of cropland acres unsupported by federal conservation programs are some of the factors likely responsible for these rankings. Iowa and other agricultural powerhouses like Illinois and Kansas ought to continue being prioritized in federal efforts to address N pollution, since these states produce an outsize amount of this pollution. California's large agricultural presence also contributes to its middle-of-the-pack rankings, yet the numerous state programs there improve its standing relative to Iowa. California's policies seem to have an impact particularly on conservation practices, which speaks to their effectiveness given the complications with using these management strategies in vegetable cultivation.

Maryland's high ranking for conservation practices is no surprise given its highest-in-the-nation cover crop adoption. What is striking, however, is that this high conservation practices ranking has not led to a high reduced ecosystem impacts ranking, even though the state has far fewer harvested cropland acres than Iowa or California. This discrepancy suggests that voluntary incentive programs, which Maryland excels at, are not sufficient to mitigate or prevent ecosystem impacts. Finally, Georgia achieves high rankings in both conservation practices and reduced ecosystem impacts, which is unexpected given the vacuum of relevant policy in the state. The higher concentration of small farmers growing diverse sets of crops may influence the lesser impact of Georgia's agriculture on neighboring ecosystems and lead to higher conservation practice adoption.

Understanding the power of special interest groups in the state is also important to comprehending all influences on state policy. States with many farms having sales over $250,000 may have state and local Farm Bureaus that advocate more for the interests of large corporate farms than small enterprises, worsening environmental impacts. States with a small number of large farms, like Maryland, can also manage incentive programs more easily due to a smaller number of acres that need funding. The number of large farms in a state is correlated with the amount of direct federal payments it receives, representing entrenched agricultural interests in high-payment states.

Political partisanship, although complicated and ever-changing, can also offer some insight into state N pollution policies. One measure of political partisanship is the current distribution of governmental power: for example, a trifecta means that a state's house, senate, and governorship are all under the control of the same party. States under a democratic trifecta or with a high state policy liberalism score are more likely to favor government intervention of the type addressed in this paper. For instance, California and Maryland, states with two of the top ten policy liberalism scores, both have much more developed N policy portfolios at the state level than either Iowa or Georgia. Of the four states analyzed, these two are the only states that require farmers to submit detailed nutrient management plans to their state governments. California and Maryland also have the largest state infrastructure for incentive programs, perhaps contributing to their conservation practices ranking. Because of Iowa's change in government control in 2017, it is likely a recalculation of its state policy liberalism score would produce a score below zero. Iowa and Georgia, thus more conservative states in terms of their policymaking, do not have any mandatory N pollution regulations. These states also have limited support for incentive programs, with much more reliance on the federal government for conservation program funding. The impact of partisanship can be seen in the policy portfolios for each state outlined in the final section of the table. To maintain brevity while providing an accurate representation of the N policies implemented in each state, not all policies listed in the policy portfolio section of the table below are addressed above in the state analysis sections.

Table 5: Sociopolitical Factors Relevant to N Mitigation Policy and State-Level Policy Portfolios (Union of Concerned Scientists, 2018; Caughey and Warshaw, 2016; Grossman et al., 2021; Ballotpedia, 2023; USDA NASS, 2017; USDA NASS, 2022; etc.)

	Iowa	California	Maryland	Georgia
Need for Intervention				
Conservation Practices Rank (2018)	47	25	3	18
Reduced Ecosystem Impacts Rank (2018)	49	32	35	8
Special Interests				
Number of Farms with Sales over $250,000 (2021)	23,600	13,500	1,680	5,400
Direct Federal Payments, $1,000 [Share of Payments] (2021)	2,103,591 [8.1%]	1,176,066 [4.5%]	96,741 [0.4%]	590,445 [2.3%]
Partisanship				
State Government Control (2011-present)	Divided government (2011–2016) Republican trifecta (2017–present)	Democratic trifecta (2011–present)	Democratic trifecta (2007–2014) Divided government (2015–2022) Democratic trifecta (2023–present)	Republican trifecta (2005–present)
State Policy Liberalism Score (2014)	0.607	2.48	1.96	-2.13
Policy Portfolio to Address N Pollution				
Federal	Soil Health EQIP Initiative (incentive-based); Mississippi River Basin Healthy Watersheds Initiative	Cover Crop Initiative (incentive-based)	Chesapeake Bay Program (regulatory)	Cover Crop Initiative (incentive-based)

	(incentive-based); Cover Crop Initiative (incentive-based)			
State	Iowa Nutrient Reduction Strategy (self-regulatory)	Irrigated Lands Regulatory Program (regulatory); Organic Transition Pilot Program (incentive-based); Conservation Agriculture Planning Grants Program (incentive-based); Healthy Soils Program (incentive-based); Sustainable Groundwater Management Act (regulatory)	Agricultural Nutrient Management Program (regulatory); Agricultural Water Quality Cost-Share (incentive-based); Cover Crop Program (incentive-based)	Lower Chattahoochee River Cover Crop Project (incentive-based)

Characteristics of Innovations

To successfully incentivize more rapid adoption of cover crops and comprehensive nutrient management and to better understand the impacts of changes to policies and financial incentives, knowing why certain states are mitigating N pollution more quickly than others is invaluable. Thus, this section will focus on understanding the reasons behind the above trends in conservation practice adoption and associated policies, with the hope of presenting a more complete picture of what N management could look like in the United States. One helpful framework with which to view barriers to technological adoption is presented by Everett Rogers in *The Diffusion of Innovations*—he terms this framework the five "characteristics of innovations" (1983). These characteristics are as follows (Rogers, 1983):

- Relative advantage: How much of a benefit does an innovation provide an adopter over the previous method of fulfilling the same function? Although it is often measured in economic terms, this idea incorporates social and psychological factors as well—what matters is not the objective strength of the innovation, but how advantageous it is perceived to be. Innovations perceived as providing a higher relative advantage to their adopters will spread more quickly.
- Compatibility: How consistent is the innovation with "the existing values, past experiences, and needs of potential adopters?" If an innovation is wholly incompatible with existing values, the (at least partial) adoption of a new value system may be necessary for the innovation to achieve widespread use. Highly compatible innovations will spread more quickly.
- Complexity: How easy is the innovation to understand and implement? Less complex innovations will spread more quickly because there are fewer new skills and pieces of

information required to use them. The large number of management decisions farmers make throughout the growing season adds significantly to the complexity of conservation practices, since there are numerous other management techniques affecting even a single change in practice adoption.

- Trialability: How easily can the innovation be tried on a limited scale? This characteristic is particularly relevant to this report given the consolidation of agricultural production and the resulting financial hardship faced by small-scale farmers. If only large entities can try an innovation due to its limited trialability (high risk, large start-up costs, etc.), it is far less likely to be adopted quickly.
- Observability: To what degree are the results of the innovation "visible to others?" Peer-to-peer discussion is a key piece of a network model of innovation adoption, and even strong top-down marketing and communications cannot match a well-established ground-level spread of ideas. This characteristic also interacts with financial hardship, since farmers who compete with one another to sell to similar crop markets are unlikely to share their experiences with and knowledge gained from conservation practice adoption. Innovations for which results are more visible will be adopted more quickly.

It is clear that paying special attention to the differences between various agricultural contexts is a critical component of promoting the adoption of cover cropping and nutrient management. In addition, Rogers' characteristics of innovations have surfaced in diverse ways on the topic of conservation practice adoption (Table 5). Notwithstanding these findings and the lack of significance when predicting sustainable farm management through farmer identity, adopter characteristics are the subject of more research than contextual variables or innovation characteristics (Oca Munguia and Llewellyn, 2020). In fact, "innovation characteristics were the least researched group" in a recent literature review, comprising only 10% of studies "despite being the most consistent variables in regression analyses" (Oca Munguia and Llewellyn, 2020). While there are numerous positive trends in the adoption of cover crops and nutrient management in the United States, there are many opportunities for additional research, policy, and financing programs to fill current gaps and accelerate progress towards more sustainable agricultural systems.

Table 6: Examples of Rogers' characteristics of innovations as they apply to conservation agriculture practices.

Characteristic	**Examples found in conservation practice adoption**
Relative Advantage	Increased benefits from adopting multiple conservation practices at once; local factors affecting the efficacy of practices in intricate ways; limited access to conservation finance and associated disparities between small and large farms; renters' inability to ensure they will benefit from investments in soil and ecosystem health
Compatibility	Diverse needs of farmers conflicting with the implementation of conservation practices (crop yield protection, risk management, desired crop rotations, weed and pest management concerns, fertilizer accessibility, etc.)
Complexity	Complicated differences in local factors and their impact on conservation practice effectiveness; obscure and understudied interactions between conservation practices; intricate and highly variable budgeting processes; additionality, "crowding in," permanence, and unintended consequences of well-meaning policies
Trialability	Complexity of practice adoption hindering experimentation; limited access to equipment, seed, and other supplies; expensive nature of those materials; high proportion of rented cropland; dominance of cash-rent agreements; inflexible existing subsidies and stringent program requirements
Observability	Difficulty of assessing practice outcomes from aerial view of farms; temporary "unkempt" look of certain

	cover crop systems, especially when those systems require fewer pesticide applications; little incentive to share insights with direct competitors

It is highly important to conceptualize conservation agriculture as a system, since farmers who adopt one soil health management practice are much more likely to practice others and also see significantly increased benefits from this holistic approach. Cover crops can provide additional and unique benefits to nutrient management systems by "producing crop residues that increase soil organic matter and help control weeds, improving soil structure and increasing infiltration, protecting the soil surface and dissipating raindrop energy, reducing the velocity of water moving over the soil surface, [and] anchoring soil and adding carbon deep in the soil profile (via roots)" (SARE, 2012). These additional benefits are amplified by simultaneous adoption and ought to be valued accordingly through programs like Iowa's EQIP that require the implementation of multiple conversation practices. Yet cover crops often demand increased application of pesticides, an indirect consequence necessitating a systems approach to address.

Shifting holistically from current exploitative agricultural management to a suite of conservation strategies is not only key for environmental protection—it can also be cost-effective in the long term. 67% of the farmers interviewed in a Soil Health Institute and Cargill study reported increased yields after implementing a soil health management system, with only 2% reporting a decrease in yields (Soil Health Institute and Cargill, 2021). In addition to numerous soil health benefits, farmers had average savings of $24.00/acre for corn and $15.67/acre for soybeans, with 85% of corn and 88% of soybean farmers increasing their net income through the adoption of a soil health management system (Soil Health Institute and Cargill, 2021). Clearly, there are many factors that affect this profitability on an individual farm, including the requirements of conservation finance programs: for example, cover crop subsidies in Iowa are much higher for corn-soybean rotations than corn-corn fields, allowing corn-soybean farmers who adopted cover crops to increase their revenue on average by $140/acre in one study (Imerman and Imerman, 2019).

Achieving this shift in practice utilization, though, is quite complicated, as there are countless factors that influence farmers' decision making on the local, state, and federal levels. These factors relate extensively to all of Rogers' characteristics of innovations, most notably compatibility, trialability, and observability. As with the distribution of management practices themselves, numerous studies investigate potential barriers to adoption in different regions. The most notable and most discussed, particularly for cover crop adoption, is the Corn Belt/Midwest. One study found that social factors, often quite local or specific to given counties, usually occurred in "clusters" that influenced adoption (Popovici et al., 2020). Regardless of the presence of financial incentive programs, early adoption of cover crops (in the 1990s and early 2000s) by community members was associated with a significant increase in current usage (Popovici et al., 2020). This early adoption coincided with factors likely to increase cover crop benefits, including the presence of rolling hills (which increased the need to reduce soil erosion), rotational grazing (which allowed producers to use cover crops as feed), the presence of more cattle (heightening the cost savings of cover crops as feed) (Popovici et al., 2020). In counties where these opportunities for management changes occurred, other factors like the presence of a network of cover crop users (which created a culture conducive to adoption), the existence of incentive programs beyond EQIP and CSP that often have less onerous requirements to receive funding, and NRCS and conservation district employees promoting cover crop usage beyond their job description were in turn more common, further bolstering overall support for cover crops (Popovici et al., 2020). Other literature supports the idea that local watershed and cost-share groups are critical to the success of cover crop adoption, since the targeted support they can provide can mitigate trialability concerns while maximizing relative advantage (Arbuckle and Roesch-McNally, 2015). Most research, though, illustrates that practice adoption can occur as a comprehensive change to existing systems that gradually increases incentives and support for management changes (Popovici et al., 2020). Policies should thus prioritize targeting areas where cover crop benefits are the highest, since these regions are where the creation of a "cover crop culture" is most achievable (Popovici et al., 2020; Arbuckle and Roesch-McNally, 2015). A mounting body of research supports the claim that meeting BMP adoption goals requires small-scale, tailored access to information and financial incentives, all the while keeping farm profits at the center of the decision-making process (Liu et al., 2018; Prokopy et al., 2019; Knowler and Bradshaw, 2007).

Beyond variables that increase practice adoption rates, there are common barriers to adoption in Iowa that apply to other U.S. states as well. In a survey of Iowan cover crop users, farmers were overall happy with the results of their management changes, with only one farmer out of a total twenty-nine surveyed planning to halt their use of cover crops (Roesch-McNally et al., 2017). One common concern, though, was a lack of sufficient time to plant cover crops in the fall and terminate them in the spring, which is a difficult barrier to address through policy (Roesch-McNally et al., 2017). This concern is less common in areas like Georgia, where the climate provides a longer growing season and thus additional flexibility (O'Connell et al., 2014). Despite a distinct conservation ethic among farmers, the survey also found that yield was a central matter, since farmers prioritized staying afloat financially over more abstract moral concerns (Roesch-McNally et al., 2017). Farmers emphasized that society needed to more fully bear the costs of implementing cover crops, since existing subsidies for traditional agricultural systems are so high that they often outcompete cover crop usage; many concluded that fertilizer savings were not enough to cover the costs of applying and terminating cover crops, stating that they would only continue this practice with continuous financial incentives (Roesch-McNally et al., 2017). Since farmers do not experience the full benefit that increased soil health offers to society, offsetting this disparity with additional incentives may be helpful to increase adoption in certain locations.

Research outside of Iowa corroborates the finding that local factors are important to practice adoption, underscoring the importance of further study to better understand optimal management strategies in diverse settings. For instance, farmers in North Carolina cited the subtropical climate of the U.S. Southeast as well as the longer growing season as important components of their decision to adopt and continue using cover crops (O'Connell et al., 2014). Areas with lower adoption, like California's San Joaquin Valley, often had local factors that reduced the efficacy of conservation practices instead of increasing it. Higher crop diversity, compatibility with existing irrigation systems, more stringent pest control regulations, and soil type differences were all significant barriers to conservation practice adoption in this region, yet they do not apply nearly as much to other agricultural production areas (Bossange et al., 2016). Furthermore, observability was found to be a critical concern in the San Joaquin Valley: many farmers surveyed noted that a single failed trial visible to other farmers could severely impact future practice adoption (Bossange et al., 2016). The presence of local assistance, both financial and logistical/educational, can greatly improve practice adoption in the U.S., making these programs a strong candidate for additional funding.

The diversity in local characteristics described above demonstrates the importance of a multifaceted policy approach to increasing adoption of conservation practices. In a review of 35 years of quantitative literature, Linda S. Prokopy and her colleagues conclude that there are "very few consistent determinants of practice adoption," with 76% of variables analyzed being statistically insignificant across geographies (2019). Despite this inconsistency, variables positively associated with practice adoption included positive farmer attitudes towards a given practice, information access, social networks, education, income, farm size, crop diversity, and number of livestock (Prokopy et al., 2019). While most of these variables are somewhat intuitive (e.g., larger farms with higher incomes are better able to trial practices and shoulder the associated risk), outlining even a small number of them conveys the large number of influences on conservation practice adoption.

Assessing the characteristics of only the conservation practices necessary to reduce N pollution, and not their adopters, risks ignoring the explicitly social influences on practice adoption and farmer decision making. The difficult financial situation faced by farmers contributes to numerous existing power imbalances that inhibit conservation practice adoption for renters and smallholder farmers as well as women and BIPOC farmers (USDA NASS, 2017; O'Connor, 2020). It also raises the stakes of competition between farmers, reducing incentives to share methods behind the successful implementation of conservation practices. In 2014, a majority (54%) of U.S. cropland was rented, highlighting the importance of considering the unique barriers renters face (Bigelow, Borchers, and Hubbs, 2016). The unstable and dynamic nature of renting has contributed to significant vulnerability on the part of renters, constraining them from investing heavily into conservation practices (Carolan, 2005). Factors contributing to a short-term, bottom-line farm management approach from renters include intense competition for cropland, which drives up rents and furthers consolidation, and the dominance of cash rent agreements instead of cost-sharing ones, which restricts communication and leads to increased turnover (Carolan, 2005). These variables add on to the plain conflict of interest present: farmers have little incentive to invest in soil health outcomes they are unlikely to experience, and landlords who receive rent payments regardless of the success of their tenants simply lose money if they provide financial support for conservation practice adoption.

Another conflict of interest comes in risk assessment, with banks driving farmers away from conservation practices without heeding their role in environmental degradation. In the words of one farmer, “checks from the government are nice,” and there is little incentive to rock the boat when using traditional corn-soybean rotations results in significant financial support (Carolan, 2005). Banks conform to this risk assessment paradigm, being much more likely to award leasing loans to farmers using corn-soybean rotations due to federal government support increasing the security that those farmers will repay their loans (Carolan, 2005; Zhang and Tidgren, 2018). Renters are therefore likely to persist in using corn-soybean rotations despite other factors to maximize their eligibility to receive loans and thus continue to make a living. This shift in bank loan awards is another example of the potential for agriculture financing programs to result in unintended consequences, underscoring the value of carefully crafted policy.

Another group facing unique barriers to conservation practice adoption is smallholder farmers. In the U.S. and around the world, this group faces heightened economic vulnerability and limited access to sustainable technologies. A group of leading scientists in conservation agriculture have outlined numerous obstacles for smallholder farmers in their “Nebraska Declaration on Conservation Agriculture” (CGIAR, 2013). They note that soil and ecosystem health benefits are usually only important to smallholder farmers “through their potential short-term effect on profits or reduced risk,” indicating the importance of research that can expand access to cost-effective technologies that meet farmers' short-term objectives while also improving soil health (CGIAR, 2013). Encouraging practice adoption in smallholder contexts could be bolstered by numerous actions, including giving higher weight to short-term returns and upfront costs in models, paying more attention to "the potential for sociocultural characteristics to affect exposure to innovations and their perceived relative advantage," and further considering farmers' access to information and the quality and/or presence of extension services in their area (Llewellyn and Brown, 2020). The increased heterogeneity of smallholder farmers necessitates a greater emphasis on the understanding of local factors, which are already crucial to implementing meaningful policy encouraging conservation agriculture.

These disparities are not the only reason to supplement voluntary agricultural policies with regulation and mandatory programs. Conservation practices like cover cropping and conservation tillage reflect the conclusions of research finding that "stringent environmental regulations or a credible threat of their adoption are necessary conditions for VEPs (voluntary environmental programs) to attract a large amount of business participation" (DeLeon and Rivera, 2010). The authors of a book on the subject, *Voluntary Environmental Programs,* write that "VEPs originally conceived and trumpeted as 'win-win' policy alternatives are actually—in the strictly voluntary form typical of the United States—seen to be serving the interest of dirty businesses to the exclusion of environmental protection interests" (DeLeon and Rivera, 2010). This finding applies strongly to agricultural contexts, in which the influence of corporate spending has governed policymaking for decades. VEPs, while theoretically having the potential to greatly improve environmental outcomes, are at best a first step towards goals that mandatory regulations are necessary to achieve (DeLeon and Rivera, 2010).

It is clear that paying special attention to the differences between various agricultural contexts is a critical component of promoting the adoption of cover cropping and nutrient management. Just examining the differences in agriculture between Iowa, California, Maryland, and Georgia has already revealed an incredible diversity of cropping practices and policies. By tailoring programs, whether financial or educational, towards individual populations of farmers, rapid progress can be made towards N emissions reduction from agriculture. Cost-share programs and other mechanisms to reduce financial burdens on farmers not only incentivize the adoption of multiple conservation practices, increasing efficacy, but also have the greatest impact in supporting vulnerable populations of farmers. These efforts can also begin the necessary process of deconstructing modern industrialized agriculture, most importantly the vast subsidies encouraging environmentally catastrophic monocultures, which will be necessary to solve the N pollution crisis.

Chapter V: Discussion and Conclusion

N fertilizer overuse is a serious global problem that affects many of the nine planetary boundaries humanity is at risk of transgressing (Steffen et al., 2015). Solving this problem, however, is an incredibly complicated task due to the centrality of N fertilizers to our food systems. One key finding from this study is that addressing N pollution in concert with the other impacts of N fertilizers, such as greenhouse gas emissions, will require a diverse set of policies at the local, state, and federal levels. For example, more than one-third of emissions associated with N fertilizers come from their production, highlighting the importance of increases in efficiency to reduce overall demand (Gao and Cabrera Serrenho, 2023). Yet in much of the United States, including California and the Midwest, even substantial increases in NUE will not solve pressing water quality issues (Tomich et al., 2016; Cassman and Doberman, 2021). Furthermore, reducing nitrous oxide emissions to levels compatible with the Paris Agreement goals necessitates transformative and abrupt change (IPCC, 2022; Tian et al., 2020). The 15th Conference of Parties summit on biodiversity, held in Montreal in December 2022, operated under a goal of halving nutrient loss to the environment by 2030 despite the present reality of increasing nutrient loss (Gao and Cabrera Serrenho, 2022; UNEP, 2022). Achieving this goal will require drastic change, advancing beyond incremental technological improvement and gradual practice adoption towards systemic shifts in agricultural operation. One study emphasized the “broader vision” necessary in farmland management, including closing leaky N cycles, aiming for cleaner fertilizer manufacturing, and taking care to address the “carbon-nitrogen nexus by a more holistic consideration” (Pan et al., 2022).

Addressing the formidable challenges posed by N pollution will also require system-wide change, taking forms in the long term that go beyond the policies mentioned in this paper. The conventional wisdom regarding nutrient management and fertilizer application is the 4R Nutrient Stewardship guidelines, which were developed by the fertilizer industry in response to growing nutrient overloading around the world (Johnston and Bruulsema, 2014). The idea of the 4Rs is to apply "the Right Source of nutrients, at the Right Rate, at the Right Time and in the Right Place" (Johnston and Bruulsema, 2014). While applying fertilizer optimally is certainly a key piece of the solution, such efforts in isolation will be woefully inadequate at addressing certain forms of nutrient runoff and at moving society towards the goal of halving nutrient loss by 2030. In this sense, it is no surprise that the fertilizer industry wishes to focus on application patterns, since these tame changes may obfuscate the systemic change that is necessary. As mentioned throughout this paper, encouraging "holistic" and simultaneous adoption of conversation practices maximizes their benefits and cost-effectiveness. But a true shift towards the ideal of regenerative agriculture would also mean an overhaul of corn-soybean dominance, drastic changes to or the obsoletion of concentrated animal feeding operations (CAFOs), flexible and adaptive land use policies, reductions in food waste and in N-intensive dietary choices, and the replacement of the vast majority of traditional N fertilizers with other N fixation methods. One study estimated that "strategic conversion" of less than 3% of cropland in the Upper Mississippi, Ohio, and Missouri River watersheds would "achieve a 45% reduction in nitrate losses and reduce extent of the hypoxia zone within regulatory targets" (McClellan et al., 2014). Seizing opportunities to convert vulnerable cropland away from intensive agricultural use, despite the economic concerns present, could be an important tool in mitigating N pollution.

The above example demonstrates that traditional economic assessments of policies are insufficient to evaluate pollution reduction efforts that address large externalities such as health impacts from N runoff. One study examining four policy scenarios—higher N prices, a fee for N leaching, a fee for a lacking N balance, and programs to increase voluntary reduction of N use by farmers—found that all of these policies were effective but led to an "exponential increase in economic costs" (Mandrini et al., 2022). This hyperbolic language does not square with the subsequent analysis, which revealed that reducing N leaching by 20% would cost $147 million per year but would yield $524 million per year in reduced healthcare costs from N-associated water pollution alone (Mandrini et al., 2022). Frontline communities are currently paying the true costs of N fertilizer overuse that are not being shouldered by agrichemical corporations or most farmers, representing a disincentive for agricultural interests to reevaluate dominant economic paradigms. Furthermore, prioritizing cost-effectiveness through market-based solutions with a low overall abatement potential will not be sufficient to halve nutrient loss to the environment by 2030. Catastrophic impacts on human health, biodiversity, climate change, and more from N pollution will persist and worsen if concerted action is not taken in this decade, a reality that ought to inspire real urgency (UNEP, 2022; IPCC, 2022; Houlton et al., 2019). Despite this threat, global human-induced nitrous oxide emissions, "which are dominated by nitrogen additions to croplands," rose 30% from 1980–2020 (Tian et al., 2020). This high growth even "exceeds some of the highest projected emission scenarios," making rapid N emissions reduction paramount to global stability (Tian et al., 2020).

While the need to reduce N emissions globally is not in doubt, the optimal ways to achieve this goal are seldom agreed upon. This paper's scope within the United States, and examining only four particular state contexts, means that its findings are not generalizable across the world or necessarily across the country. Much of the recent growth in N emissions has come from developing nations, which face unique challenges and diverse political climates and weather patterns, meaning that U.S.-centric recommendations will be insufficient to complete solvency. Future studies building upon the small existing body of literature addressing N abatement in developing nations and across the globe will be incredibly valuable in developing appropriate policies.

In addition, while this paper argues that traditional economic assessments of value are shortsighted and inadequate for optimally addressing N pollution, there are real and powerful financial constraints that affect federal and state governments as well as farmers across the country. The scientific community has much to gain from working with and learning from farmers as we seek to understand farm practice adoption and address key environmental challenges. Additional research that taps into the on-the-ground obstacles to N emissions reduction and evaluates potential support mechanisms to aid farmers in transitioning to less N-intensive management systems is critical to upholding equity and justice while transforming traditional agricultural practices.

Finally, treating the environment as a cohesive system requires consideration of the impacts of policies aimed at lessening N flows into the environment on other key elements like phosphorus and carbon, issues which this study was unable to address. Practices like no-till agriculture that may have a positive impact on carbon emissions can offset or even reverse this reduction of greenhouse gases through additional nitrous oxide release, demonstrating the complex nature of soil nutrient cycling (Kaye and Quemada, 2017). Furthermore, additional cover crop use in Vermont has been associated with a seven-fold increase in herbicide application as farmers resort to chemical termination of their cover crops, a practice with serious environmental implications (Dillon, 2021). The authors of the California Nitrogen Assessment are correct in their claim that “any successful strategy to reduce nitrogen emissions from agriculture must take a comprehensive approach to the most important forms of nitrogen leakage into the environment," including ammonia, nitrate, and nitrous oxide (Tomich et al., 2016). Future research exploring and characterizing these intricate chemical interactions will be invaluable to policymakers seeking to mitigate environmental degradation in all its forms.

Despite these limitations, this study's review of relevant laws and policies addressing N pollution across the country and in Iowa, California, Maryland, and Georgia has revealed several key directions future mitigation efforts must take to achieve sufficient emissions reductions. First, innovative legal approaches ought to be further explored to bolster federal and state governmental claims to regulatory authority and apply existing environmental laws to the problem of N pollution. Second, when aiming to increase the adoption of sustainable cropping practices like cover cropping and nutrient management, federal and state governments ought to practice targeted, context-specific outreach and aim to incentivize the adoption of multiple conservation management practices, maximizing financial and ecological benefits. Targeting outreach may need to involve scaled payments based on farm size, as current incentives are insufficient to raise adoption among small farmers, who stand to gain little from the time-consuming process of applying for federal and state funds. These voluntary programs cannot be the sole method of raising practice adoption, however, and they must be accompanied by strict regulation and monitoring. Finally, society must consider and begin to implement the fundamental transformations to current highly destructive agricultural systems that are integral to realizing long-term planetary flourishing, ensuring humanity reaches a future with food security, human health, and a stable climate.

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