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Nutrients in Agricultural Production: A Water Quality Overview

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February 20, 2015

Congressional Research Service
7-5700
www.crs.gov
R43919

CRS REPORT
Prepared for Members and Committees of Congress

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Summary

Nutrients are elements essential to plant and animal growth. In agricultural production, the focus generally rests on the three primary macronutrients—nitrogen (N), phosphorus (P), and potassium (K)—because of their relative abundance in plants. As crops grow and are harvested, they gradually remove the existing nutrients from the soil and over time will require additional nutrients to maintain or increase crop yield. When nutrients are added in excess of the plants' ability to utilize them, there is an increased risk that the nutrients will enter the surrounding environment (water or air) and create environmental problems. The nutrients of primary environmental concern in agriculture are nitrogen and phosphorus.

One of the better-known environmental responses to high levels of nutrients is eutrophication—the enrichment of water bodies, which can promote the growth of algae. Under certain conditions, algal blooms can occur that can deplete the oxygen content of water, block sunlight to other organisms, and potentially produce toxins. These harmful algal blooms can contaminate surface and drinking water supplies, potentially harming animal and human health.

Over time, through research and technological advancements, an understanding of how crops utilize nutrients and how nutrients move in the environment have led to the development of a number of best management practices (BMPs) for nutrient management. Primarily, nutrient BMPs focus on preventing or reducing the ways in which excess nutrients can enter the environment. Crop production BMPs for nutrient management generally focus on applying the right amount of nutrients, from the right source, in the right place, at the right time. BMPs for livestock operations are typically prescribed for concentrated animal feeding operations (CAFOs), where animals are raised or bred in close quarters, thus creating a concentrated source of nutrients.

Currently, few federal regulations govern the environmental impacts from agriculture. Some environmental laws specifically exempt agriculture from regulatory requirements, and others are structured so that agriculture is not addressed by most, if not all, of the regulatory impact. The primary regulatory authority protecting water resources is the Clean Water Act (CWA). Regulatory requirements for agricultural nutrients under the CWA are limited to permitting requirements for large CAFOs and the establishment of total maximum daily loads, which are pollution limits for state-identified impaired waters.

The major federal response to nutrient pollution from agriculture continues to be through research, education, outreach, and voluntary technical and financial incentives. A number of U.S. Department of Agriculture agencies provide support through education, outreach, and research, while federal funds are provided through conservation programs to help agricultural producers adopt BMPs for nutrient reduction.

As the 114th Congress reviews nutrient pollution in U.S. waterways, among the issues being discussed is how to address nutrients from agricultural sources. Whether the current balance between regulatory action and voluntary response is enough to meet environmental goals, who should bear the cost of preventing and correcting nutrient loading, and whether the tools for correction are adequate are among the issues being discussed. How these issues are resolved will have important implications for agriculture, which has taken a keen interest in water quality policy and legislation.

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Introduction

United States agriculture has been touted as a model for production and a leader of innovation. The nation's intense agricultural production, however, can lead to adverse impacts to the surrounding environment. In some cases, it is the excess of basic nutrients required for plant and animal growth that can cause this degradation. Ongoing research aims to improve understanding of nutrients used and released in agricultural production, including how they interact in the environment, the damages they can cause, and ways to prevent or correct the damage.

Federal policies concerning agricultural nutrients have changed over time. Currently, few federal regulations govern the environmental impacts of nutrients from agriculture. Some environmental laws specifically exempt agriculture from regulatory requirements, and others are structured so that agriculture is not addressed by most, if not all, of the regulations. The major federal response continues to be through research, education, outreach, and voluntary technical and financial incentives to producers.

Recent events involving degraded water quality have raised questions as to whether the current federal response to agricultural nutrients is adequate or should be altered. This has prompted both administrative and congressional action.[1] This report discusses the types and sources of nutrient pollution from agricultural production; possible environmental effects of nutrient pollution; examples of current control measures; the federal response to excess nutrients, including regulatory and incentive-based programs; and future considerations for nutrient management policy at the federal level.[2]

Caveats

Agriculture is one of a number of industries that produce, use, or release nutrients that may adversely affect the environment. The lack of discussion in this report of other industries that might release excess nutrients does not imply that one industry is more or less to blame for environmental harms. The science and methods of pinpointing the exact source of excess nutrients causing environmental harm are still evolving. Regardless, whether released by agriculture, lawn care companies, or sewage treatment plants, the environmental harms of excess nutrients are much the same.

A large body of research, including numerous technical publications, explores the relationship between agriculture and nutrients. This report gives an overview of current knowledge, while further complexities of individual issues are discussed in many of the sources cited throughout the report.

Similarly, the examples used to describe best management practices and federal response should not be considered exhaustive lists. In many cases, the success or failure of a particular nutrient management practice will vary greatly by location. This report highlights examples of these practices but is not meant to imply or suggest that they can be universally applied. In addition to the federal response, the private sector, nonprofit groups, and state and local governments play

[1] U.S. Congress, Senate Committee on Agriculture, Nutrition, and Forestry, *Farmers and Fresh Water: Voluntary Conservation to Protect Our Land and Waters*, 113th Cong., 2nd sess., December 3, 2014.

[2] While distinctly related, air quality issues are not discussed in detail but may be mentioned where applicable.

active roles in the management of nutrients from agriculture, either through regulation or technical support. These nonfederal efforts are outside the scope of this report.

Nutrients: A Primer

Nutrients are elements essential to plant growth.[3] Plant roots absorb nutrients—including water, oxygen, and others—from the soil.[4] As crops grow and are harvested, they gradually remove the existing nutrients from the soil. Over time, most soils will require additional nutrients to maintain or increase crop yield. When nutrients are added in excess of the plants' ability to utilize them, there is an increased risk that the nutrients will enter the surrounding environment (water or air) and create problems such as algal blooms (discussed below).

Plants utilize nutrients in different ways, and each plant has a different set of nutrient requirements. How, where, and when plants utilize nutrients can greatly affect the overall yield and plant production. For a farmer seeking to maximize crop yields and lower input costs, it can be critical to understand a crop's nutrient requirements.

Basic nutrients—carbon, hydrogen, and oxygen—are the most abundant elements in plants. In addition, plants utilize other nutrients commonly referred to as macronutrients and micronutrients (see **Figure 1**). In agricultural production, the focus generally rests on the three primary macronutrients—nitrogen (N), phosphorus (P), and potassium (K)—because of their relative abundance in plants. Micronutrients, while not commonly discussed, may have just as much of an effect on plant growth as macronutrients when levels are too high (toxic) or too low (deficient). This report focuses on two of the three primary macronutrients (nitrogen and phosphorus), because of the volume used in agricultural production and the relative potential for environmental harm if they are overused.[5] This is not meant to indicate that other nutrients do not also pose an environmental harm if overapplied.

Plants use nutrients in an ionic form rather than as raw elements (see **Figure 2**). Nutrients are taken up by plants in three forms:

- interception—by direct contact with the nutrient;
- mass flow—when nutrients move with water as the plant transpires;[6] and
- diffusion—when nutrients move from high to low concentration.

[3] Nutrients are also essential to animal health; however, they are discussed in this report in the context of nutrients as a by-product of livestock production (e.g., manure, bedding, etc.) rather than an input.

[4] Some soils are naturally fertile because they contain minerals high in key elements, while others include high levels of organic matter and thus high levels of key nutrients. There are a number of physical, chemical, and biological soil properties that affect the nutrient availability for plants.

[5] Potassium is a mineral naturally found in soils. It is essential for plant growth and is frequently found in amounts that exceed the amount used by crops in a given season. Unlike other minerals, however, potassium does not act as a pollutant in the environment and therefore is not discussed in depth in this report.

[6] Transpiration is the process by which moisture is carried through plants from roots to small pores on the underside of leaves, where it changes to vapor and is released to the atmosphere. Transpiration is essentially evaporation of water from plant leaves. For more information, see U.S. Geological Survey, *The Water Cycle*, "Transpiration – The Water Cycle," http://water.usgs.gov/edu/watercycletranspiration.html.

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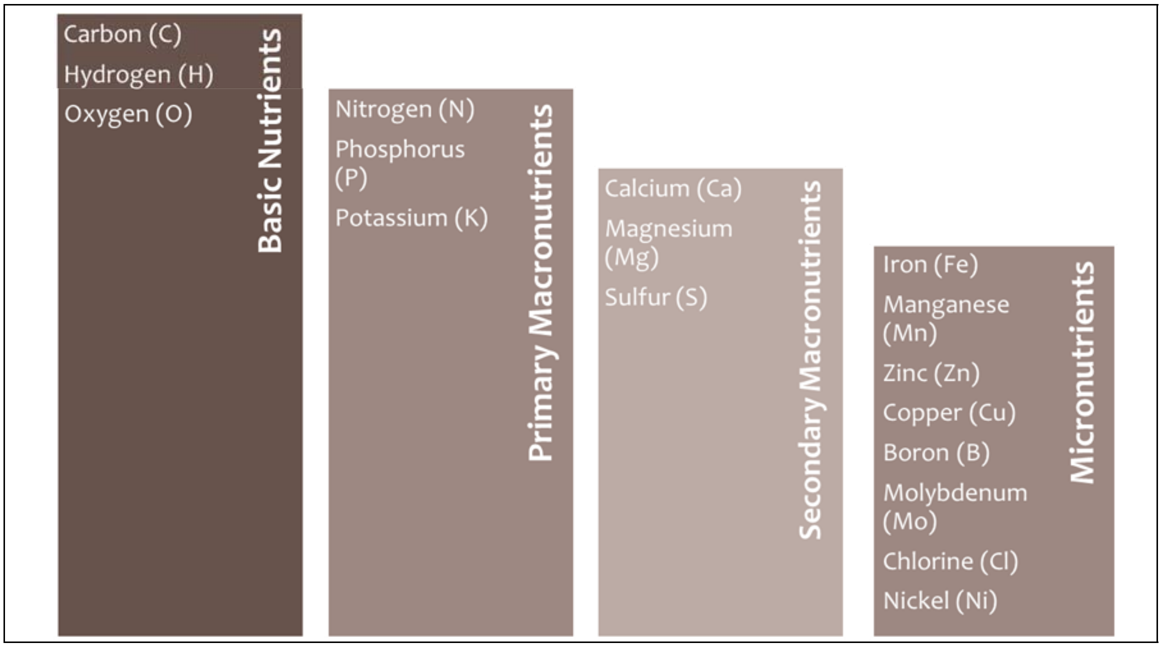
Interception accounts for a very low percentage of nutrients taken up by plants. Mass flow, on the other hand, is the most substantial method of nutrient movement toward a plant's roots. This is particularly important for more "mobile" nutrients (e.g., nitrogen) and less important for relatively "immobile" nutrients (e.g., phosphorus). Diffusion is most important for nutrients that are relatively immobile, have low solution concentrations, and are needed in large amounts (e.g., phosphorus and potassium).

Figure 1. Essential Elements for Plant Growth



Source: U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS)—4 Nutrient Stewardship, *Overview of Soil Fertility, Plant Nutrition, and Nutrition Management*, Education and Training Module, http://www.nutrientstewardship.com/nrcs/overview/multiscreen.html.

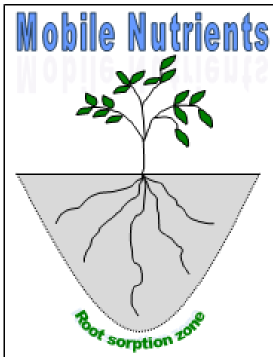
Notes: This figure does not represent a definitive list. Some research publications include more or fewer elements or use different categories than those presented here. Other elements, such as sodium (Na), cobalt (Co), vanadium (V), and silicon (Si), are known to be beneficial in some plants, but generally are not considered essential to most plants and therefore not included.

Plants use nutrients at different times and at different rates throughout the growing cycle. For example, for corn, phosphorus is important early in the growing season, but not necessarily later in the season. Nitrogen is important in both the beginning and later in the growing season, before the plant begins the stem-extension phase. Various nutrients are also applied differently by farmers, based on knowledge about nutrient mobility in soils. For example, nitrogen can be applied using a broadcast method (discussed further under "Best Management Practices") because of its mobility in the soil. Phosphorus, on the other hand, is most effective when placed below the soil surface near the root system because it is generally immobile.

Adding Nutrients—Fertilizers

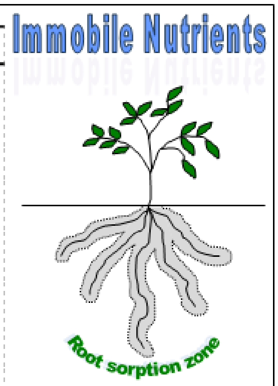
Fertilizers are either organic or inorganic materials applied to the soil to promote plant growth. They may either contain a specific nutrient or may be used to increase the availability of other plant nutrients. Organic fertilizers are those derived from living matter (e.g., manure) whereas inorganic fertilizers are synthetic or mined (e.g., urea as a nitrogen source or potash as a potassium source).[7]

Figure 2. Relationship Between Nutrient Mobility and Plant Extraction



Element	Form
Nitrogen (N)	NO_3^- (nitrate), NH_4^+ (ammonium)
Sulfur (S)	SO_4^{-2} (sulfate)
Chlorine (Cl)	Cl^- (chloride)
Boron (B)	H_3BO_3 (boric acid), $H_2BO_3^-$ (borate)

Mobile nutrients are obtained from all the soil surrounding the plant's roots.



Element	Form
Potassium (K)	K^+
Phosphorus (P)	$H_2PO_4^-$, HPO_4^{-2} (phosphate)
Calcium (Ca)	Ca^{+2}
Magnesium (Mg)	Mg^{+2}
Iron (Fe)	Fe^{+2} (ferrous), Fe^{+3} (ferric)
Manganese (Mn)	Mn^{+2}
Zinc (Zn)	Zn^{+2}
Copper (Cu)	Cu^{+2}
Molybdenum (Mo)	MoO_4^{-2} (molybdate)
Nickel (Ni)	Ni^{+2}

Immobile nutrients are obtained from a small amount of soil immediately surrounding the plant's roots.

Source: CRS, modified from W. R. Raun, G. V. Johnson, and R. W. Mullen, et al., "Bray Nutrient Mobility Concept," in *Soil-Plant Nutrient Cycling and Environmental Quality* (Stillwater, OK: Oklahoma State University), http://soil5813.okstate.edu/BOOK.htm.

Organic Fertilizers

The primary organic fertilizer is animal manure. Manure can be a good source of plant-available nutrients (including but not limited to nitrogen and phosphorus), as well as providing increased soil organic matter, increased water and nutrient retention in soil, and decreased soil density. The nutrient content of manure can vary greatly depending on animal type, diet, bedding, moisture content, and storage method.[8]

Prior to the development of inorganic fertilizers, organic "wastes" were a major source of nutrients for crop production. According to the U.S. Department of Agriculture (USDA), 15.8 million acres, or about 5% of all U.S. cropland, use manure as fertilizer (**Table 1**).[9] A number of factors prevent a wider use of manure fertilization. Primarily, the cost of transporting manure can be prohibitive.[10] The nutrient content of the manure, the type of crop grown and nutrients required (i.e., the nutrient needs of plants being grown may not match nutrients in readily available manure), compaction from manure application equipment, and the relative cost and availability of inorganic fertilizers, among other factors, also affect the use of organic wastes as fertilizers.

[7] Craig C. Sheaffer and Kristine M. Moncada, *Introduction to Agronomy: Food, Crops, and Environment*, 2nd ed. (Clifton Park, NY: Delmar, 2012).

[8] Determining the nutrient levels of manure can be done through sampling and testing prior to application. Because the nutrient content of manure is usually the largest unknown and first step to preventing overapplication, sampling and testing is strongly encouraged as a best management practice (discussed further in "Best Management Practices" below).

[9] James M. MacDonald, Marc O. Ribaudo, and Michael J. Livingston, et al., *Manure Use for Fertilizer and for Energy: Report to Congress*, USDA, Economic Research Service (ERS), AP037, Washington, DC, June 2009, http://www.ers.usda.gov/media/156155/ap037_1_.pdf.

[10] One exception to this is for poultry litter, which is dry (and typically less costly to transport) and produced on farms that typically have no crop production. Thus, crops such as peanuts and cotton, which are grown in areas near poultry production (e.g., the Southeast), tend to rely on poultry litter transported from off the farm.

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Table 1. Acres Receiving Manure from Various Animal Types

(by crop and species, 2006)

	Acres applied (thousand), by source of manure					
Crop	**Dairy**	**Beef Cattle**	**Swine**	**Poultry**	**Other[a]**	**All**
Barley	54	36	4	4	2	100
Corn	5,612	1,617	1,161	472	224	9,086
Cotton	67	101	0	228	1	397
Oats	218	139	8	3	7	375
Peanuts	0	8	0	44	0	52
Sorghum	1	37	7	1	0	46
Soybeans	354	327	139	132	30	982
Wheat	107	250	26	12	6	401
All	**6,413**	**2,515**	**1,345**	**896**	**270**	**11,439[b]**

Source: James M. MacDonald, Marc O. Ribaudo, and Michael J. Livingston, et al., *Manure Use for Fertilizer and for Energy: Report to Congress*, USDA, ERS, AP037, Washington, DC, June 2009, http://www.ers.usda.gov/media/156155/ap037_1_.pdf.

a. Other includes equine, sheep, and biosolids.

b. Other crops, such as hay and grasses, account for approximately 4.3 million acres receiving manure. These are not reflected in this table, but are in the earlier stated total of 15.8 million acres receiving manure in the United States.

From a livestock perspective, animal waste is a by-product of production that must be managed to avoid environmental harms and for the health of the animals themselves if raised in captivity. For a confined production system, manure must be utilized—typically by being collected, stored, and distributed elsewhere, likely on available crop- or pastureland. In the case of grazing livestock, the animals deposit manure directly onto pastureland, thus fertilizing the associated grassland. High stocking rates, however, may lead to an imbalance, which in turn could create an excess supply of nutrients. If not properly managed, manure can adversely impact water quality through surface runoff and erosion, direct discharges to surface waters, spills and other dry-weather discharges, and leaching into soil and groundwater. It can also result in emission to the air of particles and gases such as ammonia, hydrogen sulfide, and volatile organic chemicals.

Soil Organic Matter

Soil organic matter (SOM) is created by the cycling of organic compounds in plant, animals, and microorganisms into the soil. Essentially, SOM is soil composed of anything that once lived, including plant and animal remains, cell and tissues of soil organisms, and plant roots and soil microbes. Well-decomposed matter can form "humus," a dark brown, porous, spongy material that is essential for maintaining optimum soil physical conditions important for plant growth, water-holding capacity, and nutrient availability.[11] In most soils, SOM accounts for less than 5% of the total volume but can considerably impact the nutrients available for plants.

The amount of SOM is controlled by a balance between plant and animal materials and losses from decomposition. There are a number of benefits to increasing SOM, including reduced erosion and the storing of nutrients (nitrogen, phosphorus, and sulfur). These are primarily achieved through the use of cover crops and reduced or no-till tillage systems (see the "Best Management Practices" section).

[11] USDA, NRCS, National Soil Survey Center, *Soil Quality Indicators: Organic Matter*, Soil Quality Information Sheet, Lincoln, NE, April 1996.

Theoretically, of the total manure produced, more could be utilized on additional cropland than what is currently utilized in order to potentially reduce the risk of environmental harms from excessive concentrations. Regions with a higher capacity for manure are largely due to the type of soils and crops grown in the area. For example, the soils (mollisols) and crops (corn) grown in the Midwest are able to utilize additional nitrogen from manure (**Figure 3**), whereas the soils (ultisols) and crops (cotton and rice) in the Southeast are able to handle more phosphorus from manure (**Figure 4**). In some cases the ability to utilize additional manure application corresponds to areas with large livestock populations. In other cases, livestock production occurs in areas with

Figure 3. Capacity of Cropland to Assimilate Nitrogen

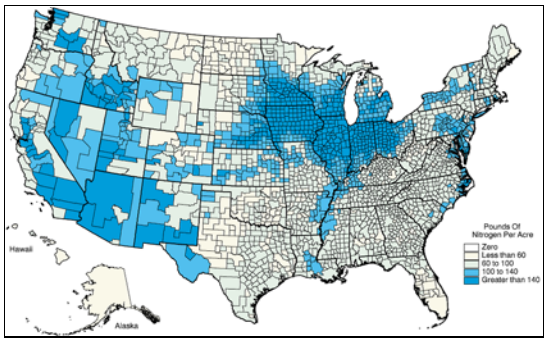


Figure 4. Capacity of Cropland to Assimilate Phosphorus

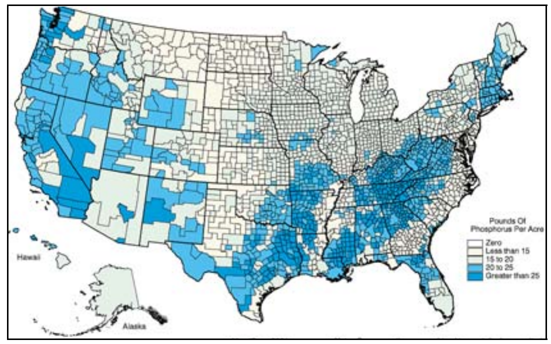


Figure 5. Manure Nitrogen in Excess of Need

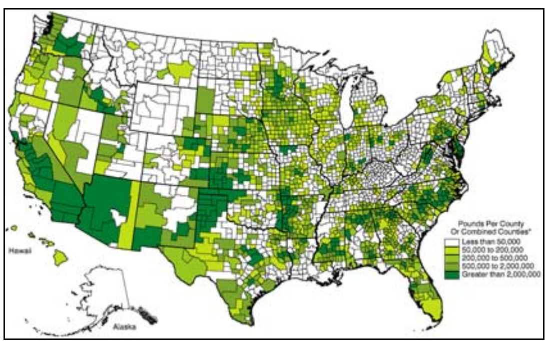
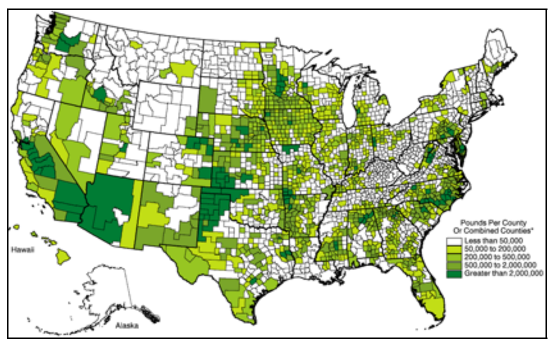


Figure 6. Manure Phosphorus in Excess of Need



Source: Robert L. Kellogg, Charles H. Lander, and David C. Moffitt, et al., Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States, USDA, NRCS, ERS, nps00-0579, Washington, DC, December, 2000, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_012133.pdf.

Notes: Figures 5 and 6 assume no export from the farm.

low or modest capacity to assimilate additional manure, thereby increasing the risk of excessive concentrations. When the amount of manure produced by an operation is more than the assimilative capacity of the land,[12] an excess of manure is created (**Figure 5** and **Figure 6**).[13] This

[12] The assimilative capacity refers to the estimated amount of nutrients taken up and removed at harvest for cropland and the amount that could generally be applied to pastureland without accumulating nutrients in the soil.

[13] Robert L. Kellogg, Charles H. Lander, and David C. Moffitt, et al., "Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States," USDA, NRCS, ERS, nps00-0579, Washington, DC, December, 2000, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/ (continued...)

can create a greater risk for potential runoff and leaching of manure nutrients and subsequent water quality issues. Geographically, areas with excess farm-level nutrients correspond to areas with increasing numbers of confined animals.[14]

Inorganic Fertilizers

Inorganic fertilizers consist of nutrients that are mined or created synthetically. In most cases, compared to organic fertilizers, inorganic fertilizers are more concentrated, their nutrient content is easily identifiable, and in some cases, they are more cost effective to use. This does not, however, make inorganic fertilizers any less damaging when found in excess in the environment. Similar to organic fertilizers, when applied in excess, inorganic fertilizers can be lost to the environment through volatilization into the air, leaching into groundwater, emission from soil to air, and runoff into surface water.

The use of inorganic fertilizers has changed over time and continues to outpace the use of organic fertilizers in the United States. The introduction of seed varieties that respond more favorably to specific nutrients, the use of more precise application technology, and the overall price of commercial fertilizers have driven much of this change.[15] The three primary inorganic fertilizers produced commercially are nitrogen-, phosphorus-, and potassium-based products. In general, commercial nitrogen fertilizer use has increased more than phosphorus and potassium (**Figure 7**). Corn, which uses intensive fertilizer applications, accounts for almost 40% of the total U.S. commercial fertilizer consumption, principally due to the high number of planted acres and crop requirements.[16]

(...continued)

nrcs143_012133.pdf.

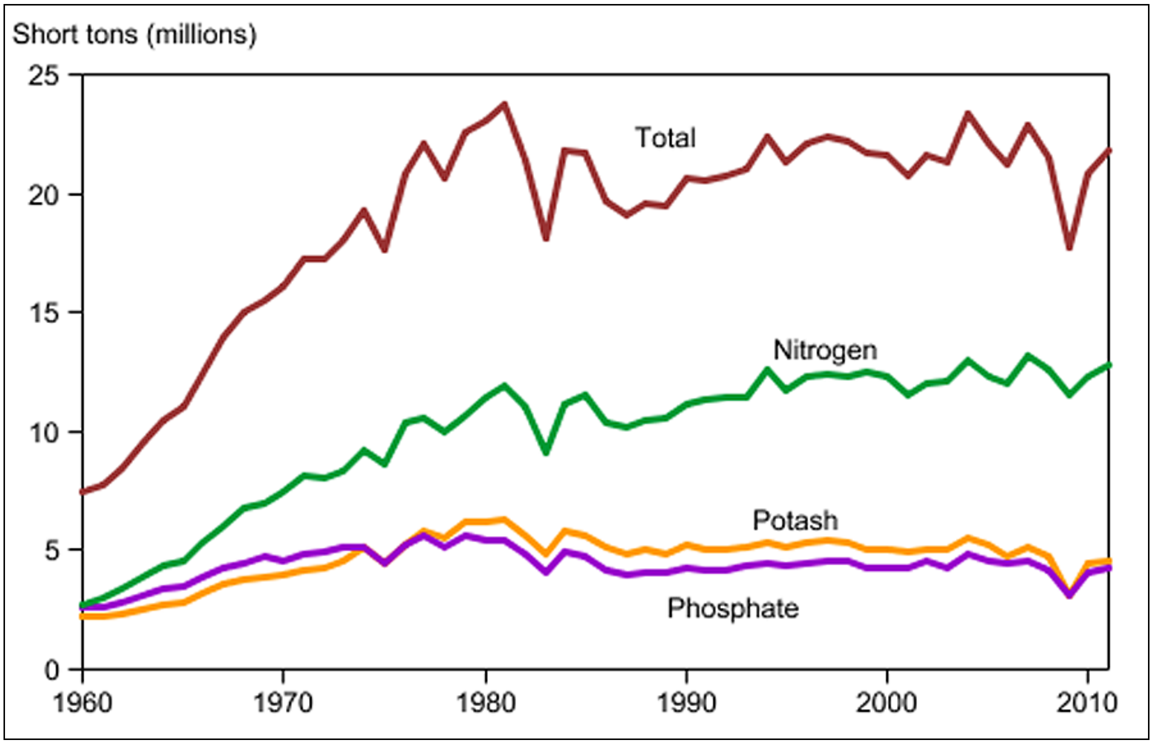
[14] Ibid.

[15] Richard Nehring, *Fertilizer Use and Markets*, USDA, ERS, July 12, 2013, http://www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/fertilizer-use-markets.aspx.

[16] Ibid.

Figure 7. Fertilizer Use in U.S. Agriculture

1960-2011



Source: Richard Nehring, *Fertilizer Use and Markets*, USDA, ERS, July 12, 2013, http://www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/fertilizer-use-markets.aspx.

Nitrogen

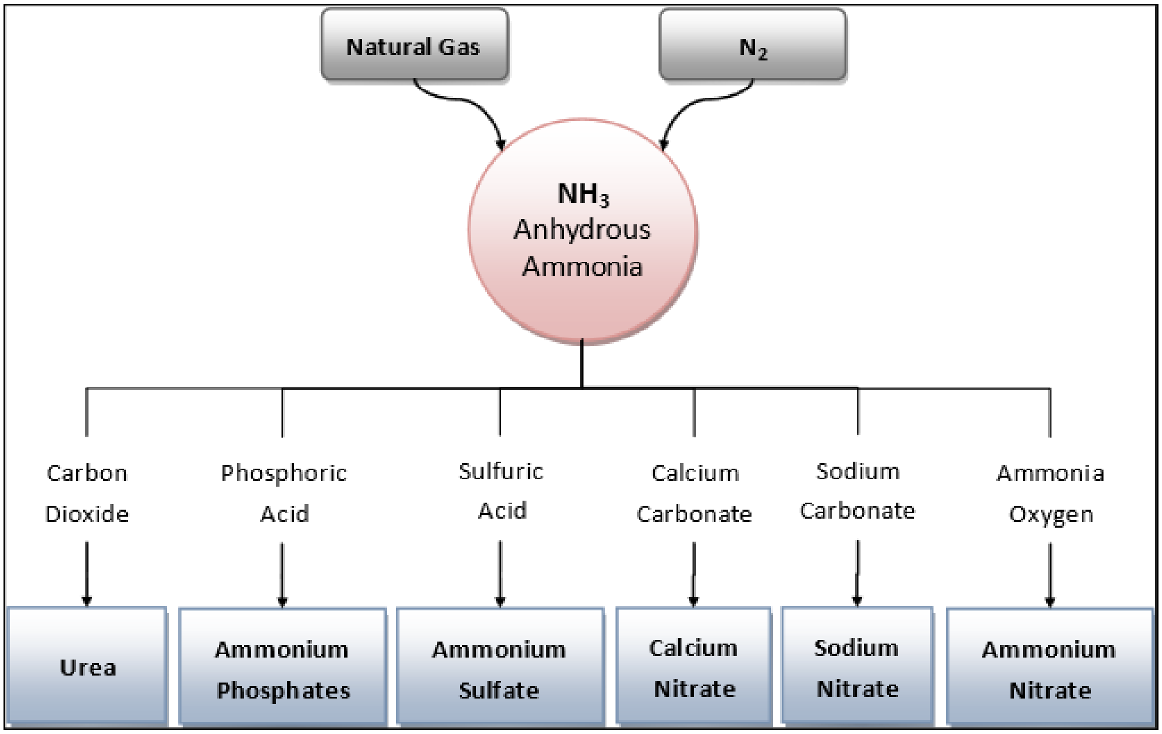
Nitrogen (N) is an abundant element, with gaseous nitrogen (N_2) accounting for 78% of the earth's atmosphere. Despite this abundance, N_2 cannot be used as a nutrient by living organisms unless converted to a useable form. This conversion occurs synthetically through the Haber-Bosch process, developed in the early 20th century, which converts "unreactive" N_2 to a more usable "reactive" form.[17] The process uses heat and pressure to combine N_2 with hydrogen from natural gas. The result is NH_3 (anhydrous ammonia), which can be used as a fertilizer directly or reacted with other compounds to form other products (**Figure 8**).[18] Approximately 74% of the NH_3 produced worldwide is for nitrogen fertilizer. Domestically, NH_3, urea (NH_3 with carbon dioxide, $CO(NH_2)_2$), and dissolved N (with water) account for 90% of total N fertilizer use.[19]

[17] Marc Ribaudo, Jorge Delgado, and LeRoy Hansen, et al., *Nitrogen in Agricultural Systems: Implications for Conservation Policy*, USDA, ERS, ERR-127, Washington, DC, September 2011.

[18] Craig C. Sheaffer and Kristine M. Moncada, *Introduction to Agronomy: Food, Crops, and Environment*, 2nd ed. (Clifton Park, NY: Delmar, 2012).

[19] John L. Havlin, Samuel L. Tisdale, and Werner L. Nelson, et al., *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*, 8th ed. (Boston: Pearson, 2014).

Figure 8. Nitrogen-Containing Fertilizers



Source: Adapted from Craig C. Sheaffer and Kristine M. Moncada, *Introduction to Agronomy: Food, Crops, and Environment*, 2nd ed. (Clifton Park, NY: Delmar, 2012).

Phosphorus

Phosphate rock is the primary raw material used to manufacture soluble phosphorus (P) fertilizers. The sedimentary deposit is found in a number of countries, with the largest deposits in northern Africa, China, the Middle East, and the United States. Annual world phosphate rock production is projected to increase from 228 million tons in 2013 to 260 million tons in 2017.[20] In the United States, mines in Florida and North Carolina account for over 85% of domestic output. Other domestic mining operations are located in Idaho and Utah. In 2013, 95% of U.S. mined phosphate rock was used to manufacture phosphate fertilizers and animal feed supplements.[21]

Potassium

Similar to phosphorus, potassium fertilizer is primarily a mined material. Mined and manufactured salts containing soluble potassium (K) are referred to as potash.[22] The largest high-grade potash deposit in the world is in the Saskatchewan province of Canada. Domestic production occurs in Michigan, New Mexico, and Utah. In 2013, approximately 85% of potash sales in the United States were by the fertilizer industry.

[20] Stephen M. Jasinski, *Phosphate Rock*, USGS (U.S. Geological Survey), Mineral Commodity Summaries, February 2014, http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2014-phosp.pdf.

[21] Ibid.

[22] Stephen M. Jasinski, *Potash*, USGS (U.S. Geological Survey), Mineral Commodity Summaries, February 2014, http://minerals.usgs.gov/minerals/pubs/commodity/potash/mcs-2014-potas.pdf.

Effects of Nutrient Excess on Water Quality

As nutrients cycle through the soil-plant-atmosphere continuum, some are recovered by plant uptake, some incorporated into the soil organic matter (SOM), and some precipitated as solid minerals.[23] The remainder can be transported to surface water, groundwater, and the atmosphere. The increased use of nutrients in agricultural production has increased the potential for nutrient excess and associated environmental and health impairments. Recent water and air quality concerns have brought attention to excessive nutrients in the environment and the damage they can create.[24] The nutrients of primary environmental concern in agriculture are nitrogen and phosphorus.

Water quality concerns are present across the United States for a number of reasons, including pollution from excess nutrients, heavy metals, and toxic substances, to name a few.[25] Overall, data reported by the U.S. Environmental Protection Agency (EPA) and states indicate that 44% of river and stream miles assessed by states and 64% of assessed lake acres do not meet applicable water quality standards and are impaired for one or more desired uses.[26] In 2006, EPA issued an assessment of streams and small rivers and reported that 67% of U.S. stream miles are in poor or fair condition and that nutrients and streambed sediments have the largest adverse impact on the aquatic species in these waters.[27] Agricultural production can contribute both nutrient and sediment loading[28] to waterways if not properly managed.

Nitrogen

As stated previously, nitrogen is a mobile nutrient that can occur in a variety of forms. Nitrogen is affected by chemical and biological processes that can change its form and transfer it to or from water, soil, biological organisms, and the atmosphere. The increasing use of reactive nitrogen in agriculture also increases the potential for nitrogen to be lost to the environment as ammonia (NH_3), ammonium (NH_4), nitrate (NO_3), nitrogen oxides (NO_x), and nitrous oxide (N_2O).[29]

Excess nitrogen can be transferred to water sources in a number of ways, including:

- soil erosion—either by wind or water, erosion can move soil particles containing nitrogen into surrounding waterways;

[23] John L. Havlin, Samuel L. Tisdale, and Werner L. Nelson, et al., *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*, 8th ed. (Boston: Pearson, 2014).

[24] While distinctly related, air quality issues are not discussed in detail in this report.

[25] For additional information, see CRS Report R43867, *Water Quality Issues in the 114th Congress: An Overview.*

[26] U.S. Environmental Protection Agency, *National Water Quality Inventory: Report to Congress, 2004 Reporting Cycle*, EPA 841-R-08-001, January 2009, http://water.epa.gov/lawsregs/guidance/cwa/305b/2004report_index.cfm.

[27] U.S. Environmental Protection Agency, *Wadeable Streams Assessment: A Collaborative Survey of the Nation's Streams*, EPA 841-B-06-002, December 2006, http://www.epa.gov/owow/streamsurvey/.

[28] Erosion caused by water is the detachment and transport of soil particles by rainfall or irrigation. These soil particles flow through channels to associated waterways and are referred to as a sediment load. This is a naturally occurring process, but it can be accelerated with heavy water events and an unstable soil surface.

[29] Marc Ribaudo, Jorge Delgado, and LeRoy Hansen, et al., *Nitrogen in Agricultural Systems: Implications for Conservation Policy*, USDA, ERS, ERR-127, Washington, DC, September 2011.

- runoff—dissolved nitrogen, either as inorganic (e.g., nitrate) or organic (e.g., manure) fertilizer, applied directly to the soil surface can "run off" the field with moving water (e.g., rain, snowmelt, or irrigation) if not incorporated into the soil; and
- leaching—water moving through the soil profile can transport dissolved nitrogen to underground water sources or through tile drains[30] to surface water.

Phosphorus

Phosphorus is an immobile nutrient and therefore is generally transferred to water through sediment-based runoff or erosion. More than 80% of phosphorus transported from cultivated lands is associated with soil particle and organic material erosion during flow events (e.g., rain or irrigation).[31] To a lesser extent, phosphorus leaching can occur through subsurface flow, primarily transported in drainage waters (e.g., through tile drains). While some soils can absorb applied phosphorus, they are not infinite sinks. Once the capacity of the soils to absorb phosphorus is exceeded, the excess will dissolve and move more freely with water.[32] Continued application of phosphorus beyond plant requirements can be a major cause of soil phosphorus saturation; both surface runoff and subsurface flow are linked to soil phosphorus concentration.

Environmental Effects

One of the better-known environmental responses to high levels of nutrients is eutrophication—the enrichment of water bodies, which can promote the growth of algae. When nutrients (e.g., nitrogen and phosphorus) and sunlight stimulate algal growth (e.g., algae, seaweed, and phytoplankton), this increases the amount of organic matter in an aquatic ecosystem over time. Algae are a natural part of the ecosystem, and most species of algae are not harmful. However, high levels of nutrients and ideal growing conditions can overfeed algae, creating algal blooms that deplete the oxygen content of water, block sunlight to other organisms, and potentially produce toxins. These harmful algal blooms (HABs) can contaminate surface and drinking water supplies, potentially harming animal and human health. Cyanobacteria (blue-green algae) and red tides are examples of HABs that produce toxins harmful to humans and animals.[33]

Algal blooms, whether toxic or not, can cause significant environmental and economic problems when the algae die. As organisms die and sink to the bottom, they are consumed (decomposed) by oxygen-dependent bacteria, depleting the water of oxygen. When this eutrophication is extensive and persistent, bottom waters may become hypoxic (depressed concentration of dissolved oxygen), or even anoxic (no dissolved oxygen). Hypoxic conditions in lakes and coastal waters

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[30] Tile drains are a subsurface drainage system that removes excess water from the soil profile through a series of perforated tubes.

[31] A. N. Sharpley, T. Daniel, and T. Sims, *Agricultural Phosphorus and Eutrophication, Second Edition*, USDA, Agricultural Research Service, ARS-149, September 2003, http://www.ars.usda.gov/is/np/Phos&Eutro2/agphoseutro2ed.pdf.

[32] Joseph L. Domagalski and Henry Johnson, *Phosphorus and Groundwater: Establishing Links Between Agricultural Use and Transport to Streams*, U.S. Geological Survey, Fact Sheet 2012-3004, January 27, 2012, http://pubs.usgs.gov/fs/2012/3004/.

[33] For more information, see CRS Report IN10131, *Harmful Algal Blooms and Drinking Water*.

can cause die-offs of fish and other aquatic life. If these conditions persist, a "dead zone" may develop in which little life exists.

Cyanobacteria

Cyanobacteria live in terrestrial, fresh, brackish, or marine water. Cyanobacterial harmful algal blooms (CyanoHABs) occur when organisms that are normally present grow exuberantly.[34] CyanoHABs are caused by a combination of conditions, including warm water temperatures, high levels of light, and abundant nutrients (primarily phosphorus and nitrogen). Nutrients play a key role, and major sources include agricultural runoff (organic and inorganic); discharges from sewage treatment plants; and storm-water runoff from lawns, streets, and elsewhere. CyanoHABs can contain various toxins that can affect the liver, skin, or nervous system. Exposure to cyanotoxins can cause a range of health effects, from mild rashes to severe illness (and rarely death) in humans. Deaths of exposed wildlife, livestock, birds, and pets have been documented worldwide. Most human exposures are thought to occur during recreational activities, such as swimming and boating; through accidental ingestion or inhalation of water; or when skin comes into contact with toxins. Exposures also can result from drinking or showering in contaminated water or eating contaminated shellfish.[35]

Red Tide

In the case of red tides, microscopic marine alga called *Karenia brevis* (*K. brevis*) grows quickly and creates blooms that look red or brown (hence "red tide"). *K. brevis* produces toxins called brevetoxins, which are deadly to fish and other marine organisms. Brevetoxins can become concentrated in the tissues of shellfish that feed on *K. brevis* and make those who eat these shellfish sick with neurotoxic shellfish poisoning (NSP). NSP can produce neurologic symptoms (e.g., tingling in fingers and toes) and gastrointestinal symptoms in humans. The effects of environmental exposure to brevetoxins are less well known. However,

Why Phosphorus?

Question: If both nitrogen and phosphorus are required for a harmful algal bloom (HAB), why is phosphorus generally described as "causing" a HAB?

Answer: Nitrogen is an abundant element that is essential to the growth of aquatic life. Its abundance makes it difficult to control the atmospheric exchange of nitrogen and carbon in the water, and the fixation of atmospheric nitrogen by some blue-green algae.[36] This makes phosphorus the limiting factor for a HAB. This is why control efforts typically focus on phosphorus reduction to reduce the potential for accelerated eutrophication of fresh waters.[37]

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[34] Centers for Disease Control and Prevention, *Harmful Algal Blooms (HABs)*, http://www.cdc.gov/nceh/hsb/hab/default.htm.

[35] U.S. Environmental Protection Agency, *Cyanobacteria/Cyanotoxins*, http://www2.epa.gov/nutrient-policy-data/cyanobacteriacyanotoxins.

[36] When salinity increases, as in estuaries, nitrogen generally becomes the element controlling aquatic productivity. David K. Mueller and Dennis R. Helsel, *Nutrients in the Nation's Waters—Too Much of a Good Thing?* U.S. Geological Survey, Circular 1136, January 11, 2013, http://pubs.usgs.gov/circ/circ1136/.

[37] Studies indicate that increased nitrogen and phosphorus together stimulate the most growth. David W. Litke, *Review of the Phosphorus Control Measures in the United States and Their Effects on Water Quality*, U.S. Geological Survey, Water-Resources Investigations Report 99-4007, Denver, CO, 1999, http://pubs.usgs.gov/wri/wri994007/pdf/wri99-4007.pdf. One example of a recent control strategy focusing on phosphorus is the International Joint Commission, *A Balanced Diet for Lake Erie: Reducing Phosphorus Loadings and Harmful Algal Blooms*, Report of the Lake Erie Ecosystem Priority, February 2014, http://www.ijc.org/files/publications/2014%20IJC%20LEEP%20REPORT.pdf.

evidence suggests that air and skin exposure near red tides can result in irritation of the eyes, nose, and throat, as well as coughing, wheezing, and shortness of breath.[38]

Ciguatera

Ciguatera is another illness caused by eating fish that contain toxins produced by HABs. Ciguatera is caused by *Gambierdiscus toxicus*, a marine microalga. The toxin accumulates and can move up the food chain, for example, through large carnivorous reef fish (barracuda, black grouper, blackfin snapper, amberjack, and yellowfin grouper). Symptoms are similar to NSP and can go away in days or last for years.[39]

Human Health Effects

In addition to HABs, excess nutrients in water have other known health effects, depending on the type and condition of exposure. Conjectural evidence suggests that an excess of both nitrogen and phosphorus may contribute to infections and noninfectious pathogens, potentially causing epidemic conditions.[40] This, however, is a difficult relationship to make given the interrelated nature of humans and wildlife disease emergence.[41]

The primary route of human exposure to nitrogen is through ingestion of contaminated drinking water. The most well-known effect is methemoglobinemia, a blood disorder in which an abnormal amount of methemoglobin (a form of hemoglobin) interferes with the body's ability to release oxygen to body tissue.[42] Infants are especially susceptible to this condition, which is why it is sometimes referred to as "blue baby syndrome."[43] Other known health effects include various cancers, adverse reproductive outcomes (neural tube defects), diabetes, and thyroid conditions.[44] No comprehensive research has examined the health effects of nitrate ingestion, or whether the current regulatory limits on nitrogen in drinking water are adequately protective.[45]

Because of phosphorus's role in eutrophication and associated HABs, the environmental and health concerns are much the same as those for nitrogen. The direct health effects of excess phosphorus fertilizers are less well known than the effects of nitrogen fertilizers.

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[38] Centers for Disease Control and Prevention, *Harmful Algal Blooms (HABs)*, http://www.cdc.gov/nceh/hsb/hab/default.htm.

[39] Centers for Disease Control and Prevention, *Harmful Algal Blooms (HABs)*, http://www.cdc.gov/nceh/hsb/hab/default.htm.

[40] Pieter T. J. Johnson, Alan R. Townsend, and Cory C. Cleveland, et al., *Linking Environmental Nutrient Enrichment and Disease Emergence in Humans and Wildlife*, National Institutes of Health, public access author manuscript, April 2010.

[41] Ibid.

[42] Ward, 2008.

[43] Ibid.

[44] Ibid.

[45] Ibid. For additional information on U.S. drinking water regulations, see CRS Report RL31243, *Safe Drinking Water Act (SDWA): A Summary of the Act and Its Major Requirements.*

Best Management Practices

Nutrient management is a practice whereby nutrient cycles are kept in balance with the surrounding ecosystem. As most crop production is not considered to be a naturally occurring part of an ecosystem, how production is managed is increasingly important for the overall health of the surrounding environment and sustainability of production. Over time, through research and technological advancements, nutrient management has become increasingly sophisticated. An advanced understanding of how crops utilize nutrients and how nutrients move in the environment has led to the development of a number of best management practices (BMPs) for nutrient use. Primarily, nutrient BMPs focus on preventing or reducing the ways in which excess nutrients can enter the environment—erosion, runoff, leaching, volatilization, denitrification, and nitrification.

In many cases, the success of a BMP depends on how and where it is applied. Not all BMPs will work in every location, and more than one BMP may be required to correct a nutrient imbalance. For example, a BMP may help reduce one nutrient but do little to reduce another. Additionally, not all BMPs are fail-safe, and they can require a significant amount of time and investment to achieve a successful balance.

This section discusses select examples of nutrient BMPs that can lessen the potential harm to water quality. These examples should not be considered a comprehensive list. USDA's Natural Resources Conservation Service (NRCS) maintains national practice standards for many of these BMPs (**Table 2**); however, state and local regulations may affect how the standards apply locally.

Table 2. Select NRCS Practice Standards Related to Nutrient Reduction and Water Quality

Name	Practice Code[a]	Link
Animal mortality facility	316	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026388.pdf
Agrichemical handling facility	309	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263506.pdf
Composting facility	317	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026122.pdf
Conservation crop rotation	328	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263170.pdf
Constructed wetland	656	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_025770.pdf
Contour buffer strips	332	http://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid= nrcs143_026249&ext=pdf
Contour farming	330	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1241315.pdf
Cover crop	340	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263176.pdf
Drainage water management	554	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026409.pdf
Feed management	592	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046856.pdf
Filter strip	393	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1241319.pdf
Grassed waterway	412	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263177.pdf
Irrigation water management	449	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263179.pdf
Nutrient management	590	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046433.pdf

Name	Practice Code[a]	Link
Residue and tillage management, no till	329	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1249901.pdf
Residue and tillage management, reduced till	345	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1251402.pdf
Short-term storage of animal waste and byproduct	318	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263507.pdf
Stream crossing	578	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046932.pdf
Stripcropping	585	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026280.pdf
Terrace	600	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263187.pdf
Waste storage facility	313	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026465.pdf
Waste treatment	629	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1144479.pdf
Waste treatment lagoon	359	http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026002.pdf

Source: CRS from USDA, NRCS, "National Conservation Practice Standards," http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/ncps/.

Notes: This is not intended to be a comprehensive list. In some cases, additional practices are required to complete a conservation system. For example, a manure management system may consist of a number of practices (e.g., waste storage facility [313] and nutrient management [590]), including some not on this list (e.g., waste transfers [634], pumping plants [533], irrigation water conveyance [428], and irrigation system sprinkler [422]).

a. Practice codes refer to an NRCS numbering system and are included for reference purposes.

Crop Production

Crop production BMPs for nutrient management generally focus on the "4Rs"—applying the *right* amount of nutrients, from the *right* source, in the *right* place, at the *right* time. Other associated BMPs try to prevent nutrients and sediment from leaving the field and entering waterways. Select examples of crop production BMPs for water quality improvement include:

Figure 9. Soil Sample

Source: Tim McCabe, USDA, NRCS.

Note: A soil sample is drawn early in the crop year to test for N availability in the soil and again later in the spring to determine additional need.

Nutrient Diagnosis and Testing. Fertilizer recommendations are often based on nutrient diagnostic methods, such as soil testing (**Figure 9**), plant analysis, and canopy sensing. These activities measure the amount of nutrients present and help determine additional need. The results, combined with data on expected yields and field conditions, help producers minimize excessive nutrient release into the environment.

Figure 10. No-Till System and Crop Rotation

Source: CRS.

Note: An example of soybeans in corn residue using a no-till system. Also an example of a crop rotation between corn, soybeans, and wheat.

Cover Crops. Legume crops and cover crops can provide nitrogen through biological fixation and nutrient recycling. The use of cover crops helps to sequester nutrients, primarily nitrogen; reduce soil run-off; and improve nutrient use efficiency.

Crop Rotation. Crop rotations are planned sequences of two or more crops grown on the same ground over a period of time. Whether rotating with other commodity crops or perennials, the use of crop rotations has been known to improve nutrient cycling and reduce energy needs (**Figure 10**).

Planning. Nutrient management planning calculates the amount of nutrients required for maximum yield, while minimizing the overall environmental impacts of nutrient use. NRCS defines nutrient management as the management of the "4Rs."[46]

Tillage Systems. The use of no-till (**Figure 10**) or reduced till systems can increase soil organic matter, reduce nutrient use, reduce sediment loss, enhance ground-water retention, and reduce runoff and leaching of nutrients. No-till[47] systems maintain most of the crop residue on the soil surface by not using traditional full-width tilling methods throughout the year. Reduced till, also referred to as mulch till, disturbs the majority of the soil's surface with noninversion tillage methods[48] and uniformly spreads residue on the soil surface.

Figure 11. Stripcropping

Source: Tim McCabe, USDA, NRCS.

Note: Alternating strips of alfalfa with corn on the contour.

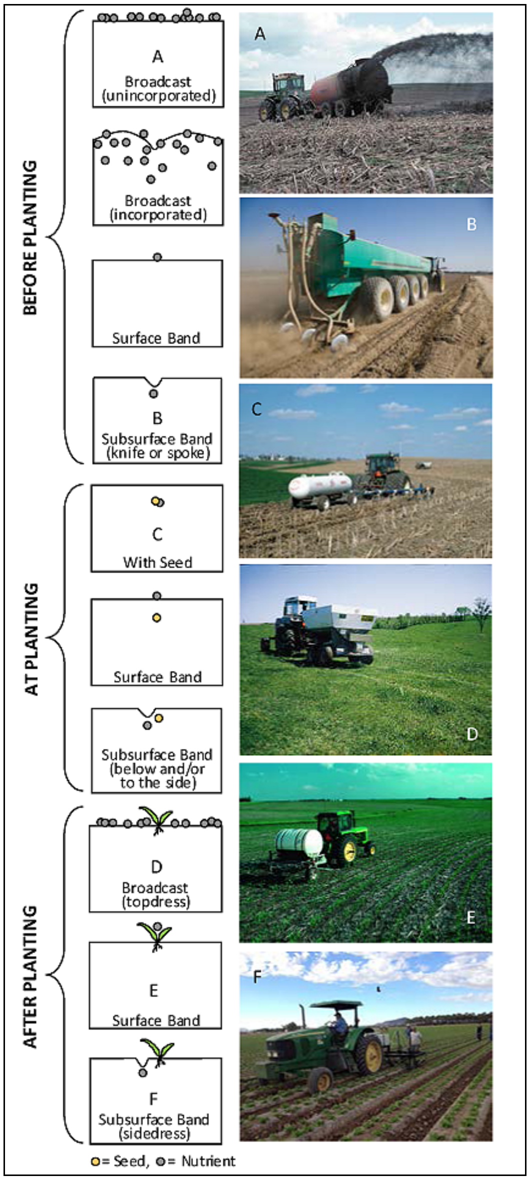
Stripcropping. The use of grass or close-growing crops alternated with row crop production can slow runoff, reduce erosion, and increase filtration. This can reduce the loss of nitrates and soluble phosphorus (see **Figure 11**).

[46] USDA, NRCS, *Conservation Practice Standard - Nutrient Management*, Code 590, January 2012, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046433.pdf.

[47] Also referred to as zero-till, direct (seed) drilling, slot plant, row till, strip till, or generically as conservation tillage.

[48] Noninversion tillage can include chisel plowing, field cultivating, tandem disking, or vertical tillage.

Figure 12. Select Examples of Nutrient Application Methods



Source: CRS adapted from John L. Havlin, Samuel L. Tisdale, and Werner L. Nelson, et al., *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*, 8th ed. (Pearson, 2014), figs. 10-15. Photos A-E from USDA, NRCS. Photo F from the University of Arizona, College of Agriculture and Life Sciences/College of Engineering, https://www.cals.arizona.edu/abe/featured/rotary-soil-injection-approaches-improved-side-dress-applications.

Note: Not all application methods represent a BMP.

Application Method. How a plant uses nutrients will determine where nutrients should be placed for most efficient uptake. The application method is determined based on crop type, nutrient diagnosis and testing, and planning. Different application methods are available based on the time of application (see **Figure 12**).

Application Timing. How a plant uses nutrients will determine when nutrients should be applied for most efficient uptake. In some cases, this might mean more than one application at different times (often referred to as split application).

Inhibitors. Nitrification inhibitors maintain ammonium longer by eliminating a bacterium where the ammonium is present, thereby delaying denitrification and reducing leaching potential. Urease inhibitors allow urea to be retained in the soil longer, thereby reducing nitrogen volatilization.[49]

Application Amount. The amount of nutrient application should be based on the results of nutrient diagnosis and testing; realistic expected yields and yield history; and residual nutrients from manure, legumes, and irrigation water applied to reduce overapplication.

Filter and Buffer Strips. A strip of vegetation located near the edge of the field along streams, lakes, wetlands, and other adjacent waters in order to trap sediment and denitrify residual nitrates in subsurface flow.

Constructed Wetlands. Surface or subsurface drainage tile water may be channeled through artificially created wetlands to provide nutrient filtration.

[49] Robert Mullen and Ed Lentz, *Nitrogen Inhibitors, What Is What and Should You Consider Their Use?* Ohio State University Extension, C.O.R.N. Newsletter 2011-08, Columbus, OH, 2011, http://corn.osu.edu/newsletters/2011/2011-08-1/nitrogen-inhibitors-what-is-what-and-should-you-consider-their-use.

Figure 13. Terraces and Grassed Waterways

Source: Jeff Vanuga, USDA, NRCS.

Note: Shows contour terraces and grassed waterways.

Irrigation Management. Coordinating the use of irrigation water and nutrient application can impact nutrient uptake, runoff, and leaching. Other irrigation system practices, such as tailwater recovery, can also assist in capturing residual nutrient loss.

Terraces and Grassed Waterways. Terraces are a series of ridges and channels constructed across a slope to intercept sediment and nutrient runoff. Grassed waterways are channels with established vegetation that reduces runoff (see **Figure 13**).

Animal Agriculture

Best management practices for livestock operations are typically prescribed for concentrated animal feeding operations where animals are raised or bred in close quarters, thus creating a concentrated source of nutrients. Other BMPs for grazing operations can reduce the potential for nutrient and sediment contamination by controlling animals' movements within grazing sites.

Nutrient Testing. The nutrient content of manure can vary greatly. Nutrient testing of manure can inform feed and fertilizer application recommendations. Testing results can help minimize nutrient release into the surrounding environment.

Planning. Animal waste planning helps producers determine their current waste and nutrient production and distribution capacities. Balancing the production and distribution of waste is critical to preventing excess nutrient release.

Feed Management. Modifying animal feed diets can reduce the nutrient content of the manure.

Carcass Disposal. Improper disposal of livestock and poultry carcasses can impact surface and groundwater resources. Animal mortality facilities vary and can consist of composters, refrigeration, incinerators, or burial pits, among others.

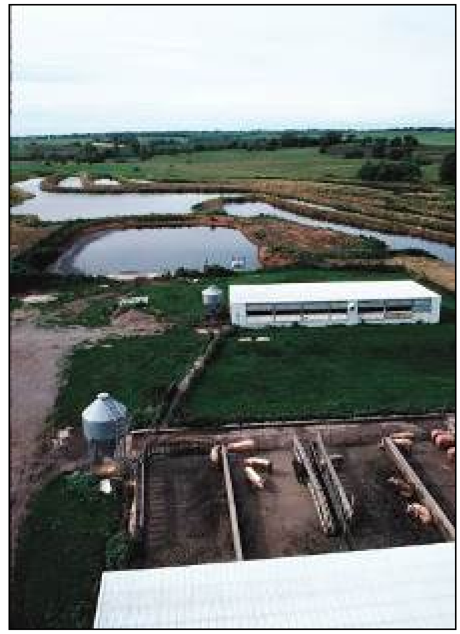
Constructed Wetlands. Constructed wetlands can provide nutrient filtration from wastewater and contaminated runoff from livestock and agricultural processing facilities. Constructed wetlands generally use hydrophytic vegetation (i.e., grows in water) in a shallow basin where the contaminated water, both entering and exiting the wetland, is controlled (**Figure 14**).

Waste Storage and Handling. The storage of manure waste can allow for greater flexibility in nutrient application and timing for crop production. Practices such as short-term storage—consisting of plastic sheeting—or longer-term storage facilities (e.g., pits or lagoons) are generally pursued as part of a larger nutrient management plan.

Lagoon. A lagoon is a pond-like earthen basin that provides biological treatment and long-term storage of animal waste. Generally manure is diluted with water, decomposed through a biological process, and then used in a separate form such as irrigation liquid. The biological reaction is achieved by either anaerobic bacteria (inhibited by oxygen) or aerobic bacteria (requiring oxygen).

Stream Crossing. A stabilized area constructed across a stream or waterway to provide access for people or livestock while reducing sediment and nutrient loading in the stream.

Figure 14. Constructed Wetland



Source: Tim McCabe, USDA, NRCS.

Note: A series of hillside terraces form constructed wetlands that filter water from a hog operation.

Federal Response to Agricultural Nutrients

Currently, few federal regulations govern the environmental impacts from agriculture. Some environmental laws specifically exempt agriculture from regulatory requirements, and others are structured so that agriculture is not addressed by most, if not all, of the regulatory impact. The major federal response continues to be through research, education, outreach, and voluntary technical and financial incentives.

Regulation—Clean Water Act[50]

Federal environmental law does not regulate all agricultural activities.[51] In terms of environmental impacts, the primary regulatory focus has been on protecting water resources and is governed by the Clean Water Act (CWA). As with many environmental regulations affecting industries, regulations affecting agriculture have been and continue to be controversial and draw congressional attention.

The CWA provides one exception to policies that generally exempt agricultural activities—and specifically the livestock industry—from environmental rules. The law protects water quality through a combination of ambient water quality standards established by states, limits on effluent discharges, and permits. The regulatory structure of the CWA distinguishes between "point

[50] While not discussed in this report, chemical fertilizers used in agriculture production are also regulated. For more information, see CRS Report R43070, *Regulation of Fertilizers: Ammonium Nitrate and Anhydrous Ammonia.* Also, facilities that emit large quantities of air pollutants may be regulated under the Clean Air Act. Some livestock operations also may be subject to requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund) and the Emergency Planning and Community Right-to-Know Act (EPCRA). For additional information, see CRS Report RL33691, *Animal Waste and Hazardous Substances: Current Laws and Legislative Issues*.

[51] For additional background, see CRS Report R41622, *Environmental Regulation and Agriculture.*

sources" (e.g., manufacturing and other industrial facilities that are regulated by discharge permits) and "nonpoint sources" (pollution that occurs in conjunction with surface erosion of soil by water and surface runoff of rainfall or snowmelt from diffuse areas, such as farm and ranch land). Most agricultural activities are considered to be nonpoint sources, since they do not discharge wastes from pipes, outfalls, or similar conveyances. Pollution from nonpoint sources is generally governed by state water quality planning provisions of the act.

Concentrated Animal Feeding Operation (CAFO) Permits[52]

The CWA prohibits the discharge of pollutants from any point source to waters of the United States unless authorized under a permit that is issued by EPA or a qualified state, and the act expressly defines concentrated animal feeding operations (CAFOs) as point sources.[53] Permits limiting the type and quantity of pollutants that can be discharged are derived from effluent limitation guidelines promulgated by EPA under the National Pollutant Discharge Elimination System (NPDES) program. In 2003, EPA revised regulations that were first promulgated in the 1970s defining the term CAFO for purposes of permit requirements and specifying effluent limitations on pollutant discharges from regulated feedlots. The 2003 rules were challenged in federal court (*Waterkeeper Alliance et al. v. EPA*, 399 F.3d 486 (2nd Cir. 2005)), and parts of the regulations were remanded to EPA for revision and clarification. As a result, EPA issued revised regulations in 2008.[54]

The 2008 CAFO rule applies to approximately 15,300 of the largest animal feeding operations that confine cattle, dairy cows, swine, sheep, chickens, laying hens, and turkeys, or less than 10% of all animal confinement facilities in the United States. The rule details requirements for permits, annual reports, and development of plans for handling manure and wastewater. The rule contains a performance standard that prohibits discharges from regulated CAFOs except in the event of wastewater or manure overflows or runoff from an exceptional 25-year, 24-hour rainfall event. Parts of the rule are intended to control land application of animal manure and wastewater.

Total Maximum Daily Load (TMDL)[55]

Section 303(d) of the CWA requires states to identify waters that are impaired by pollution, even after application of pollution controls. For those waters, states must establish a total maximum daily load (TMDL) to ensure that water quality standards can be attained. A TMDL is essentially a pollution budget, a quantitative estimate of what it takes to achieve standards, setting the maximum amount of pollution that a waterbody can receive without violating standards. If a state fails to do this, EPA is required by the CWA to make its own TMDL determination for the state.

[52] For additional information, see CRS Report RL33656, *Animal Waste and Water Quality: EPA's Response to the Waterkeeper Alliance Court Decision on Regulation of CAFOs*.

[53] CAFOs are large animal feeding operations. The regulatory threshold of animal feeding operations that are covered by CWA regulations varies by animal type (e.g., facilities housing 700 or more mature dairy cattle; 30,000 or more laying hens or broilers), as detailed in EPA rules, which also specify CAFO pollution control requirements (40 C.F.R. Part 122 and 40 C.F.R. Part 412).

[54] U.S. Environmental Protection Agency, "Revised National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitations Guidelines for Concentrated Animal Feeding Operations in Response to the Waterkeeper Decision, Final Rule," 73 *Federal Register* 225, November 20, 2008, pp. 70417-70486.

[55] For additional information, see CRS Report R42752, *Clean Water Act and Pollutant Total Maximum Daily Loads (TMDLs)*.

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Throughout the United States, more than 20,000 waterways are known to be violating applicable water quality standards and require a TMDL. Lawsuits have been brought with the intention of pressuring EPA and states to develop TMDLs because the waters have been identified as being impaired (that is, not meeting applicable water quality standards). The Chesapeake Bay TMDL is the largest single TMDL developed to date.

Since 1995, EPA and states have developed a total of 67,726 TMDLs, addressing 70,901 causes of water quality impairment in U.S. waters. Of the 67,726 total TMDLs, 5,927 (8.75%) addressed nutrient impairments, and 3,904 (5.8%) addressed sediment impairments.[56] According to EPA, 42,316 waterbodies remain impaired in the United States, due to 74,594 causes of impairment (i.e., a waterbody may be impaired by more than one pollutant). TMDLs are to be established for these waterbodies. Of the total known causes of current impairment, 7,688 (10.3%) are known to be caused by nutrients, and 6,466 (8.7%) are known to be caused by sediment.[57] Generally it is not possible to determine how many of the nutrient impairments for which TMDLs are to be developed are caused by agriculture or other possible sources until the TMDL is developed by a state. The identification and listing of impaired waters are done by states.

Production Support

In large part, the federal response to nutrient pollution from agriculture is through voluntarily adopted technical and financial assistance. A number of USDA agencies provide support through education, outreach, and research, while federal funds are provided through conservation programs to adopt BMPs for nutrient reduction.

Technical Assistance, Education, and Outreach

USDA offers technical support to producers through direct assistance and research. Nutrient management planning assistance is available at no cost through NRCS. Agency resources and planning techniques draw on publicly reviewed and scientifically based principles. Various conservation practices (the BMPs described above) may be prescribed, based on needs and resource goals. Unless the nutrient management plan was created for a CAFO to meet the regulatory requirements under the CWA NPDES program, implementation of a nutrient management plan and associated BMPs are voluntary. Other state- and local-level programs (e.g., tax credits, pollution violation compliance, cost-share agreement, or local ordinance) may require implementation of a nutrient management plan, but this varies greatly by state.

Nutrient management education and outreach is primarily handled through the land-grant university system and the extension programs of the National Institute of Food and Agriculture (NIFA).[58]

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[56] U.S. Environmental Protection Agency, *National Summary of Impaired Waters and TMDL Information*, http://iaspub.epa.gov/waters10/attains_nation_cy.control?p_report_type=T.

[57] Ibid.

[58] For additional information, see CRS Report R40819, *USDA's Research, Education, and Economics (REE) Mission Area: Issues and Background.*

Financial Assistance

In addition to technical assistance, NRCS also administers a number of conservation programs that offer financial assistance for nutrient management. According to NRCS, 8.6% of all acres receiving NRCS conservation assistance for water quality between FY2005 and FY2012 were for practices that support nutrient management.[59]

Conservation Activity Plans

Amendments in the 2008 farm bill[60] allow NRCS to use financial assistance to pay for conservation plan development. The plans are referred to as Conservation Activity Plans (CAPs), of which two are for nutrient management—#102 comprehensive nutrient management plan (CNMP, for CAFOs and AFOs) and #104 nutrient management plan (non-livestock, crop production). EQIP can also pay for plan implementation, but this is handled separately from the CAPs. The main practice standard for nutrient management implementation is the 590 practice standard (see **Table 2**). CAP #102 or #104 describes which nutrients need to be managed and how they could be managed, whereas the 590 nutrient management practice will fund the activities required to manage them (e.g., soil testing, design, and labor).

Many of the programs that fund nutrient management BMPs are authorized in omnibus farm bills, the most recent of which is the Agricultural Act of 2014 (P.L. 113-79). The Environmental Quality Incentives Program (EQIP) is the largest farm bill program that funds nutrient management practices, including conservation activity plans for nutrient management as well as financial assistance to implement other nutrient management practices recommended in the nutrient management plan (e.g., cover crops, buffer strips, waste lagoons). Other farm bill programs, such as the Conservation Stewardship Program (CSP), provide incentives encouraging producers to adopt additional nutrient-reducing practices. Land retirement and easement programs, such as the Conservation Reserve Program (CRP) and the Agricultural Conservation Easement Program (ACEP), remove land from production and establish resource-conserving vegetation for wildlife and water quality benefits.[61]

The Clean Water Act Section 319 Program authorizes grants to states, territories, and tribes to help address national water quality challenges posed by nonpoint sources of pollution, such as runoff from farmland, forests, and city streets.[62] State Section 319 programs generally address nonpoint source pollution from a variety of sectors, not just agriculture. According to EPA, states use their Section 319 funding, along with a state match (40% match is required), to implement statewide, non-regulatory programs that promote implementation on a widespread basis (e.g., promote broad use of nutrient management in agriculture).[63]

59 USDA, NRCS, *Soil and Water Resources Conservation Act (RCA) Report*, National Conservation Programs Profile, http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/rca/ida/?cid=stelprdb1187041. Nutrient management is also considered under the soil quality category of the report.

60 Food, Conservation, and Energy Act of 2008 (P.L. 110-246). These provisions were unchanged when reauthorized in the Agricultural Act of 2014 (P.L. 113-79).

61 For additional information on private land conservation programs, see CRS Report R40763, *Agricultural Conservation: A Guide to Programs*.

62 For more information on the CWA 319 program, see http://water.epa.gov/polwaste/nps/cwact.cfm.

63 EPA, Office of Wetlands, Oceans, and Watersheds, *A National Evaluation of the Clean Water Act Section 319 Program*, November 2011, http://water.epa.gov/polwaste/nps/upload/319evaluation.pdf.

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Research and Monitoring

USDA conducts nutrient management research both through its in-house research agencies—Agricultural Research Service (ARS) and the Economic Research Service (ERS)—and through funds provided to states and localities by NIFA. The ARS conducts numerous research projects within 17 national programs, five of which support nutrient management-related research.[64] The ERS, which conducts economic research on policy issues, has produced a number of publications that analyze the societal and economic impacts of nutrient use in the United States from the standpoint of both production and environmental quality.

USDA also participates in a multi-agency effort led by NRCS, called the Conservation Effects Assessment Project (CEAP). The purpose of CEAP is to quantify the environmental effects of conservation practices and programs and develop the science base for managing the agricultural landscape for environmental quality. Project findings are used to guide USDA conservation policy and program development and potentially to assist producers with making more informed conservation decisions. To date, a number of CEAP publications focus on nutrient management.[65]

The U.S. Geological Survey (USGS), as part of its National Water Quality Assessment Program, is conducting studies on the transport and fate of agricultural nutrients in agricultural settings across the country. Early study results highlight how environmental processes and agricultural practices interact to affect the movement and transformation of agricultural chemicals in the environment. The study covers surface water, groundwater, the unsaturated zone, the streambed, and the atmosphere, as well as the pathways that interconnect these compartments. In an attempt to make the findings nationally relevant, the study areas represent major agricultural settings, such as diverse irrigated crop systems in Western states and corn and soybean row crop systems in the Midwest.[66]

Policy Questions

Despite advancements made through research, education, and funding, environmental problems with excess nutrients from agriculture remain throughout the United States. As policymakers consider these issues, additional questions may be asked.

- **Regulatory-Voluntary Balance**: Currently, few environmental regulations govern nutrients from agriculture; instead, a more voluntary incentive-based approach is used. What benefits are achieved through the voluntary approach, and how could they be strengthened? Could additional benefits be achieved

[64] ARS national programs supporting nutrient related research include NP #211—Water Availability and Watershed Management, NP #212—Climate Change, Soils, and Emissions, NP #214—Agricultural and Industrial Byproducts, NP #215—Pasture, Forage and Rangeland Systems, and NP #216—Agricultural System Competitiveness and Sustainability. Other national programs, such as NP #305 (Plant Genetic Resources, Genomics and Genetic Improvement) and NP #305 (Crop Production), may also include research that impacts nutrient management through the development of plant varieties and production practices that require less nutrients. Research project information may be found at http://www.ars.usda.gov/research/programs.htm.

[65] Additional information and publication links may be found here: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/ceap/?cid=nrcs143_014153.

[66] For additional information on the National Water-Quality Assessment Program and the Agricultural Chemicals Team, see http://in.water.usgs.gov/NAWQA_ACT/.

through regulation, and at what cost? What is an acceptable balance between the two?

- **Federal-State-Local Balance**: In many cases, the enforcement of federal laws that address environmental pollution is delegated to the states. Does this model work? Should more or less oversight or action occur, and at what level? How can regional and watershed planning impact the overall effectiveness of the current environmental laws?
- **Use of Current Resources**: Congress authorizes and appropriates billions of dollars for federal conservation efforts each year. Demand for these resources continues to outpace supply. How are current federal resources for conservation being utilized? How effective are they, and how can they be improved? Are federal leveraging programs—such as the Regional Conservation Partnership Program, which leverages federal funds with private funds—an effective way to extend the federal dollar? Agencies and stakeholders have suggested "targeting" limited resources to areas of greatest need. To what extent is targeting effective, and what barriers to targeting exist?
- **The Source of the Problem**: The exact sources and causes of nutrient pollution can vary greatly by location. Case study analysis and modeling can assist with identifying sources at the local level but provide little in the way of nationwide conclusions. What additional research or monitoring efforts are required to identify sources of nutrient pollution? At what level should these efforts occur—field level, state level, nationally?
- **Effectiveness of the Solution**: Conservation BMPs are frequently held up as being the solution to agricultural nutrient pollution. What scientific evidence supports the use of these BMPs? Can additional research and innovation provide other "tools" in the response "toolbox"?
- **Value Versus Cost of Conservation**: Agricultural producers seek to maximize profit, while simultaneously minimizing cost. Does the value of conservation BMPs outweigh the cost? Are savings and efficiencies (if any) adequately communicated to producers to increase adoption?
- **Consequences of Actions**: Nutrient pollution may or may not directly impact the polluters themselves. According to ERS, the cost of removing nitrates from U.S. drinking water supplies is over $4.8 billion per year. The bulk of this cost is borne by large water utilities and then passed on to consumers. It is estimated that if the agricultural industry were required to pay based on its contribution to nitrate loading, agriculture's share would be about $1.7 billion per year.[67] Who should bear the cost of nutrient loading? Can education and outreach connect on-farm actions to potential off-farm results?

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[67] Marc Ribaudo, Jorge Delgado, and LeRoy Hansen, et al., *Nitrogen in Agricultural Systems: Implications for Conservation Policy*, USDA, ERS, ERR-127, Washington, DC, September 2011, p. 4.

Conclusion

Increased demand to feed a growing population is frequently cited as the reason for additional agricultural output. Applying additional nutrients for increased yields and managing nutrients from animal production will likely continue if these demands are realized. This will only elevate the importance of managing these additional nutrients correctly or potentially repeating and exacerbating the environmental degradation that has occurred in the past.

Agriculture is one of a number of industries that produces, uses, or releases nutrients that may adversely affect the environment. The exact source of water impairments is frequently not identified until major ecological events prompt additional research. Even then, the nature of how nutrients move through the environment can make their origin difficult to track. It is agriculture's use of nutrients and large land-use presence across the United States that have brought attention to how the industry utilizes and manages nutrients. And while best management practices exist to eliminate or reduce nutrients from entering waterways, they are not required, they may not be effective or affordable in all locations, and the success will depend on how and where they are applied.

Some advocate for the additional regulation of agricultural nutrient activities, while others seek to expand incentive-based resources. The track record of success and failure for both options varies, making the likely solution a balance of the two. It is this exact balance that Congress continues debate through the oversight of current federal activities and consideration of new or modified initiatives. Research, data, and monitoring continue to impact the debate, but perhaps not as much as larger water impairments that affect public health and safety.

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