# FERTILE GROUND: ACCELERATING THE GROWTH OF PRECISION FERTILIZING

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ABSTRACT

*Excessive fertilizer use on farms across America harms ecosystems, health, economies, and even agricultural production. Precision fertilizing technologies can greatly reduce fertilizer use without adversely impacting crop yields, but these innovations have not yet achieved widespread adoption in the United States. The slow deployment of precision fertilizing technologies is due in part to inadequate federal and state policy support. This Article examines the primary barriers to widespread adoption of precision fertilizing in the United States and identifies potential policy strategies capable of addressing those obstacles. Farmers' aversion to financial risk, limited internet connectivity in rural areas, and pervasive externality problems have heretofore prevented most farmers from*

*embracing precision fertilizing. Among other things, modifications to existing federal agricultural programs such as nutrient credit trading and Best Management Practices that account for and prioritize precision fertilizing could do much to accelerate the deployment and use of these powerful technologies.*

## I. Introduction

The brackish waters across much of today's Mississippi River Delta are unnaturally still, with many native species dead or driven away.[1] The only life now thriving in the river's dead zones is invasive algae that feeds on the river's excessive concentrations of nitrogen.[2] The Mississippi River Delta's dead zones already cover nearly 10,000 square miles and continue to grow each year.[3]

In dead zones like those afflicting the Mississippi River, high nutrient concentrations enable harmful algal blooms to proliferate and make it nearly impossible for most other life to survive.[4] These largely lifeless regions are increasingly pervasive throughout the United States and result primarily from fertilizer runoff that flows into the country's river basins.[5] Globally, 65% of applied nitrogen fertilizer is unabsorbed by crops and instead flows into water bodies, where it can upset the delicate balances that have supported a vibrant diversity of life in those environments for centuries.[6]

1. Shannon McDonagh, *Map Reveals Fish-Killing 'Dead Zone' Size of New Jersey in Gulf of Mexico*, NEWSWEEK (Aug. 9, 2024), https://www.newsweek.com/gulf-mexico-oxygen-mississippi-agriculture-marine-habitat-1934627 [https://perma.cc/MM6X-P979]; *Explaining the Gulf of Mexico Dead Zone*, RESTORE THE MISS. RIVER DELTA (Sept. 7, 2024, 5:28 PM), https://mississippiriverdelta.org/learning/explaining-the-gulf-of-mexico-dead-zone/ [https://perma.cc/T7U2-FBVY] (explaining that the overabundance of nutrients in the Mississippi River Delta causes marine life to move away into deeper waters).

2. Tatiana Schlossberg, *Fertilizers, a Boon to Agriculture, Pose Growing Threat to U.S. Waterways*, N.Y. TIMES (July 27, 2017), https://www.nytimes.com/2017/07/27/climate/nitrogen-fertilizers-climate-change-pollution-waterways-global-warming.html.

3. *Id.*

4. Allison Rees Armour-Garb, *Minimizing Human Impacts on the Global Nitrogen Cycle: Nitrogen Fertilizer and Policy in the United States*, 4 N.Y.U. ENV'T L.J. 339, 364–65 (1995).

5. David Biello, *Fertilizer Runoff Overwhelms Streams and Rivers—Creating Vast "Dead Zones,"* SCI. AM. (Mar. 14, 2008), https://www.scientificamerican.com/article/fertilizer-runoff-overwhelms-streams.

6. *See* Hannah Ritchie, *Excess Fertilizer Use: Which Countries Cause Environmental Damage by Overapplying Fertilizers*, OUR WORLD IN DATA (Sept. 7, 2021) [hereinafter *Excess Fertilizer Use*], https://ourworldindata.org/excess-fertilizer [https://perma.cc/6HFL-GH7K].

Excess fertilizer can have devastating consequences on ecosystems, biodiversity, human health, and economies.[7] Fertilizers have been linked to a plethora of adverse health conditions including cancer, respiratory illness, and worsened allergies.[8] Excess fertilizer runoff can also increase water treatment costs and degrade natural environments, eroding tourism revenues and inflicting other economic harms.[9] Of course, farmers who use more fertilizer than needed diminish their own profits as well.

Restoring healthy nutrient levels in America's natural water systems is a complex policy challenge because the phosphorous, nitrogen, and other nutrients in agricultural fertilizers are essential for crop growth and development.[10] Humankind has long relied on fertilizers containing these ingredients to sustain adequate levels of food production.[11] Historically, applying fertilizers in precise amounts and locations has been impracticable or even impossible, so out of necessity farmers have overapplied them to ensure sufficient yields.[12]

Fortunately, emerging technologies provide viable means of maintaining food production levels while greatly reducing excessive fertilizer use. Precision agriculture innovations collect and manage detailed data and analytics on agricultural conditions and modulate various activities to improve crop yields and decrease costs.[13] Precision fertilizing is a subcategory of precision agriculture focused specifically on optimizing fertilizer use in agricultural settings.[14] Precision

7. *Four Reasons Why the World Needs to Limit Nitrogen Pollution*, UNITED NATIONS ENV'T PROGRAMME (Jan. 16, 2023), https://www.unep.org/news-and-stories/story/four-reasons-why-world-needs-limit-nitrogen-pollution [https://perma.cc/S36C-QVVL].

8. Sofi Zeman, *Living in the 'Sacrifice Zone,'* THE PRICE OF PLENTY (Sept. 7, 2024, 4:34 PM), https://projects.wuft.org/priceofplenty/justice/living-in-the-sacrifice-zone-louisiana-residents-face-fertilizer-industry-in-their-communities/ [https://perma.cc/PK6E-4VL8].

9. *The Effects: Economy*, U.S. ENV'T PROT. AGENCY (May 9, 2024), https://www.epa.gov/nutrientpollution/effects-economy [https://perma.cc/V94Z-AUEX].

10. Hannah Ritchie, *Can We Reduce Fertilizer Use Without Sacrificing Food Production?*, OUR WORLD IN DATA (Sept. 9, 2021) [hereinafter *Can We Reduce Fertilizer Use?*], https://ourworldindata.org/reducing-fertilizer-use [https://perma.cc/2N3Q-5BWK].

11. *Id.*

12. Glenn Sheriff, *Efficient Waste? Why Farmers Over-Apply Nutrients and the Implications for Policy Design*, 27 REV. AGRIC. ECON. 542, 543 (2005).

13. *The Environmental Benefits of Precision Agriculture Quantified*, ASS'N OF EQUIP. MFRS. (Mar. 21, 2024), https://www.aem.org/news/the-environmental-benefits-of-precision-agriculture-quantified [https://perma.cc/4CVZ-ZCU9].

14. *Precision Agriculture*, INT'L FERTILIZER ASS'N (Sept. 10, 2024, 3:17 PM), https://www.fertilizer.org/science/innovation/precision-agriculture [https://perma.cc/THY2-8N7X].

fertilizing can enable farmers to increase yields, decrease labor costs, and reduce total fertilizer use and its attendant harms.[15]

Unfortunately, precision fertilizing has yet to achieve widespread adoption in the United States.[16] The costs and uncertainties associated with introducing new farming technologies such as precision fertilizing deters many farmers from investing in them.[17] Laws and policies designed to address such barriers are thus increasingly needed to help accelerate the deployment of precision fertilizing technologies on farms across America. This Article analyzes the challenges associated with driving the adoption of precision fertilizing technologies and proposes specific legal and policy strategies for addressing them. Policies that optimally encourage the adoption of precision fertilizing equipment and methods must account for the specific attributes of agricultural fertilizer use, including the elevated risk aversion of farmers, the externality problems that perpetuate fertilizer overuse, and existing models for agricultural policymaking. These considerations support the use of policies such as targeted loan guarantees, tax credits, and agricultural education programs to reduce the costs and risks associated with precision fertilizing techniques and increase their accessibility and appeal to farmers throughout the country.

Part II of this Article provides an overview of the United States agricultural industry, and the current state of fertilizer use in the United States. Part III describes the capabilities and benefits of precision fertilizing techniques and highlights how existing laws are inadequately promoting the adoption of these techniques today. Part IV creates a framework for addressing the lack of precision fertilizing by considering agriculture industry characteristics, existing legislation and regulation, and externality issues. Part V then outlines a suite of policies capable of accelerating the adoption of precision fertilizing technologies across the United States.

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15. *Id.*

16. *See* JONATHAN MCFADDEN ET AL., ECON RSCH. SERV., U.S. DEP'T OF AGRIC., PRECISION AGRICULTURE IN THE DIGITAL ERA: RECENT ADOPTION ON U.S. FARMS 8 (2023), https://www.ers.usda.gov/webdocs/publications/105894/eib-248.pdf?v=141.6 [https://perma.cc/4LEK-RTR6].

17. David Fiocco et al., *Agtech: Breaking Down the Farmer Adoption Dilemma*, MCKINSEY & CO. (Feb. 7, 2023), https://www.mckinsey.com/industries/agriculture/our-insights/agtech-breaking-down-the-farmer-adoption-dilemma [https://perma.cc/3DK8-EH5J].

## II. THE EVOLUTION OF SYNTHETIC FERTILIZER USE IN UNITED STATES AGRICULTURE

Fertilizer use has long played a crucial role in United States agriculture. From their early roots in the nineteenth century to their contemporary significance in modern farming practices, fertilizers have profoundly shaped agricultural productivity, sustainability, and environmental dynamics.[18] Unfortunately, in recent decades, fertilizer overuse and farmers' heavy reliance on synthetic nutrients in fertilizers have inflicted a growing and diverse array of environmental, health, and economic harms.[19]

### *A. The World's Increasing Reliance on Fertilizer*

Over the past half-century, farmers have increasingly relied on synthetic fertilizers to supply food for the planet's ever-growing population.[20] Chemical technologies, mechanical advancements, and the proliferation of electricity access after World War II largely shaped modern American agriculture.[21] These developments have ultimately enabled larger industrial organizations to dominate United States agriculture and have reduced the need for agricultural labor while feeding a growing population.[22] The United Nations estimates the Earth will have 9.7 billion people by 2050 and 10.4 billion people by 2100.[23]

Nitrogen and phosphorous fertilizers bolster crop growth, helping to sustain adequate global food production.[24] In 2008, for example, half of the world's

18. Carolyn Dimitri & Anne Effland, *From Farming to Food Systems: The Evolution of US Agricultural Production and Policy into the 21st Century*, 35 RENEWABLE AGRIC. & FOOD SYS. 391, 393 (2020).

19. *Excess Fertilizer Use*, *supra* note 6.

20. *Can We Reduce Fertilizer Use?*, *supra* note 10.

21. John Ikerd, *Farm and Food Policies for a Sustainable Future*, 6 BUS., ENTREPRENEURSHIP & TAX L. REV. 34, 37 (2022) (noting that technology from chemical warfare transitioned to the production of cheap nitrogen fertilizers and commercial pesticides, and that mechanical developments were used post-war to produce affordable tractors for agricultural use).

22. *See id.*

23. *Population*, UNITED NATIONS (Sept. 7, 2024, 4:14 PM), https://www.un.org/en/global-issues/population [https://perma.cc/UH2C-2S2S].

24. *Next Gen Fertilizer Challenges*, U.S. ENV'T PROT. AGENCY (Nov. 3, 2023), https://www.epa.gov/innovation/next-gen-fertilizer-challenges [https://perma.cc/L3Z6-XWFG].

population relied on nitrogen fertilizer-supported food supplies.[25] American farmers use nitrogen fertilizer at more than 40 times the rate farmers did in the 1950s.[26] That increase, though instrumental in helping farmers to feed a growing nation, has substantially outpaced the population growth of the country.[27] Without nitrogen fertilizers, average corn yields would decrease by as much as 40%.[28] In short, humankind has long relied heavily on fertilizers and would be unable to sustain current population levels without their continued use.

### *1. The Burgeoning Cost of Fertilizer for Farmers*

One unfavorable side effect of the United States food industry's growing dependence on synthetic fertilizers is added volatility in agricultural commodity prices. In 2021, 40% of every $10 Midwest farmers spent to grow corn was attributable to fertilizer costs.[29] Geopolitical instability and other factors have only amplified this price volatility risk. Most recently, fertilizer prices roughly doubled between 2020 and 2021 as the world waded through the COVID-19 pandemic.[30] Russia's invasion of Ukraine in 2022 further inflated fertilizer prices.[31]

The growing volatility and unpredictability of fertilizer prices has become a significant challenge for agricultural producers and rural economies. In 2022, many farmers opted to purchase less fertilizer due to the prices increasing.[32] By one calculation, farmers relying on anhydrous ammonia fertilizer would have had

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25. Jenessa Duncombe, *Index Suggests That Half of Nitrogen Applied to Crops Is Lost*, EOS (Aug. 23, 2021), https://eos.org/articles/index-suggests-that-half-of-nitrogen-applied-to-crops-is-lost [https://perma.cc/H2EQ-XD7B].

26. Joe Wertz, *Farming's Growing Problem*, THE CTR. FOR PUB. INTEGRITY (Jan. 22, 2020), https://publicintegrity.org/environment/unintended-consequences-farming-fertilizer-climate-health-water-nitrogen [https://perma.cc/NVQ7-GVQT].

27. *Id.*

28. *Understanding Fertilizer and Its Essential Role in High-Yielding Crops*, MOSAIC (Sept. 7, 2024, 4:57 PM), https://www.cropnutrition.com/resource-library/understanding-fertilizer-and-its-essential-role-in-high-yielding-crops [https://perma.cc/6GZ7-6KNQ].

29. Mónica Cordero, *Farmers Endured a Rough Year, but Fertilizer Companies Cashed In*, WIS. WATCH (Dec. 28, 2022), https://wisconsinwatch.org/2022/12/farmers-endured-a-rough-year-but-fertilizer-companies-cashed-in [https://perma.cc/ANM7-8DM7].

30. *How Precision Agriculture Can Solve the Problem of High Fertilizer Prices*, AGREMO (Apr. 29, 2022), https://www.agremo.com/how-precision-agriculture-can-solve-the-problem-of-high-fertilizer-prices/ [https://perma.cc/7THC-4BP8].

31. Jennifer Kee et al., *Global Fertilizer Market Challenged by Russia's Invasion of Ukraine*, ECON. RSCH. SERV., U.S. DEP'T OF AGRIC.: AMBER WAVES (Sept. 18, 2023), https://www.ers.usda.gov/amber-waves/2023/september/global-fertilizer-market-challenged-by-russia-s-invasion-of-ukraine [https://perma.cc/XA3N-FFFE].

32. Cordero, *supra* note 29.

to triple their fertilizer budgets to account for market price increases.[33] Another study estimated that feed grain farms would face average cost increases of $128,000 each in 2022 due to higher fertilizer expenses.[34] Farms' heavy dependence on fertilizer products magnifies the severity of these volatile market challenges.[35]

*2. Windfalls for Fertilizer Producers in an Increasingly Anticompetitive Market*

Although fertilizer price volatility has been devastating for farmers, it has been a boom for some fertilizer manufacturers.[36] Prices for many fertilizer products have increased at rates far greater than that of inflation.[37] Many fertilizer manufacturers have increased their profitability despite selling less fertilizer in recent years.[38] One leading potash fertilizer producer saw a profit increase of 1,575% between 2020 and 2022.[39] The United States' leading potash and phosphate fertilizer producer experienced a 438% increase in net earnings over that period.[40]

Such exorbitant profits are due in part to the ever-increasing market concentration of the American fertilizer industry.[41] Just three companies control 80% of the United States' phosphoric acid production capacity and only two companies control all domestic potash production.[42] Four companies supplied 75% of the United States' nitrogen fertilizer as of 2019.[43] Since the 1980s, mergers have

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33. *Id.*

34. JOE L. OUTLAW ET AL., AGRIC. & FOOD POL'Y CTR., TEX. A&M UNIV., ECONOMIC IMPACT OF HIGHER FERTILIZER PRICES ON AFPC'S REPRESENTATIVE CROP FARMS 8–9 (2022), https://afpc.tamu.edu/research/publications/files/711/BP-22-01-Fertilizer.pdf [https://perma.cc/UZ9E-DX24].

35. Cordero, *supra* note 29.

36. *Id.*

37. *Id.*

38. *Id.*

39. Noah Zahn, *The Price of Plenty: Fertilizer Companies Cash in While Farmers Struggle*, WUSF (June 8, 2023), https://www.wusf.org/environment/2023-06-08/the-price-of-plenty-fertilizer-companies-cash-in-farmers-struggle [https://perma.cc/R3W8-5FKG].

40. *Id*.

41. *See* Exec. Order No. 14036, 86 Fed. Reg. 36987, 36987 (July 14, 2021).

42. WEN-YUAN HUANG, ECON RSCH. SERV., U.S. DEP'T OF AGRIC., FACTORS CONTRIBUTING TO THE RECENT INCREASE IN U.S. FERTILIZER PRICES, 2002-08, at 10 (2009), https://ers.usda.gov/sites/default/files/_laserfiche/outlooks/35824/10935_ar33.pdf?v=66022 [https://perma.cc/D2NN-RVC7].

43. Anton Bekkerman et al., *The History, Consolidation, and Future of the U.S. Nitrogen Fertilizer Production Industry*, CHOICES, Jul. 8, 2020, at 1, 1.

consolidated the industry from roughly 46 American firms to just 13 by 2008.[44] Noting concerns about overconcentration within the fertilizer industry, President Biden issued Executive Order 14036 in July of 2021 aimed at addressing the problem.[45] The Order explained that "[f]armers are squeezed between concentrated market power in the agricultural input industries" and as a result "farmers' share of the value of their agricultural products has decreased."[46] Although the Order is a positive first step, much more action will be needed to prevent fertilizer markets from having such outsized impacts on United States agriculture.

*3. The Agricultural Industry's Excessive Use of Fertilizer*

Perhaps the most troubling aspect of agriculture's relationship with fertilizers is that farmers often use far too much of them. Nitrogen Use Efficiency (NUE) is a measure of the amount of nitrogen applied to a crop that is absorbed by the plants.[47] An NUE of 60% means only 60% of applied nitrogen fertilizer is taken up by the plant, while the remaining 40% of applied fertilizer ends up elsewhere.[48] One index estimates an NUE of just 50% for the United States, suggesting that roughly half of all nitrogen applied to crops in the country is lost.[49] Although other studies have given NUE estimates of up to 66%, even at that level American farms are losing nearly 30% of the nitrogen they apply.[50]

Unable with their current equipment and methods to apply fertilizers more precisely, most farmers understandably tend to err on the side of overapplying fertilizers to ensure adequate crop yields.[51] A common practice among farmers is to apply fertilizers uniformly, even though soil conditions and the corresponding need for fertilizer varies substantially across a field.[52] According to one study, farmers fail to apply the right amount of fertilizer about 90% of the time.[53]

44. *Id.* at 2.

45. Exec. Order No. 14036, 86 Fed. Reg. at 36987.

46. *Id*.

47. *Can We Reduce Fertilizer Use?*, *supra* note 10.

48. *Id*.

49. Duncombe, *supra* note 25.

50. *Can We Reduce Fertilizer Use?*, *supra* note 10.

51. *See id*.

52. Peter C. Scharf et al., *Sensor-Based Nitrogen Applications Out-Performed Producer-Chosen Rates for Corn in On-Farm Demonstrations*, 103 AGRONOMY J. 1683, 1683 (2011).

53. DJ McCauley, *Cover Crops, Sensors, and Food Security*, EOS (Jan. 25, 2021), https://eos.org/articles/cover-crops-sensors-and-food-security [https://perma.cc/G7ZT-K94T]; *see also* Elizabeth R. Schwab et al., *Assessing the Accuracy of Farmers' Nutrient Loss Risk Perceptions*, 68 ENV'T MGMT. 539, 541 (2021) (noting a study with particularly "low

Inaccurate information about optimal fertilization amounts and general uncertainty about weather or other farm conditions can further contribute to these over application practices.[54]

### *B. The Consequences of Overfertilizing*

Heavy use of fertilizer products has delivered significant benefits to global and domestic food production, but these production gains have come at a hefty cost. Millions of tons of fertilizer run off farmland and into nearby watersheds each year, wasting billions of dollars, driving up food production costs, and harming ecosystems, public health, and the United States' economy.[55]

#### *1. Environmental Harms*

The environmental damage caused by runoff of excess fertilizer is severe and multifaceted.[56] Cumulative nutrient buildup and climate change are increasingly magnifying these harms.

##### i. Algal Blooms and Dead Zones

One prominent form of environmental damage attributable to fertilizer overuse is the proliferation of dead zones and toxic algal blooms throughout the waters of the United States.[57] Eutrophication is a process by which the growth of plant life is promoted due to the accumulation of nutrient resources in bodies of water.[58] When nutrients for plant development reach abnormally high levels, certain plant species like algae begin to dominate ecosystems, outcompete other life forms, and disrupt ecological balances in a natural environment.[59]

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accuracy in farmer estimates of nitrogen and phosphorus" where accurate estimation was as low as 12% for nitrogen levels and 13% for phosphorus).

54. *See* Sheriff, *supra* note 12, at 543.

55. *See* Ashanti Johnson & Melanie Harrison, *The Increasing Problem of Nutrient Runoff on the Coast*, AM. SCIENTIST (Mar.–Apr. 2015), https://www.americanscientist.org/article/the-increasing-problem-of-nutrient-runoff-on-the-coast [https://perma.cc/2PRV-LSRM].

56. *See* Mary Beth Blauser, *Solving the Puzzle of Nutrient Overload Piece by Piece*, 1 CHI. KENT J. ENV'T & ENERGY L. 48, 48–49 (2010).

57. *The Effects: Dead Zones and Harmful Algae Blooms*, U.S. ENV'T PROT. AGENCY (Jan. 3, 2024), https://www.epa.gov/nutrientpollution/effects-dead-zones-and-harmful-algal-blooms [https://perma.cc/DK6T-HJ2B].

58. Blauser, *supra* note 56, at 58.

59. *Id.* at 58–60.

Overuse of certain kinds of fertilizers substantially contributes to eutrophication in water ecosystems across the United States.[60] Fertilizers often contain nitrogen and phosphorous, which are key nutrients for plant life.[61] When excess fertilizer runs off into nearby water bodies, it introduces additional nitrogen and phosphorous to their ecosystems.[62] While certain types of aquatic plant life, including algae, flourish in these artificially nutrient-rich waters, other life forms often suffer.[63] Eutrophication in coastal areas, for example, decreases the availability of oxygen, killing off fish and shellfish.[64]

Harmful algal blooms are among the most destructive products of eutrophication.[65] The rapid proliferation of algae releases toxins that can be lethal to aquatic wildlife, birds, and even humans.[66] Even when algae do not produce toxins, their overabundance in ecosystems can still choke out other life forms,[67] altering local soil biota and killing plants.[68] Because of these harmful effects, fertilizers are among the most substantial threats to biodiversity.[69]

60. *Id.* at 57–58.

61. Sally Reill, *A Guide to Understanding Fertilizers*, OR. ST. UNIV. EXTENSION SERV. (Jan. 2019), https://extension.oregonstate.edu/gardening/techniques/guide-understanding-fertilizers [https://perma.cc/3MAH-FNKK].

62. Blauser, *supra* note 56, at 63.

63. *Id.* at 58.

64. Peter M. Vitousek et al., *Human Alteration of the Global Nitrogen Cycle: Sources and Consequences*, 7 ISSUES ECOLOGY 737, 744 (1997).

65. *What is Eutrophication?*, NAT'L OCEAN SERV., NAT'L OCEANIC & ATMOSPHERIC ADMIN. (June 16, 2024), https://oceanservice.noaa.gov/facts/eutrophication.html [https://perma.cc/3934-9FJT].

66. *What is a Harmful Algal Bloom?*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. (Apr. 27, 2016), https://www.noaa.gov/what-is-harmful-algal-bloom [https://perma.cc/A7E7-NTFZ].

67. *Id.*

68. Simon Attwood, *Nutrient Management and Biodiversity*, INT'L FERTILIZER ASSOC. (Oct. 11, 2021), https://www.fertilizer.org/news/nutrient-management-and-biodiversity [https://perma.cc/9JV5-RWF6].

69. Paul Sutherland, *Too Much of a Good Thing: Fertilizer 'One of the Three Major Drivers of Biodiversity Loss This Century,'* MONGABAY (July 14, 2014), https://news.mongabay.com/2014/07/too-much-of-a-good-thing-fertilizer-one-of-the-three-major-drivers-of-biodiversity-loss-this-century/ [https://perma.cc/NY2S-ZDRC] (reporting that fertilizer use is "projected to be one of the three major drivers of biodiversity loss this century").

ii. Climate Change Contributions

Excessive fertilizer use is also a significant contributor to climate change.[70] Both the production of fertilizer and its ultimate breakdown release substantial amounts of greenhouse gases.[71] The production of ammonia, one of the most common ingredients in fertilizers and the second-most produced chemical in the world, requires vast energy inputs.[72] The chemical's production accounts for up to 2% of worldwide carbon dioxide emissions.[73] The eventual decomposition of fertilizer likewise results in greenhouse gas emissions.[74] For example, one product of the breakdown of nitrogen fertilizer is nitrous oxide—a potent greenhouse gas.[75] A single molecule of nitrous oxide warms the planet about 300 times as much as a molecule of carbon dioxide.[76] In total, the use of nitrogen-based fertilizers accounts for roughly 6% of global radiative forcing.[77]

The climate effects of fertilizer overuse may additionally create a global warming feedback loop. Increasing global temperatures are correlated with increasing rainfall in certain United States regions, which are projected to increase nitrogen runoff by up to 20% by the end of the century.[78] That increased fertilizer runoff then further contributes to climate change by breaking down into even more nitrous oxide.[79] Such feedback effects are just one example of how fertilizer overuse can exacerbate existing environmental conditions in new and complex ways.[80]

70. *See* Benjamin Z. Houlton et al., *A World of Cobenefits: Solving the Global Nitrogen Challenge*, 7 EARTH'S FUTURE 853, 865 (2019); Karthish Manthiram & Elizabeth Gribkoff, *Fertilizer and Climate Change*, CLIMATE PORTAL, MASS. INST. OF TECH. (July 15, 2021), https://climate.mit.edu/explainers/fertilizer-and-climate-change [https://perma.cc/YQF7-THA7]; Schlossberg, *supra* note 2.

71. Manthiram & Gribkoff, *supra* note 70.

72. *Id.*

73. *Id.*

74. *Id*.

75. Annise Maguire, *Shifting the Paradigm: Broadening Our Understanding of Agriculture and Its Impact on Climate Change*, 33 ENVIRONS 275, 289 (2010).

76. *Four Reasons Why the World Needs to Limit Nitrogen Pollution*, *supra* note 7.

77. Houlton et al., *supra* note 70.

78. Schlossberg, *supra* note 2.

79. *Agricultural Runoff Contributes to Climate Change*, U.S. NAT'L SCI. FOUND. (Nov. 8, 2021), https://new.nsf.gov/news/agricultural-runoff-contributes-climate-change [https://perma.cc/5VCD-KWNU].

80. *See generally id.*

### *2. Human Health Hazards*

Although fertilizer use has significantly improved nutrition across the globe, synthetic fertilizers also threaten human health.[81] Industry stakeholders and policymakers seldom consider societal costs associated with these fertilizer-related health risks.[82]

Numerous health hazards are traceable to excessive fertilizer use.[83] For instance, nitrate contamination is associated with a variety of severe health conditions, including reproductive disorders and various cancers.[84] Elevated nitrogen levels also can cause some pollen-producing plants to become more productive, thereby increasing the frequency and severity of seasonal allergies, hay fever, asthma and other allergen-related conditions.[85] Excessive levels of nitrogen in surface water have also been linked to higher quantities of malarial mosquito larvae.[86] One study connected 4,300 deaths from particulate pollution to increased ammonia emissions from fertilizer use.[87] Only reductions in total fertilizer use are likely to mitigate most of these health risks.

### *3. Economic Losses*

Excessive fertilizing's harms to natural water systems impose massive economic costs on governments and private enterprises each year as well.[88] Water treatment plants, river or lake-related tourism activities, and even real estate values near bodies of water can suffer adverse effects from excessive fertilizing.[89] Unfortunately, the farmers engaged in excessive fertilizing rarely bear most of these broader social costs.[90]

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81. Alan R. Townsend et al., *Human Health Effects of a Changing Global Nitrogen Cycle*, 1 FRONTIERS ECOLOGY & ENV'T 240, 244 (2003).

82. *Id.* at 242.

83. *Id.*

84. *Id.*

85. *Id*.

86. *Id.* at 243.

87. Wertz, *supra* note 26.

88. *See* Jodi Helmer, *Toledo's Blooming Algae Crisis*, NAT. RES. DEF. COUNCIL (Apr. 2, 2020), https://www.nrdc.org/stories/toledos-blooming-algae-crisis [https://perma.cc/NKY6-M8YJ] (detailing a 2014 toxic algae outbreak in Toledo, Ohio that impacted Lake Erie's tourism industry worth $13 billion).

89. *See id.*

90. Benjamin Bryce & Robert Skousen, *Bloomin' Disaster: Externalities, Commons Tragedies, and the Algal Bloom Problem*, 21 U. DENV. WATER L. REV. 11, 27 (2017).

i. Water Treatment Costs

Excessive nutrient levels in lakes and rivers across the United States, partly attributable to fertilizer overuse, can significantly increase water treatment costs.[91] For example, the Ohio state government expended over $13 million over two years to treat drinking water from a lake affected by a harmful algal bloom.[92] Ultimately, most of the additional water treatment costs resulting from fertilizer overuse are passed on to state and local taxpayers.[93] Removing excess nitrogen and phosphorous from drinking water is an expensive process, but failing to do so is often costly as well.[94] One Florida study traced increased emergency room visit costs in one county to worsened respiratory illnesses resulting from harmful algal blooms.[95]

ii. Harms to Tourism and Fishing Industries

Fertilizer overuse and its attendant harms can also impact local fishing and tourism industries. By one estimate, nitrogen pollution from upstream farms causes as much as $2.4 billion in damages each year to fisheries and marine habitats in the Gulf of Mexico.[96] Algal blooms have materially disrupted multiple American commercial fisheries in recent years, reducing yields, increasing risks of shellfish poisoning, and even temporarily suspending some operations.[97] One algal bloom in Maine required the closure of shellfish beds, leading to losses of $2.5 million in soft shell clam harvests and almost $500,000 in mussel harvests.[98]

Algal blooms can devastate local water-based tourism as well by making lakes or rivers unsafe for water sports, recreational fishing, or other water-related

91. *See* OFFICE OF WATER, U.S. ENV'T PROT. AGENCY, A COMPILATION OF COST DATA ASSOCIATED WITH THE IMPACTS AND CONTROL OF NUTRIENT POLLUTION, at III-10 (2015) [hereinafter A COMPILATION OF COST DATA], https://www.epa.gov/sites/default/files/2015-04/documents/nutrient-economics-report-2015.pdf [https://perma.cc/8FD2-R9NS] (reporting on costs associated with nutrient pollution including economic losses, drinking water treatment, and restoration costs across numerous American municipalities).

92. *Id.*

93. *See generally id.*

94. *See generally id.*

95. Porter Hoagland et al., *The Costs of Respiratory Illnesses Arising from Florida Gulf Coast Karenia Brevis Blooms*, 117 ENV'T HEALTH PERSP. 1239, 1243 (2009).

96. *What's the Problem with Fossil Fuel-Based Fertilizer?*, UNION OF CONCERNED SCIENTISTS (Dec. 5, 2023), https://www.ucsusa.org/resources/whats-wrong-fossil-fuel-based-fertilizer [https://perma.cc/Q43V-C9CK].

97. *See* A COMPILATION OF COST DATA, *supra* note 91, at III-2 to III-5.

98. *Id.* at III-4 (describing economic losses for 2012).

activities.[99] An algal bloom in one Ohio lake led to $47 million in local tourism revenue losses over two years.[100]

iii. Property Value Reductions

Overuse of agricultural fertilizers can even erode real property values in areas that depend on healthy lakes and rivers.[101] Heightened concentrations of pollutants in water have been correlated with decreased values for waterfront properties and nearby homes.[102] For instance, a study found that a one-meter difference in water clarity is associated with residential property value changes up to $61,000 in New England.[103] For waterfront land in Minnesota, the property value difference is as high as $85,000.[104]

### *4. Agricultural Harms*

In some instances, fertilizer overuse imposes additional costs and harms on the offending farm itself. For example, high nitrogen levels in soil often lead to significant increases in local pest populations.[105] Many crop pathogens also cause more damage to plants when the availability of nitrogen is high.[106] Similarly, algal blooms can disrupt commercial fisheries and shellfish operations.[107] American farmers' heavy reliance on fertilizers may even be contributing to decreased agricultural diversity.[108]

99. *See generally* Andrew Bechard, *Harmful Algal Blooms and Tourism: The Economic Impact to Counties in Southwest Florida*, 50 REV. REG'L STUD. 170, 171 (2020) (comparing data across tourism areas including lodging and restaurant sectors).

100. *See* A COMPILATION OF COST DATA, *supra* note 91, at III-2.

101. *Id*. at III-6.

102. *Id.*

103. *Id.* at ES-2.

104. *Id.*

105. *Nitrogen Excess*, STATEWIDE INTEGRATED PEST MGMT. PROGRAM, UNIV. OF CAL. AGRIC. & NAT. RES. (Sept. 7, 2024, 3:50 PM), https://ipm.ucanr.edu/pmg/garden/plants/disorders/nitrogenexcess.html [https://perma.cc/NDU2-4FWP].

106. *See id*.

107. *Effects of Harmful Algal Blooms on West Coast Fishing Communities*, NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES (Sept. 25, 2024), https://www.fisheries.noaa.gov/west-coast/science-data/effects-harmful-algal-blooms-west-coast-fishing-communities [https://perma.cc/VE8R-SFPD].

108. *See* Armour-Garb, *supra* note 4, at 343–44.

### *C. The Complexities of Addressing Overfertilization*

As harmful as fertilizer overuse can be, some fertilizer use is necessary to meet global food demand and sustain humankind. Calls to reduce fertilizer use thus raise complex questions about how to strike a more optimal balance that allows fertilizers to serve their crucial purposes while minimizing their widespread harms.[109] Substantial policy changes will likely be needed to adequately curb fertilizer overuse across the country. Promising new technologies are emerging that could enable farmers to substantially reduce fertilizer use without significantly affecting food production, but these technologies will have an impact only to the extent that legal and policy structures motivate farmers to deploy them.

## III. UNDERSTANDING PRECISION FERTILIZING AND ITS POTENTIAL

Precision fertilizing technologies can enable farmers to enjoy the benefits of fertilizer use while mitigating its harms, but various barriers have prevented widespread precision fertilizing activity in the United States.

### *A. Examples of Precision Fertilizing*

A diverse and growing array of modern precision fertilizing technologies can greatly enhance the efficiency of fertilizer use in agricultural settings. The global positioning system (GPS) is among the most beneficial tools used in precision fertilizing techniques, however it is not widely adopted.[110] GPS-based precision agriculture systems include both manual control and automated guidance technologies, which can allow for more precise application of fertilizers based on highly localized data.[111]

Yield monitoring technologies coordinate multiple measurement systems to generate readily implementable information for current and future crops, such as determining where inputs such as fertilizer are needed most.[112] Using wirelessly-connected sensors and other devices, yield monitoring systems gather and synthesize location-specific data about moisture content, grain flow, and other

109. *See Can We Reduce Fertilizer Use?*, *supra* note 10.

110. *See, e.g.*, Dimitri & Effland, *supra* note 18, at 395 (stating that in 2010, "GPS guidance systems were used in about half of planted acres for crops such as corn, rice and peanuts"); MCFADDEN ET AL., *supra* note 16, at 8 (stating that in 2013 and 2019, about 12% of United States farms used GPS for agricultural activities).

111. *See* MCFADDEN ET AL., *supra* note 16, at 44.

112. *See Yield Monitoring in Precision Agriculture: Importance and Basic Components*, GEOPARD AGRIC. (June 16, 2022), https://geopard.tech/blog/yield-monitoring-in-precision-agriculture-importance-and-basic-components/ [https://perma.cc/AJU4-LFJT].

factors to enable farmers to better monitor crop growth.[113] Among other things, these systems can help farmers avoid over and under-fertilizing.[114] Variable rate technologies (VRTs) precisely manage the release of fertilizers and other chemical inputs in agricultural settings.[115] VRTs reduce fertilizer run-off by accounting for varying soil and topographical conditions to help farmers apply more optimal amounts.[116]

Other types of precision fertilizing technologies include digital imagery, satellite imagery, automated section control, coverage maps, controlled traffic farming, and telematics.[117] Precision fertilizing technologies can work together in varying combinations based on factors such as a farm's budget, climate conditions, topography, and crop selection.[118]

### *B. An Array of Possibilities for Farmers*

Today's growing variety of precision fertilizing technologies presents valuable opportunities for farmers.[119] Precision fertilizing technologies can serve beneficial functions at any scale, from small family farms to massive agricultural operators.[120] Some small family farms could see significant cost savings from installing a few sensors in key locations across its fields to measure fertilizer concentrations.[121] At the same time, some industrial farms with more financial resources might find it worthwhile to install sophisticated and highly-connected

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113. *See id.*

114. *See id.*

115. *See Variable Rate Technology Adoption Is on the Rise*, ECON. RSCH. SERV., U.S. DEP'T OF AGRIC. (Aug. 15, 2023), https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=107116 [https://perma.cc/2GLS-YM4C].

116. *See id.*

117. *See* MCFADDEN ET AL., *supra* note 16, at 45–46 (defining drones, aircraft, or satellite imagery as "a form of remotely-sensed data collected from satellite, crewed aircraft, and small unmanned aerial vehicles"; defining automated section control as technology that "is associated with liquid sprayers and planters"; defining coverage maps sharing technology as "allow[ing] two or more machines to share data regarding where applications have already been made"; defining controlled traffic farming as "a practice that limits the soil surface of the field from experiencing wheel tire or track traffic"; defining telematics as "the wireless transfer of data between farm equipment, connected devices, and/or the cloud").

118. *Id.* at 18.

119. Tamás Mizik, *How Can Precision Farming Work on a Small Scale? A Systematic Literature Review*, 24 PRECISION AGRIC. 384, 390 (2022).

120. *Id.* at 396 (suggesting that even low-cost sensors "not suitable for high precision" can still be used by small or low-income farms to increase crop outputs).

121. *Id.* at 398 (suggesting that a modular introduction to precision technology is a way for small farms to achieve higher revenues).

precision fertilizing infrastructure to help optimize their nutrient efficiency.[122] In these latter contexts, continuous data collection and analysis can even inform long-term decision-making to increase crop performance.[123] Such analysis may even become more accurate and effective as unique data for each acre of farmland accumulates over time.[124]

Smaller farms in close proximity may be able to pool resources and share precision fertilizing systems and data in ways that reduce the financial barriers associated with adopting these technologies.[125] Chemicals and fertilizers often do not go where they are intended, especially in extreme weather.[126] One current innovator is H2gr0, LLC, a start-up company that has patented technology to optimize the use of fertilizers and chemicals across multiple farms by utilizing cloud-based social networking software that enables farmers within the region to report and track chemical distribution using existing and low-cost precision tools.[127] While a single small farm may have a small environmental footprint, it is the aggregate overuse of chemicals and fertilizers from individual farms within a geographic region that leads to problems such as eutrophication in the Gulf of Mexico.[128] Sensors and a closed-loop control system formed by H2gr0's cloud-based software communicate with devices to report on who is dispersing chemicals where and in what quantity based on weather conditions.[129] The cloud-based software then reports this tracked chemical and fertilizer information to impacted

122. *Id*. at 385–86.

123. *See id.* at 391.

124. *Id.*

125. *Id.* at 402.

126. *See* Anna Gloria Billé & Marco Rogna, *The Effect of Weather Conditions on Fertilizer Applications: A Spatial Dynamic Panel Data Analysis*, J. ROYAL STAT. SOC'Y SERIES A, Sept. 2021, at 1, 3 (reviewing how climatic variations such as rainfall disrupt the spatial application of nitrogen variation).

127. *See* H2GR0 (Sept. 4, 2024, 5:30 PM), https://www.h2gr0.com/ [https://perma.cc/5YMV-T8KC].

128. *See* Schlossberg, *supra* note 2.

129. *See* U.S. Patent No. 11,284,562 (filed Jul. 9, 2020); U.S. Patent No. 11,406,056 (filed Oct. 28, 2019); U.S. Patent No. 11,570,946 (filed Jul. 5, 2020) (all three patents list Tyson Winarski, Swati Kumari, and Joel Dominguez as joint inventors). These three individuals are also listed as officers of H2GR0, LLC with the Arizona Corporation Commission. *H2GRO LLC*, THE ARIZ. CORP. COMM'N (Sept. 19, 2024, 3:58 PM), https://ecorp.azcc.gov/BusinessSearch/BusinessInfo?entityNumber=23017786 [https://perma.cc/4ZP6-CEDS]. Lidar, or Light Detection and Ranging, is an example of another commonly used sensor, which "is a remote sensing method used to examine the surface of the Earth." *What Is Lidar?*, NAT'L OCEAN SERV., NAT'L OCEANIC & ATMOSPHERIC ADMIN. (June 16, 2024), https://oceanservice.noaa.gov/facts/lidar.html [https://perma.cc/4VXC-N5HV].

farms, allowing them to more efficiently and accurately manage future distribution of chemicals and fertilizers.[130]

Widespread adoption of precision fertilizing will lead to advancements from manufacturers as well as producers. For example, H2gr0 has the potential to further reduce overuse of chemicals and fertilizers by providing a new business model for fertilizer companies called Fertilizer Monitoring as a Service (FMaaS).[131] Traditionally, fertilizer companies make more profits through selling more fertilizer.[132] Using a system like H2gr0, fertilizer companies can sell just the right amount of fertilizer, but no more, and additionally profit from subscriptions to fertilizer monitoring services to track the distribution of chemicals.[133] The FMaaS business model creates a profit incentive for fertilizer companies to encourage wide accessibility for precision fertilizing technology.[134] Precision fertilizing has the potential to benefit many agriculture stakeholders, not just farmers. The wide-ranging possibilities provide necessary options for all parties.

### *C. The Benefits of Precision Fertilizing*

Precision fertilizing technologies can increase a farm's profitability and simultaneously benefit the natural environment by increasing crop yields while decreasing fertilizer and labor costs.[135] In one study, sensor-based application of fertilizer achieved an 8% reduction in fertilizer use without decreasing crop yields, as compared to traditional methods.[136] Notably, that reduction resulted in a 24 to 26% decrease in surplus nitrogen, thus preventing roughly a quarter of excess nitrogen from entering the environment.[137] VRTs have likewise been shown to increase the operating profits of farms by about 1.1% on average by helping crops receive the optimal amount of fertilizer.[138] Another study found that precision fertilizing technologies are already capable of increasing fertilizer placement

130. H2GR0, *supra* note 127.

131. *See id*.

132. *Id.*; *see* Cordero, *supra* note 29 (detailing how in 2022 the fertilizer industry yielded record profits).

133. H2GR0, *supra* note 127.

134. *Id.*

135. Geoffrey Ling & Blake Bextine, *Precision Farming Increases Crop Yields*, SCI. AM. (June 26, 2017), https://www.scientificamerican.com/article/precision-farming; *see also* MCFADDEN ET AL., *supra* note 16, at 30 (finding crop yields to be generally higher for adopters of precision agriculture technology than for nonadopters across almost all types of technologies and crops).

136. Scharf et al., *supra* note 52, at 1690.

137. *Id.*

138. MCFADDEN ET AL., *supra* note 16, at 18.

efficiency by 7% and could potentially provide another 14% improvement as the technologies evolve.[139]

Precision fertilizing can also replace costly human labor with robotics so that less manpower is required to achieve equal or higher outputs.[140] One group of researchers found that "total labor hours per bushel of corn for adopters of yield and georeferenced soil maps were 35[%] lower" than those of nonadopters.[141] The study also found that "labor hours per bushel were 28[%] lower for VRT adopters" than nonadopters.[142] Such labor savings can naturally translate into significant cost savings for farmers as well.

Over the long term, precision fertilizing technologies could facilitate the accumulation of valuable farm operation data.[143] Although the primary use of this data is to inform immediate adjustments and corrections to fertilizer application, it may ultimately provide valuable insights for farmers on ways to better streamline their practices.[144] For example, precision fertilizing technologies could help farmers gather more general information about inputs, outputs, cost margins, and operating risks that could aid farmers' longer-term planning.[145] In short, precision fertilizing can provide impactful benefits to farmers at multiple stages of their operations.

### *D. Barriers to Adoption of Precision Fertilizing*

Despite their potential benefits, precision fertilizing technologies have yet to achieve widespread adoption in the United States.[146] As of 2019, only 12% of American farms used GPS-based applications for agricultural activities.[147] As of 2020, less than half of Unites States' farmers had adopted VRTs.[148] Most farmers continue to operate without these valuable tools and to overuse fertilizer products

139. *The Environmental Benefits of Precision Agriculture Quantified*, *supra* note 13.

140. Dimitri & Effland, *supra* note 18, at 396.

141. MCFADDEN ET AL., *supra* note 16, at 28.

142. *Id.*

143. Mike Boehlje, *The Value of Data/Information and the Payoff of Precision Farming*, PURDUE UNIV. (Feb. 22, 2021), https://ag.purdue.edu/commercialag/home/resource/2021/02/the-value-of-data-information-and-the-payoff-of-precision-farming [https://perma.cc/ZHB3-MGZC].

144. *Id.*

145. *Id.*

146. Terry Wayne Griffin & LaVona Traywick, *The Role of Variable Rate Technology in Fertilizer Usage*, J. APPLIED FARM ECON., Fall 2020, at 59, 60.

147. MCFADDEN ET AL., *supra* note 16, at 8.

148. Griffin & Traywick, *supra* note 146, at 59–60.

on their farms, and there is little hope that their reluctance to embrace precision fertilizing will diminish anytime soon.[149] A 2023 survey found that only 4% of farmers planned to adopt agricultural technology in the next two years.[150] Farmers' slow adoption of precision fertilizing technologies is likely attributable to a few primary factors.

*1. High Cost of Adoption*

The high cost of precision fertilizing amid disquieting economic conditions is one major barrier to the deployment of these technologies.[151] Working capital has decreased in the agricultural industry over the last decade.[152] Accordingly, many farmers presently lack the liquidity to purchase and install precision fertilizing systems.[153] This scarcity of funds is even more constraining given the agricultural industry's heavy dependence on credit to fund its operations.[154] Farmers often rely on short-term, variable-rate loans to pay for farm inputs and technologies.[155] Farm sector debt continues to increase year over year.[156] Broader financial conditions, including prevailing interest rates, are thus particularly impactful for farmers.[157]

The relatively high upfront costs of precision fertilizing equipment have surely deterred many farmers from investing in them. For example, a single farm's VRT installation could cost as much as $250,000.[158] One recent survey found that 47% of farmers had identified the high cost of agriculture technologies as a top

149. *See id.*

150. Fiocco et al., *supra* note 17.

151. *Id.*

152. Brent Gloy, *Farm Sector Working Capital at Critical Levels*, AGRIC. ECON. INSIGHTS (Jun. 24, 2019), https://aei.ag/2019/06/24/farm-sector-working-capital-at-critical-levels/ [https://perma.cc/YZ6J-PLXA].

153. Keith Good, *Rising Cost of Credit Impacting Farmers*, ILL. FARM POL'Y NEWS (Nov. 25, 2022), https://farmpolicynews.illinois.edu/2022/11/rising-cost-of-credit-impacting-farmers/ [https://perma.cc/QCW3-42N3].

154. *Id.*

155. *Id.*

156. *See Assets, Debt, and Wealth*, ECON. RES. SERV., U.S. DEP'T OF AGRIC. (Sept. 5, 2024), https://www.ers.usda.gov/topics/farm-economy/farm-sector-income-finances/assets-debt-and-wealth/ [https://perma.cc/499K-MWHF].

157. Good, *supra* note 153.

158. Phillip Clancy, *Making Your Variable Rate Technology Pay*, CROPLIFE (July 8, 2020), https://www.croplife.com/precision-tech/making-your-variable-rate-technology-pay/ [https://perma.cc/4L6D-LH5A].

three barrier to adoption.[159] For many farmers, precision fertilizing systems are presently not a financially feasible option.[160]

*2. Unclear Value Proposition*

The perceived benefits of precision fertilizing systems appear to be insufficient to persuade many farmers to invest in them. Roughly 50% of farmers responding to a 2023 survey stated they were not willing to pay *anything* for these technologies.[161] In a follow-up question, 30% of farmers explained that unclear returns on investment were a major concern.[162] For many farmers, a predictable three-to-one return on investment is needed to prompt them to consider a new technology.[163] In the eyes of many agricultural producers, precision fertilizing does not meet that benchmark.

Farmers' uncertainty regarding the benefits of precision fertilizing may be justified to some extent. Productivity gains delivered by these technologies may often be obscured by confounding factors such that many farmers who install them fail to fully recognize their benefits.[164] Accordingly, many farmers may have heard misleading accounts of underwhelming or unprofitable experiences with precision fertilizing. The novice of early adopters, farmers' personal skepticism about new technologies, and unique farm characteristics could all skew results in early studies of these technologies.[165] For these and other reasons, precision fertilizing technology stakeholders have struggled to effectively market their products to the agriculture sector.

*3. Inadequate Internet Connectivity in Rural Areas*

Limited broadband access in rural agricultural areas is another leading impediment to further adoption of precision fertilizing systems.[166] Many precision fertilizing technologies require high-speed internet connectivity: cloud-based data tracking, real-time updates for soil conditions, autonomous drones, and related

159. Fiocco et al., *supra* note 17.
160. *Id.*
161. *Id.*
162. *Id.*
163. *Id.*
164. *Id.*
165. *See* MCFADDEN ET AL., *supra* note 16, at 18.
166. *Id.* at 27.

components often cannot properly function without internet access.[167] As of 2021, 18% of American farms had no access to the internet.[168] A 2022 survey of farmers producing at least $500,000 worth of goods per year found that nearly 30% of respondents had poor or no internet access.[169] These internet access limitations are yet another constraint on the deployment of precision fertilizing technologies.

*4. Data and Privacy Concerns*

Even in rural areas with internet access, some farmers' concerns about data privacy and cybersecurity present yet another obstacle to the proliferation of precision fertilizing systems. To the extent they are cloud-connected, precision fertilizing systems are potentially vulnerable to hacking or exploitation by malicious actors.[170] Although some believe the agricultural industry has been slow to recognize cybersecurity threats, farmers' concerns about these potential harms have increased substantially in recent years.[171]

Cybersecurity concerns are an increasingly relevant obstacle to the adoption of agricultural technologies, including precision fertilizing. In 2015, the USDA upgraded its classification of cybersecurity as a higher priority issue.[172] In 2021, a Russian hacking group seized the computer systems of entities that collectively control 20% of all American beef processing plants as digital hostages in a ransomware attack.[173] One company was forced to pay roughly $11 million to the group to restore its operations.[174] In another incident, a rogue group stole data from a grain storage cooperative in Iowa.[175] About 25% of American farmers cite

167. *See* Gopal Ratnam, *Amid Technology Worries, Farm Sector Still Eyes Its Potential*, ROLL CALL (Apr. 4, 2023, 7:00 AM), https://rollcall.com/2023/04/04/amid-technology-worries-farm-sector-still-eyes-its-potential/ [https://perma.cc/V7UA-TAR6].

168. *Rural Broadband*, FARM BUREAU (Sept. 7, 2024, 4:31 PM), https://www.fb.org/issue/infrastructure/rural-broadband [https://perma.cc/Z7DU-7N9Q].

169. *30% of Largest Farmers in US Have Poor or No Internet*, PRECISION FARMING DEALER (Nov. 3, 2022), https://www.precisionfarmingdealer.com/articles/4993-30-of-largest-farmers-in-us-have-poor-or-no-internet [https://perma.cc/Z9A7-RXDR].

170. *See* John Farley, *Precision Agriculture 'Ripe for the Picking' by Hackers*, ARTHUR J. GALLAGHER & CO. (Sept. 7, 2024, 3:25 PM), https://www.ajg.com/us/news-and-insights/2020/feb/precision-agriculture-ripe-for-the-picking-by-hackers/ [https://perma.cc/8EWD-EAQS].

171. *See* Austin C. Doctor & George Grispos, *Opinion: The Rise of Precision Agriculture Exposes Our Food System to New Threats*, MODERN FARMER (Aug. 14, 2022), https://modernfarmer.com/2022/08/precision-agriculture-threats/ [https://perma.cc/G9ZM-S8XN].

172. *Id.*

173. *Id.*

174. *Id.*

175. *Id.*

concerns about data access and cybersecurity as a top barrier to adopting precision fertilizing.[176] For precision fertilizing to succeed, government actors and stakeholders will have to successfully assuage farmers' fears and develop adequate protections against such threats.

### *5. Farm-Specific Barriers*

The distinct characteristics of individual farms can present additional obstacles to precision fertilizing adoption. Larger farms generally have more acreage, resources, and capital, and thus tend to adopt precision agriculture at significantly higher rates.[177] Farm terrain can also impact the effectiveness of precision fertilizing systems as these relatively new technologies wait to mature.[178] For example, flat fields designed for monoculture crops are naturally easier for precision farming than those with rocky or uneven terrain.[179]

### *6. Generational Differences*

The average age of decisionmakers on American farms is another factor that may be slowing adoption of precision fertilizing technologies. The most recent available census data indicates that the average age of American agricultural producers is 57.5 years, which is an increase of 1.2 years from 2012.[180] Compared to younger generations, the "Baby Boomers" comprising this demographic tend to be relatively hesitant to adopt new innovations and are late adopters of new technologies.[181]

## IV. CREATING A FRAMEWORK TO EFFECTIVELY INCENTIVIZE ADOPTION OF PRECISION FERTILIZING

Considering the many barriers just described, there is much that lawmakers could do to promote more widespread deployment of precision fertilizing

176. Fiocco et al., *supra* note 17.

177. Dimitri & Effland, *supra* note 18, at 395.

178. *See* Ahmed Harb Rabia et al., *Principles and Applications of Topography in Precision Agriculture*, 171 ADVANCES AGRONOMY 143, 172–74 (2022).

179. *See id.*

180. NAT'L AGRIC. STAT. SERV., U.S. DEP'T OF AGRIC., 2017 CENSUS OF AGRICULTURE HIGHLIGHTS: FARM PRODUCERS (2019), https://www.nass.usda.gov/Publications/Highlights/2019/2017Census_Farm_Producers.pdf [https://perma.cc/PY4Q-P7ZN].

181. Griffin & Traywick, *supra* note 146, at 63; *Generations*, LIBR. OF CONG. (Sept. 4, 2024, 5:22 PM), https://guides.loc.gov/consumer-research/market-segments/generations [https://perma.cc/C6YC-9AQZ] ("Baby Boomers are defined by the [United States] Census Bureau as those born between 1946 and 1964.").

technologies. Understanding the basic features of precision fertilizing, the United States agricultural sector, and the incentive structures currently affecting farmers is useful when considering policies to better promote precision fertilizing adoption. Rapid government-funded improvements in rural broadband internet are making the prospects of widespread precision fertilizing use in the United States stronger than ever before.[182] The imminent demographic shift toward younger, more tech-savvy "Millennials" on farms across America is further setting the stage for such a shift.[183] With precision agriculture bills beginning to be introduced in Congress, there has never been a more opportune time to examine these issues and identify policies best suited to support this transition.[184]

Understanding farmers' perceptions about the costs and benefits of precision fertilizing is a crucial first step toward accelerating the adoption of these technologies. Farmers are ultimately the ones who decide whether to purchase and install precision fertilizing systems and often focus on the direct cost of adopting new technologies rather than perceived benefits of these technologies.[185] Policies that aim to promote these systems should thus consider farmers' views about the costs, benefits, and risks of such investments. This Part identifies existing frameworks and concepts that are potentially helpful in crafting policies to better promote private investment in precision fertilizing systems.

### *A. Farmers as Risk-Averse Actors*

Farmers tend to be relatively risk averse, which may influence their attitudes about precision fertilizing.[186] As compared to individuals in other industries, farmers are typically more concerned with the introduction of risk into their

182. *See* Agricultural Improvement Act of 2018, Pub. L. No. 115-334, § 6201, 132 Stat. 4490, 4729 (2018); James K. Wilcox, *Infrastructure Law Includes $65 Billion for Improving Internet Access*, CONSUMER REPS. (Nov. 15, 2021), https://www.consumerreports.org/electronics/internet/infrastructure-bill-includes-65-billion-for-internet-access-a6861027212/ [https://perma.cc/AF47-MMXB]; Tony Romm, *Biden Announces $42 Billion to Expand High-Speed Internet Access*, WASH. POST (June 26, 2023, 12:30 PM), https://www.washingtonpost.com/business/2023/06/26/high-speed-internet-white-house-announcement/.

183. *See generally Generations*, *supra* note 181.

184. *See* Promoting Precision Agriculture Act of 2023, H.R. 1697, 118th Cong. (2023) (House bill that advocates for development of voluntary standards to promote precision agriculture); Promoting Precision Agriculture Act of 2023, S. 734, 118th Cong. (2023) (H.R. 1697's companion bill introduced in the Senate during the same term).

185. Griffin & Traywick, *supra* note 146, at 61.

186. *See* Alisa Spiegel et al., *Risk, Risk Aversion, and Agricultural Technology Adoption – A Novel Valuation Method Based on Real Options and Inverse Stochastic Dominance*, Q OPEN, July 22, 2021, at 1, 1.

operations.[187] Such risk preferences can greatly impact the pace of technology adoption in agricultural settings.[188] For obvious reasons, decision makers with elevated levels of risk aversion tend to adopt new technologies at smaller scales.[189] Reducing the perceived risks of precision fertilizing investments for farmers is thus one potential means of accelerating the deployment of these technologies.

Farmers' elevated levels of risk aversion are not irrational. Historical challenges and the financial realities they face today may well explain some of their additional hesitancy to take on perceived risks.[190] Farmers often rely on short-term credit, making them more likely to prioritize predictable investments over new technologies.[191] This cautious approach can lead to missed opportunities for cost savings and productivity gains.[192] Policies aimed at incentivizing farmers to purchase and install precision fertilizing equipment will thus be more effective to the extent that they address farmers' perceptions about the actual risks and potential benefits of these new technologies.

### *B. Precision Fertilizing and Externality Theory*

Framing fertilizer overuse and the slow adoption of precision fertilizing technologies as externality problems provides additional insight into how to confront these challenges. Externality problems arise when actors do not bear all the costs or enjoy all of the benefits of their actions.[193] A negative externality refers to a cost borne by an individual other than the one deciding to take some action.[194] A positive externality refers instead to a benefit that is not felt by the decision

187. *See* Kerri Brick & Martine Visser, *Risk Preferences, Technology Adoption and Insurance Uptake: A Framed Experiment*, 118 J. ECON. BEHAV. & ORG. 383, 394–95 (2015) (showing experiments that found risk-adverse farmers were more likely to choose traditional farming methods over modern farming options, even when insurance was available to them).

188. *See id.*; *see also* Haixia Wu et al., *Farm Size, Risk Aversion and Overuse of Fertilizer: The Heterogeneity of Large-Scale and Small-Scale Wheat Farmers in Northern China*, LAND, Feb. 2021, at 1, 11.

189. Spiegel et al., *supra* note 186, at 2.

190. Marius Ruett et al., *Assessing Expected Utility and Profitability to Support Decision-Making for Disease Control Strategies in Ornamental Heather Production*, 23 PRECISION AGRIC. 1775, 1777 (2022).

191. *Id.* at 1775, 1785; Good, *supra* note 153.

192. Ruett et al., *supra* note 190.

193. HARVEY S. ROSEN, PUBLIC FINANCE 86 (5th ed. 1999); N. Gregory Mankiw, *Smart Taxes: An Open Invitation to Join the Pigou Club*, 35 E. ECON. J. 14, 16 (2009).

194. *See, e.g.*, Mankiw, *supra* note 193, at 16.

maker.[195] Externalities are indicative of market failures in which there is under or over-engagement in the affected activity.[196] Positive and negative externalities help explain why individuals may choose to engage in behavior that has a net negative result for society as a whole or choose to *not* engage in behavior that has a net positive result for society.[197]

### *1. Excessive Fertilizing as a Negative Externality Problem*

Pollution-causing activities such as fertilizer overuse are notoriously susceptible to negative externality problems.[198] Farmers benefit greatly from applying excessive fertilizers because doing so promotes higher crop yields, but they do not face many of the costs such overuse imposes on watersheds, human health, and ecosystems.[199] As the negative externality theory would predict, the fact that farmers generally do not directly bear many of the harms and costs associated with the overuse of fertilizer is partly what drives that overuse.[200]

### *2. Underinvestment in Precision Fertilizing as a Positive Externality Problem*

Farmers' inability to enjoy all of the broader social benefits of precision fertilizing similarly presents *positive* externality problems that further deter optimal levels of private investment in these technologies.[201] Farmers deciding whether to purchase a precision fertilizing system are likely to consider its price, the time and labor costs associated with installing and using it, potential cost savings from resulting reductions in fertilizer use, and any other productivity benefits.[202] However, most farmers are not likely to factor in most of the broader environmental and community health benefits of such an investment, such as decreased water treatment costs and improved sustainability.[203] Rational, self-

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195. Thomas Helbling, *Externalities: Prices Do Not Capture All Costs*, INT'L MONETARY FUND (May 10, 2017), https://www.imf.org/en/Publications/fandd/issues/Series/Back-to-Basics/Externalities [https://perma.cc/9YS9-FHBG].

196. Benjamin K. Sovacool & Chukwuka G. Monyei, *Positive Externalities of Decarbonization: Quantifying the Full Potential of Avoided Deaths and Displaced Carbon Emissions from Renewable Energy and Nuclear Power*, 55 ENV'T SCI. TECH. 5258, 5258 (2021).

197. *See id.*

198. *See* Mankiw, *supra* note 193, at 16.

199. Bryce & Skousen, *supra* note 90, at 32.

200. *See id*. at 30.

201. *See* Helbling, *supra* note 195.

202. *See* MCFADDEN ET AL., *supra* note 16, at 2.

203. *Id.* at 37.

interested farmers are thus likely to substantially under-invest in precision fertilizing technologies for their farms.

*3. Addressing Precision Fertilizing's Externality Problems*

Externality problems are market failures that often justify some form of government intervention.[204] Governments can promote and increase optimal market outcomes and social welfare by exercising their regulatory and other powers to incentivize actors to behave in more socially optimal ways.[205] Among other things, policies that help farmers internalize more of the externalized benefits of precision fertilizing can motivate them to invest in these technologies at more optimal levels.

Externality problems can justify government intervention, including expenditures of government resources to better align actors' incentives.[206] For instance, instead of expending additional government revenues to treat drinking water contamination caused by fertilizer overuse, governments can allocate funds to support the proliferation of precision fertilizing and thereby avoid those additional water treatment costs. In this sense, government subsidies that promote wider adoption of precision fertilizing should be viewed not as expensive government welfare, but as a potential cost-saving measure.

Because many of the societal harms of fertilizer overuse and societal benefits of precision fertilizing transcend state boundaries, federal government involvement is likely warranted to help address these externality problems.[207] The Mississippi River Delta dead zone is caused by the accumulation of nutrients throughout the entire watercourse of the Mississippi River, but it significantly affects three states: Mississippi, Louisiana, and Alabama.[208] Because many of the benefits of precision fertilizing investments by farms in upstream states would accrue to citizens in Mississippi, only federal government intervention may be capable of correcting this type of externality.[209]

204. Helbling, *supra* note 195.

205. *See* Carl J. Circo, *Does Sustainability Require a New Theory of Property Rights?*, 58 U. KAN. L. REV. 91, 116 (2009).

206. *See, e.g.*, Valerio Ercolani & João Valle e Azevedo, *The Effects of Public Spending Externalities*, 46 J. ECON. DYNAMICS & CONTROL 173, 174 (2014).

207. Bryce & Skousen, *supra* note 90, at 32.

208. *See id.* at 33; *Mississippi River Facts*, NAT'L PARK SERV. (Aug. 11, 2024), https://www.nps.gov/miss/riverfacts.htm [https://perma.cc/27UH-Q2Q9] (noting that the Mississippi River drains from "parts of 31 states and two Canadian provinces, about 40% of the continental United States").

209. *See* Bryce & Skousen, *supra* note 90, at 32.

### *C. Carrots Versus Sticks in Precision Farming Policy*

Although imposing liability on farmers for excessive nutrient discharges could conceivably address the negative externality problems associated with fertilizer overuse, the longstanding nature of existing agricultural law and policy cautions against that approach. Existing regulatory frameworks typically do not impose liability on agricultural producers for all pollution discharges.[210] For instance, the Clean Water Act does not treat agricultural producers as point-source polluters, thereby largely exempting the industry from regulation under the Act.[211] Instead, regulation for agricultural non-point source pollution is left to state governments, which tend to be more lenient in their approach.[212] Many previous state-level efforts to restrict fertilizer use have similarly encountered strong opposition.[213] In light of these political realities, a more plausible set of policy strategies for driving precision fertilizing investments would be one that rewards such investments rather than mandates them.[214]

## V. STRENGTHENING INCENTIVES FOR PRECISION FERTILIZING INVESTMENT

Although precision fertilizing is relatively uncommon in the United States today, effective policy reforms could greatly accelerate the deployment of these technologies across the country. Some of the most promising policies to encourage precision fertilizing investment are those that reduce costs to farmers or mitigate the financial or operational risks associated with this type of development, such as extension program initiatives, nutrient credit trading systems, loan guarantees, and tax credit programs.

### *A. Leveraging Existing Agricultural Extension Programs*

Using existing agricultural extension programs to better educate farmers about precision fertilizing and its many benefits could help to overcome some farmers' risk-aversion related resistance to these technologies. Many farmers are not aware of how precision fertilizing can help them increase crop yields while simultaneously promoting lower-cost and environmentally-friendly food

210. *See id.*

211. *See id.* at 35; 33 U.S.C. § 1362(14).

212. *See* Robin K. Craig & Anna M. Roberts, *When Will Governments Regulate Nonpoint Source Pollution? A Comparative Perspective*, 42 B.C. ENV'T AFF. L. REV. 1, 12–13 (2015) (explaining that only 19 states regulate agricultural non-point source pollution in any way); Bryce & Skousen, *supra* note 90, at 32.

213. *See* Wertz, *supra* note 26.

214. *See id.*

production.[215] Government-funded cooperatives and other extension programs have long partnered with colleges and universities to provide free educational opportunities to farmers aimed at promoting more profitable and ecological farming practices, which already have many farmers' trust.[216] Accordingly, these programs could be valuable conduits for disseminating information about precision fertilizing throughout the country.

For over a century the Cooperative Extension System (CES) has sustained the agricultural industry through education and outreach to rural communities.[217] Academics and subject matter experts across the country share their research with local communities, who then implement it into practical applications.[218] By performing and disseminating relevant research and knowledge, extension services can further the understanding of precision fertilizing to make its adoption more accessible to all farmers, thereby driving adoption of the technologies. Such activities are often worth their expense, however, because the individual and societal benefits of farming advancements are only realized to the extent that farmers learn and apply them, results may vary.[219]

Unfortunately, much of the farming-related information that extension services produce and distribute is what academics would call a "public good"—an asset that is non-excludable and non-rivalrous in consumption and thus tends to be underproduced without government intervention.[220] Much of the farming

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215. *See* U.S. GOV'T ACCOUNTABILITY OFF., GAO-24-105962, PRECISION AGRICULTURE: BENEFITS AND CHALLENGES FOR TECHNOLOGY ADOPTION AND USE 45–46 (2024).

216. *See Find Cooperative Extension in Your State*, EXTENSION FOUND. (Sept. 4, 2024, 5:14 PM), https://extension.org/find-cooperative-extension-in-your-state/ [https://perma.cc/U8UN-4APW] (listing major Cooperative Extensions in the United States and its territories); *see, e.g.*, *Agriculture and Natural Resources*, IOWA ST. UNIV. EXTENSION & OUTREACH (Sept. 10, 2024, 3:18 PM), https://www.extension.iastate.edu/ag/ [https://perma.cc/H5X7-QBYN].

217. *Cooperative Extension System*, NAT'L INST. OF FOOD & AGRIC., U.S. DEP'T OF AGRIC. (Sept. 7, 2024, 5:23 PM), https://www.nifa.usda.gov/about-nifa/how-we-work/extension/cooperative-extension-system [https://perma.cc/FE42-K6X8] (explaining how CES addresses national issues through grants and program leadership); David R. Buys & Roger Rennekamp, *Cooperative Extension as a Force for Healthy, Rural Communities: Historical Perspectives and Future Directions*, 110 AM. J. PUB. HEALTH 1300, 1300 (2020).

218. Buys & Rennekamp, *supra* note 217, at 1302.

219. *See* Sun Ling Wang, *Cooperative Extension System: Trends and Economic Impacts on U.S. Agriculture*, 29 CHOICES, no. 1, 2014, at 1, 1.

220. *See* Paul A. Samuelson, *The Pure Theory of Public Expenditure*, 36 REV. ECON. & STAT. 387, 387 (1954) (defining "collective consumption goods" as those "which all enjoy in common in the sense that each individual's consumption of such a good leads to no subtraction from any other individual's consumption of that good"); TROY A. RULE,

knowledge gained through extension activities can be used by one farmer without excluding or diminishing another farmers use of it, so most farmers would rationally opt to gain knowledge generated by others rather than invest resources to create it themselves.[221] Public funding of agricultural research and education helps to overcome this underproduction problem.[222]

Despite valid arguments in their favor, agricultural cooperative extension programs have sometimes struggled to receive adequate government support.[223] Federal grant programs funding other types of institutional research have been successful in driving innovative research and widespread adaptation of public goods.[224] For example, the SunShot Initiative launched in 2011, with the goal of drastically reducing solar energy costs, ultimately achieved its targets ahead of schedule by using a research-forward approach.[225] However, in recent years, the USDA, which oversees the CES, has shed both employees and budget dollars.[226] In spite of this challenge, the government should be responsible for funding and incentivizing cooperative extension programs in order to capture all of the agricultural advancements that can come from widespread public knowledge.

Extension services could be particularly useful in expanding knowledge about how regional differences can affect precision fertilizing. Precision fertilizing techniques can vary significantly by state and region due to differences in weather, crops, terrain, humidity, and other factors.[227] Extension services operating at the local or regional level can provide localized knowledge that accounts for these differences, helping to overcome the knowledge gap that may otherwise inhibit

RENEWABLE ENERGY: LAW, POLICY AND PRACTICE 387–88 (2d ed. 2021) (stating that public goods are non-excludable, or that "individuals cannot be effectively excluded from using it," and non-rivalrous, meaning that "use by one does not diminish availability for others").

221. Samuelson, *supra* note 220, at 387.

222. RULE, *supra* note 220, at 388.

223. *See* Jeffrey Mervis, *Weathering the Storm*, SCI. (Oct. 14, 2020), https://www.science.org/content/article/trump-has-shown-little-respect-us-science-so-why-are-some-parts-thriving [https://perma.cc/EXA5-VGGN].

224. *See, e.g.*, *The SunShot Initiative*, OFF. OF ENERGY EFFICIENCY & RENEWABLE ENERGY (Sept. 7, 2024, 4:48 PM), https://www.energy.gov/eere/solar/sunshot-initiative [https://perma.cc/UY8M-8HJH].

225. *Id.*

226. *See* Mervis, *supra* note 223; *see also Cooperative Extension System*, *supra* note 217 (showing that the majority of a typical Cooperative Extension budget comes from federal and state funding).

227. *See* Rabia et al., *supra* note 178.

precision fertilizing.[228] Extension services can also help farmers overcome the steep learning curve associated with adopting precision fertilizing.[229] By performing necessary research and training, extension services can offload some of the soft costs associated with adopting precision fertilizing from farmers, making it more appealing to them.

In addition to advancing and distributing knowledge about precision fertilizing itself, extension services may be able to increase farmers' awareness of government programs that reward precision fertilizing investment. The array of existing and potential programs that incentivize precision fertilizing is decentralized among various government entities and could be difficult for many farmers to navigate.[230] Some previous programs have failed due to a lack of information and awareness.[231] Extension programs could leverage relationships with farmers to disseminate information about precision fertilizing-related incentive programs so that more farmers are aware of them and how to benefit from them.

228. *See* Katharine Heyl et al., *Achieving the Nutrient Reduction Objective of the Farm to Fork Strategy. An Assessment of CAP Subsidies for Precision Fertilization and Sustainable Agricultural Practices in Germany*, FRONTIERS SUSTAINABLE FOOD SYS., Jan. 26, 2023, at 1, 5 (describing how knowledge exchange and advisory services in Europe can provide necessary guidance for the implementation of precision fertilizing); *Cooperative Extension System*, *supra* note 217 (explaining existing state channels where CES oversees land-grant universities through academic departments, experiment stations, and cooperative extension); *see also Cooperative Extension*, ARIZ. DEP'T OF AGRIC. (Sept. 7, 2024, 5:24 PM), https://agriculture.az.gov/training-assistance/cooperative-extension [https://perma.cc/7HJC-CABB] (providing an example of how extension services aid farmers in Arizona).

229. *See* MCFADDEN ET AL., *supra* note 16, at 37 (describing the gap in technological understanding of many farmers).

230. *See, e.g.*, *BMP Tax Credit Program*, VA. DEP'T OF CONSERVATION & RECREATION (Mar. 12, 2024, 10:37 AM), https://www.dcr.virginia.gov/soil-and-water/costshar3 [https://perma.cc/4YF7-M5PF] (detailing a state agency's efforts to encourage farmers to use precision agriculture equipment); *EPA's Efforts to Reduce Nutrient Pollution*, U.S. ENV'T PROT. AGENCY (Nov. 29, 2023), https://www.epa.gov/nutrientpollution/epas-efforts-reduce-nutrient-pollution [https://perma.cc/7VLV-94TB] (explaining the EPA's efforts to reduce nutrient pollution which is regulated by various entities located throughout state and federal government).

231. *See* Tingting Liu et al., *Factors Influencing Farmers' Adoption of Best Management Practices: A Review and Synthesis*, SUSTAINABILITY, Feb 7, 2018, at 1, 12 (2018) (explaining that timely access to information from accepted sources, like extension services, is critical for adoption of BMPs and other programs).

### *B. Making Best Management Practices (BMPs) Even Better*

Best Management Practices (BMPs) are another potential means of promoting precision fertilizing. Within agricultural law, BMPs are specific farming methods identified at the state level as reducing the environmental risks or harms associated with certain farming operations while maintaining overall outputs.[232] Examples of existing BMPs include nutrient management techniques, conservation drainage practices, field buffers, management of livestock access to streams or waterways, and engagement in watershed efforts.[233] Governments often offer financial incentives to encourage farmers' adoption of BMPs.[234] For example, Virginia offers tax credits to farmers to offset expenses associated with installing BMPs.[235] Other programs simply offer direct payments to farmers for implementing BMPs.[236]

#### *1. Environmental Success of BMPs*

BMPs and accompanying financial incentives have been successful at motivating farmers to engage in environmentally beneficial behaviors. For example, BMP programs in Virginia significantly mitigated the state's problem of high bacteria levels from non-point source runoff.[237] Financial incentives and other support provided through the state's BMP programs induced farmers to reduce

232. *See* Ekrem Ozlu et al., *Best Management Practices for Agricultural Nutrients*, NC ST. EXTENSION (June 10, 2022), https://content.ces.ncsu.edu/best-management-practices-for-agricultural-nutrients [https://perma.cc/AX3H-8R28].

233. *See Sources and Solutions: Agriculture*, U.S. ENV'T PROT. AGENCY (May 6, 2024), https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture [https://perma.cc/Q9RT-MK77].

234. L.H. Palm-Forster et al., *Farmer Preferences for Conservation Incentives that Promote Voluntary Phosphorous Abatement in Agricultural Watersheds*, 72 J. SOIL & WATER CONSERVATION 493, 493 (2017).

235. *BMP Tax Credit Program*, *supra* note 230.

236. *See* Palm-Forster et al., *supra* note 234, at 493.

237. *See* OFF. OF WATER, U.S. ENV'T PROT. AGENCY, IMPLEMENTING AGRICULTURAL BEST MANAGEMENT PRACTICES REDUCES BACTERIA LEVELS IN THE CUB CREEK WATERSHED 2 (2015), https://www.epa.gov/sites/default/files/2020-07/documents/va_cub-508.pdf [https://perma.cc/W9J3-SVWN] (specific BMP solutions used include: "livestock exclusion fencing with grazing management . . . , 62 acres of reforestation of erodible crop and pasture lands, 57 acres of continuous no-till, 35 acres of permanent vegetative cover on cropland, 21 acres of small-grain cover crop, 1,330 linear feet of stream protection and one loafing lot management system").

bacterial levels by applying proven techniques,[238] including coordination among watershed stakeholders.[239] The programs also encourage partnerships between various water conservation districts, federal agencies including USDA, state agencies including Virginia Cooperative Extension, and landowners.[240] BMP programs in Florida similarly motivated a farm in that state to work with state agencies to install subirrigation and precision fertilizing equipment on 80 acres of crops, reducing nitrogen levels in downstream surface waters by 35%.[241]

### *2. Maximizing Precision Fertilizing Adoption with BMPs*

BMPs and accompanying incentive programs can promote investment in precision fertilizing by reducing the financial risk associated with the technologies. Direct payments to farmers under such programs reduce the net costs of precision fertilizing and shift some of its externalized benefits back to farmers.[242] BMPs and financial incentives may also improve farmers' attitudes about precision fertilizing by signaling stronger approval of the technologies within a type of program that most farmers recognize and understand.[243] Because clear information on how to implement BMPs is often crucial to their success, well designed precision fertilizing BMPs would clearly indicate which technologies farmers should use and

238. *See id.* Financial incentives provided to farmers included "$7,243 in [Natural Resources Conservation Service] Environmental Quality Incentive Program funds and a combined $484,598 from the Virginia Water Quality Incentive Fund and the Virginia Natural Resources Commitment Fund. The state of Virginia also provided $36,619 in the form of tax credits issued to farmers implementing BMPs." *Id.* Additionally, the conservation district provided free technical assistance to farmers throughout the project's five years, including support for water quality monitoring. *Id.*

239. *See id.* (detailing outreach efforts to include, "farm tours, personal communications, publication of articles in local newspapers, and distribution of TMDL brochures explaining eligible BMPs and their benefits").

240. *Id.*

241. FLA. DEP'T OF AGRIC. & CONSUMER SERVS., ST. JOHNS RIVER WATER MANAGEMENT DISTRICT AGRICULTURAL SUCCESS STORY – TATER FARMS (2024), https://ccmedia.fdacs.gov/content/download/67009/file/BMP-Success-Story-Tater-Farms-in-the-St-Johns-River-Water-Management-District.pdf [https://perma.cc/KYZ7-EUE8].

242. *See* Liu et al., *supra* note 231, at 13 (explaining that availability of subsidies and other financial incentives were found to be positively correlated with adoption of BMPs).

243. *See* GREENBERG QUINLAN ROSNER RSCH. & PUB. OP. STRATEGIES, U.S. HEARTLAND FARMERS VALUE CONSERVATION PROGRAMS AND REJECT CUTTING FARM BILL CONSERVATION FUNDING 2 (2012), https://ohfarmersunion.org/docs/conservationpoll.pdf [https://perma.cc/3GJ9-KFFY] (explaining that 71% of farmers believe such "conservation programs reduce costs and help farmers' bottom line," and that 82% view them as a high or top priority for consideration in the Farm Bill).

outline flexible and observable steps for compliance.[244] Ideally, BMPs for precision fertilizing would also account for the fact that farmers tend to prefer to adopt BMPs on a smaller trial basis before implementing them across an entire farm.[245]

State governments could further enhance their financial incentive programs for precision fertilizing BMPs by incorporating additional benefits to account for the high cost and value of these technologies. Offering larger financial incentives is likely to prompt more farmers to participate in the programs.[246] Because cash flow problems can deter some farmers from participating, governments could additionally offer special financing arrangements to help reduce farmers' upfront costs of precision fertilizing investments.[247]

### *C. Expanding Tax Credits for Precision Fertilizing*

Legislation authorizing federal tax credits for precision fertilizing investment is another potentially promising means of promoting greater investment in these technologies. Subsidizing precision fertilizing through various tax policies can help farmers internalize more of the broader social benefits of precision fertilizing investments. Tax credits, exemptions, and deductions are all methods capable of reducing farmers' tax liability as a reward for precision fertilizing activities. Income tax credits directly reduce a taxpayer's total income tax liability, while exemptions and deductions indirectly diminish tax liability by reducing the taxpayer's taxable income.[248]

Regardless of their form, such tax incentives can effectively encourage rapid adoption of innovative technologies.[249] For instance, federal tax credits have done much to help drive the deployment of renewable energy technologies like wind

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244. *See* Liu et al., *supra* note 231, at 16.

245. *See* David J. Pannell et al., *Understanding and Promoting Adoption of Conservation Practices by Rural Landholders*, *in* CHANGING LAND MANAGEMENT: ADOPTION OF NEW PRACTICES BY RURAL LANDHOLDERS 11, 24–25 (David Pannell & Frank Vanclay eds., 2011).

246. *See* Hua Zhong et al., *Farmers' Willingness to Participate in Best Management Practices in Kentucky*, 59 J. ENV'T PLAN. & MGMT. 1015, 1028 (2016).

247. *See* Liu et al., *supra* note 231, at 13.

248. CTR. ON BUDGET & POL'Y PRIORITIES, TAX EXEMPTIONS, DEDUCTIONS, AND CREDITS 1–2 (2020), https://www.cbpp.org/sites/default/files/atoms/files/policybasics-exempt.pdf [https://perma.cc/F3S7-RYPU].

249. *See, e.g.*, ELIZABETH NOLL & DAVID HART, LESS CERTAIN THAN DEATH: USING TAX INCENTIVES TO DRIVE CLEAN ENERGY INNOVATION 18 (2019), https://www2.itif.org/2019-tax-incentives-clean-energy.pdf [https://perma.cc/KNL3-G6ZZ] (describing how tax incentives spurred quick adoption of various clean energy technologies).

and solar over the past couple of decades.[250] The Energy Policy Act of 2005 increased the solar investment tax credit from 10% to 30%, catalyzing large increases in the pace of solar energy development in the United States.[251] The federal production tax credit has similarly accelerated the development of wind energy across the country.[252] Federal income tax credits could directly address the positive externality problem faced by precision fertilizing by enabling farmers to internalize far more of the broader societal benefits of investing in these technologies.[253] Such credits should subsidize precision fertilizing investments, which may more accurately reflect their overall social value.[254]

Virginia has already created such a tax policy to incentivize the adoption of precision fertilizing.[255] A statute enacted in Virginia allows farmers in that state to claim an equipment tax credit equal to 25% of such expenditures, up to $17,500.[256] This credit is separate from the conventional BMP tax credit offered in the state.[257] Although other states could adopt similar provisions to incentivize precision fertilizing, adding new federal-level tax credits would be even more impactful. Regardless, such investment tax credits would ideally be highly inclusive of the wide variety of technologies contained under the umbrella of precision fertilizing and designed to benefit small and large farms.

Another plausible approach to tax incentives for precision fertilizing could base the size of a taxpayer's credit on its proven reductions in fertilizer use. Such an approach could help to better tie tax benefits to actual decreases in nutrient use. Regardless of what form they take, new tax incentives for precision fertilizing would ideally be available as *additional* policies—not replacements for existing ones—so that farmers can potentially avail themselves of multiple layers of incentives with a single investment.

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250. David Funkhouser, *How Much Do Renewables Actually Depend on Tax Breaks?*, STATE OF THE PLANET (Mar. 16, 2018), https://news.climate.columbia.edu/2018/03/16/how-much-do-renewables-actually-depend-on-tax-breaks/ [https://perma.cc/NK45-RTN7].

251. JAY BARTLETT, BEYOND SUBSIDY LEVELS: THE EFFECTS OF TAX CREDIT CHOICE FOR SOLAR AND WIND POWER IN THE INFLATION REDUCTION ACT 2 (2023), https://media.rff.org/documents/Report_23-20.pdf [https://perma.cc/W4Z3-8BJY].

252. *Id.*

253. *See* Edward A. Zelinsky, *Efficiency and Income Taxes: The Rehabilitation of Tax Incentives*, 64 TEX. L. REV. 973, 1006–07 (1986).

254. *See* Lily L. Batchelder et al., *Efficiency and Tax Incentives: The Case for Refundable Tax Credits*, 59 STAN. L. REV. 23, 44 (2006).

255. VA. CODE ANN. § 58.1-337 (West 2024).

256. *BMP Tax Credit Program*, *supra* note 230.

257. *Id.*

### *D. Modifying Nutrient Credit Trading Programs to Adequately Reward Precision Fertilizing*

Modifying nutrient credit trading programs to encourage agricultural participation could help farmers to internalize more of the benefits of precision fertilizing as well. Nutrient credit trading programs are typically operated at the state government level, but overseen by the EPA.[258] Within these programs, parties can reduce their nutrient discharges to earn transferable credits that can help others comply with regulatory limits, essentially creating a market that incentivizes net reductions in nutrient pollution.[259] By leveraging market forces, these programs encourage nutrient pollution reductions by those who can most cost-effectively achieve them.[260]

Credit trading programs have proven effective at driving overall reductions in various pollutants.[261] Such programs can also help drive innovation and accelerate the deployment of environmentally friendly new technologies.[262] Unfortunately, although farmers can participate in many existing nutrient credit trading programs,[263] most such programs do not adequately incentivize agricultural participation.[264] Within some existing programs, point source nutrient emitters also

258. U.S. GOV'T ACCOUNTABILITY OFF., GAO-18-84, WATER POLLUTION: SOME STATES HAVE TRADING PROGRAMS TO HELP ADDRESS NUTRIENT POLLUTION, BUT USE HAS BEEN LIMITED 23, 27 (2017) [hereinafter WATER POLLUTION].

259. *Water Quality Trading*, U.S. ENV'T PROT. AGENCY (Nov. 28, 2023), https://www.epa.gov/npdes/water-quality-trading [https://perma.cc/VCV6-J5WS].

260. *Nutrient Credit Trading Markets*, THE WETLANDS INITIATIVE (Sept. 7, 2024, 3:53 PM), https://www.wetlands-initiative.org/nutrient-credit-trading [https://perma.cc/5V5U-B72F].

261. Richard Schmalensee & Robert N. Stavins, *Lessons Learned from Three Decades of Experience with Cap and Trade*, 11 Rev. ENV'T ECON. & POL'Y 59, 71–72 (2017) (reviewing 30 years of cap-and-trade programs and concluding they generally offer a cost-effective means of reducing pollution).

262. *See* Margaret R. Taylor, *Innovation Under Cap-and-Trade Programs*, 109 PROC. NAT'L ACAD. SCI. 4804, 4804–05 (2012).

263. *See, e.g.*, OFF. OF RES. CONSERVATION, MD. DEP'T OF AGRIC., NUTRIENT TRADING PROGRAM 1 (2015), https://mda.maryland.gov/Documents/ag_brief/AgBrief_NutrientTrading.pdf [https://perma.cc/9WQY-RYV3] (explaining that farmers may earn nutrient credits by first complying with the applicable Total Maximum Daily Load and then reducing fertilizer application).

264. *See* Penn State College of Agricultural Sciences, *Farmers Need Better Incentive for Nutrient Credit Trading*, LANCASTER FARMING (Dec. 7, 2022), https://www.lancasterfarming.com/farming-news/news/farmers-need-better-incentive-for-nutrient-credit-trading/article_ceb2d8ce-d811-11eb-a4d3-2b10a7075697.html [https://perma.cc/5M4K-7K79] (explaining that the nutrient credit program in the Chesapeake Bay does not sufficiently reward farmers for participation).

prefer to trade only with other point sources due to uncertainty about the validity of non-point source reductions, such as those from farmers.[265]

*1. Reforming Nutrient Credit Trading Programs to Increase Farmers' Participation*

States with existing nutrient credit trading systems could encourage faster adoption of precision fertilizing technologies within their jurisdictions by modifying these trading systems to make them more accessible and rewarding for farmers. For example, the Chesapeake Bay nutrient credit trading program does not expressly state that credits can be earned by reducing fertilizer application via precision fertilizing, so the program in its current form is unlikely to drive much precision fertilizing investment.[266] Modifying these programs to clearly cover reductions achieved with precision fertilizing could help to fill this gap and encourage greater participation by farmers. To assist state governments in these updates, EPA could release guidance identifying specific precision fertilizing technologies and procedures that states should deem eligible for earning nutrient trading credits. States could then expressly declare that farmers using such practices would qualify for credits, helping to reduce uncertainty within credit trading markets and encourage participation among farmers.

State-level nutrient credit trading systems could even offer stepped-up credits to farmers who reduce their nutrient discharges via precision fertilizing as an additional incentive to invest in these technologies. Credit multipliers are mechanisms used in various market-based systems to encourage the adoption of specific technologies.[267] In the context of nutrient trading systems, such a multiplier could allow farmers to earn twice or three times as many credits for each unit of nutrient reduction achieved specifically through precision fertilizing activities.[268]

265. *See* WATER POLLUTION, *supra* note 258, at 31.

266. *See Credit Generation Requirements*, PA. DEP'T OF ENV'T PROT. (Sept. 4, 2024, 4:37 PM), https://www.dep.pa.gov/Business/Water/CleanWater/NutrientTrading/Pages/ProgramRequirements.aspx [https://perma.cc/856Z-Z448].

267. *See, e.g.*, BRIAN LIPS, CLEAN ENERGY STATES ALL., CREDIT MULTIPLIERS IN RENEWABLE PORTFOLIO STANDARDS 13–14 (2018), https://www.cesa.org/wp-content/uploads/RPS-Multipliers.pdf [https://perma.cc/MW83-5YUW] (describing the use of credit multipliers in Renewable Portfolio Standards to encourage specific renewable energy technologies).

268. *See, e.g.*, *id.* (explaining that a credit multiplier system allows participating parties to earn relatively more credits for their participation).

### *2. Valuable Benefits for Farmers and Nutrient Credit Markets*

Strengthening the rewards for precision fertilizing within nutrient credit trading systems would likely benefit farmers and promote the deployment of these technologies, while also helping to increase the effectiveness of nutrient reduction systems.[269] Reliable data is imperative to the optimal functioning of any credit trading system.[270] Difficulties measuring nutrient reductions from non-point sources are one barrier to successful agricultural industry participation in these programs.[271] Precision fertilizing could potentially help to address these challenges by producing verifiable and trackable data about nutrient reductions from farmers' precision fertilizing activities.

By increasing the financial rewards of precision fertilizing, the aforementioned reforms to nutrient trading systems would enable farmers to internalize more of the benefits of investing in these technologies, thus mitigating the externality problem that has historically led to underinvestment. Nutrient credit trading participation could create lucrative revenue streams for farmers who embrace precision fertilizing. One study estimated that some participating farms could receive roughly $35,000 per year in additional profit through these programs.[272] By allowing farmers to capture more of the broader benefits of precision fertilizing, these reforms could substantially accelerate the pace of adoption of these technologies.

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269. *See* Marc O. Ribaudo et al., *Nitrogen Sources and Gulf Hypoxia: Potential for Environmental Credit Trading*, 52 ECOLOGICAL ECON. 159, 160–61 (2005) (reviewing various studies demonstrating that agricultural sources offer nutrient pollution reduction at a significantly lower price than many point source polluters); Michelle Perez, *Can Nutrient Trading Shrink the Gulf of Mexico's Dead Zone?*, WORLD RES. INST. (Apr. 17, 2013), https://www.wri.org/insights/can-nutrient-trading-shrink-gulf-mexicos-dead-zone [https://perma.cc/KT49-F9UC].

270. Schmalensee & Stavins, *supra* note 261, at 70.

271. *See* WATER POLLUTION, *supra* note 258, at 30–31.

272. John Talberth et al., *How Baywide Nutrient Trading Could Benefit Pennsylvania Farms* 6 (World Res. Inst., Working Paper, July 2010), https://www.wri.org/research/how-baywide-nutrient-trading-could-benefit-pennsylvania-farms [https://perma.cc/DJH9-LNPK]; *see* GEORGE VAN HOUTVEN ET AL., CHESAPEAKE BAY COMM'N, NUTRIENT CREDIT TRADING FOR THE CHESAPEAKE BAY 41–42 (2012), https://www.chesbay.us/library/public/documents/Policy-Reports/nutrient-trading-2012.pdf [https://perma.cc/BQR9-RQJ6] (explaining that allowing agricultural participation in nutrient credit trading systems can deliver savings as high as 36% of total compliance cost).

### *E. Establishing a Precision Fertilizing Loan Guarantee Program*

A federal loan guarantee program could be another notable means of promoting more widespread adoption of precision fertilizing technologies.[273] Under a federal loan guarantee program for precision fertilizing equipment financing, the federal government would essentially guarantee repayment of principal and interest for qualifying agricultural borrowers.[274] Such programs have proven effective at increasing access to credit for a specific category of potential borrowers who might otherwise have difficulty securing reasonably-priced private loans.[275]

Loan guarantees have successfully reduced barriers to private financing to help promote investments in emerging technologies in other contexts.[276] For example, the Energy Policy Act of 2005 created a clean energy loan guarantee program to help facilitate lower-cost private financing for certain types of renewable energy investment.[277] Among other things, such programs helped emerging solar energy companies secure reasonably-priced financing at a time when solar was viewed as an unproven technology and high-risk investment.[278] Loan guarantees for precision fertilizing could similarly mitigate concerns about the risk of such investments and help farmers to secure more affordable financing.[279]

A loan guarantee program could also help to overcome borrowing-related risks that might otherwise deter some farmers from purchasing precision fertilizing equipment. Farmers are notoriously hesitant to take on additional debt, and elevated interest rates have only strengthened that hesitancy in recent years,[280] impairing agricultural borrowing activity for farm equipment and other

273. *See* PHILLIP BROWN, CONG. RSCH. SERV., R42152, LOAN GUARANTEES FOR CLEAN ENERGY TECHNOLOGIES: GOALS, CONCERNS, AND POLICY OPTIONS 1 (2012).

274. *Id.* at 1.

275. *Id.* at 16.

276. *See id.* at 3–7.

277. *Id.* at 5–6.

278. RULE, *supra* note 220, at 389–90.

279. *See* BROWN, *supra* note 273, at 16.

280. Chuck Abbott, *High Interest Rates Discouraging Farmers from Borrowing Money*, SUCCESSFUL FARMING (Oct. 20, 2023), https://www.agriculture.com/high-interest-rates-discouraging-farmers-from-borrowing-money-8364305 [https://perma.cc/4SLG-8SJJ] (explaining that average operating loans for farmers decreased nearly 20% between 2022 and 2023 due to increasing farm loan interest rates); Nate Kauffman & Ty Kreitman, *Farm Lending Slows as Interest Rates Rise*, FED. RES. BANK OF KAN. CITY (Jul. 12, 2023), https://www.kansascityfed.org/agriculture/agfinance-updates/farm-lending-slows-as-interest-rates-rise/ [https://perma.cc/NE45-FFUM].

purposes.[281] Loan guarantee programs are a familiar financial medium for farmers and would give many farmers access to lower-cost credit and thus help to alleviate these concerns.[282] Such a program could be tailored to account for the specific costs and risks associated with precision fertilizing technologies and be structured to not interfere with other existing agricultural finance programs.[283] Further, in the case of default, lenders may have a continuing security interest in the precision fertilizing technology.[284]

## VI. CONCLUSION

Precision fertilizing technologies are an increasingly capable means of reducing fertilizer use on farms across the United States.[285] Fertilizers are necessary to produce adequate food supplies, but excess use can have devastating effects on the environment, human health, and the economy.[286] Although precision fertilizing can enable farmers to use less fertilizers without sacrificing crop yields, relatively few American farmers are presently using them.[287] The high upfront costs of precision fertilizing equipment, farmers' risk aversion, and pervasive externality problems are likely slowing the pace of adoption of these promising technologies across the country.[288] Fortunately, through policy reforms it is possible to reduce many of these barriers and accelerate the deployment of precision fertilizing technologies across the country.

Policymakers could adjust various existing agricultural laws and programs to better incentivize precision fertilizing and introduce new policies specifically

281. P.J. Huffstutter & Bianca Flowers, *Insight: End of Cheap Money for U.S. Farmers Plows Trouble into Food Production*, REUTERS (Nov. 22, 2022, 11:34 AM), https://www.reuters.com/markets/commodities/end-cheap-money-us-farmers-plows-trouble-into-food-production-2022-11-22/ [https://perma.cc/BV92-T888].

282. *See Farm Loan Programs*, FARM SERV. AGENCY, U.S. DEP'T OF AGRIC. (Sept. 4, 2024, 5:02 PM), https://www.fsa.usda.gov/programs-and-services/farm-loan-programs/index [https://perma.cc/EY6U-HXLG] (detailing various existing federal farm loan programs).

283. *See Lending for Livestock, Credit for Crops: Purchase-Money Security Interests*, NAT'L AGRIC. L. CTR. (Jan. 5, 2021), https://nationalaglawcenter.org/lending-for-livestock-credit-for-crops-purchase-money-security-interests/ [https://perma.cc/GB84-MRRB] (explaining how agricultural lenders secure loans with security interests in agricultural equipment); *see also* Mizik, *supra* note 119, at 390 (for example, precision fertilizing technology is not expended like other agricultural inputs).

284. *See Lending for Livestock, Credit for Crops: Purchase-Money Security Interests*, *supra* note 283.

285. *See* Heyl et al., *supra* note 228, at 5.

286. Townsend et al., *supra* note 81, at 242.

287. *See* Ling & Bextine, *supra* note 135.

288. *See* Mizik, *supra* note 119, at 390.

designed to promote such investment. Federal tax credits programs, BMP programs, and nutrient credit trading systems could each help farmers to internalize more of the benefits of precision fertilizing technologies and thereby drive greater private investment in them. Further, loan guarantees and agricultural support programs could help to mitigate the risks associated with precision fertilizing investment. Educational outreach through extension programs could likewise help to inform farmers about precision fertilizing, its benefits, and the government programs that support it.

Although synthetic fertilizer uses and other modern farming practices have introduced new threats to ecosystems and human health, innovations such as precision fertilizing are emerging to address these concerns.[289] Through well-crafted policy reforms that help farmers leverage these powerful technologies, states and the federal government can help to ensure that future generations enjoy food on their tables and clear lakes and rivers in their communities.

289. *See What's the Problem with Fossil Fuel-Based Fertilizer?*, *supra* note 96.