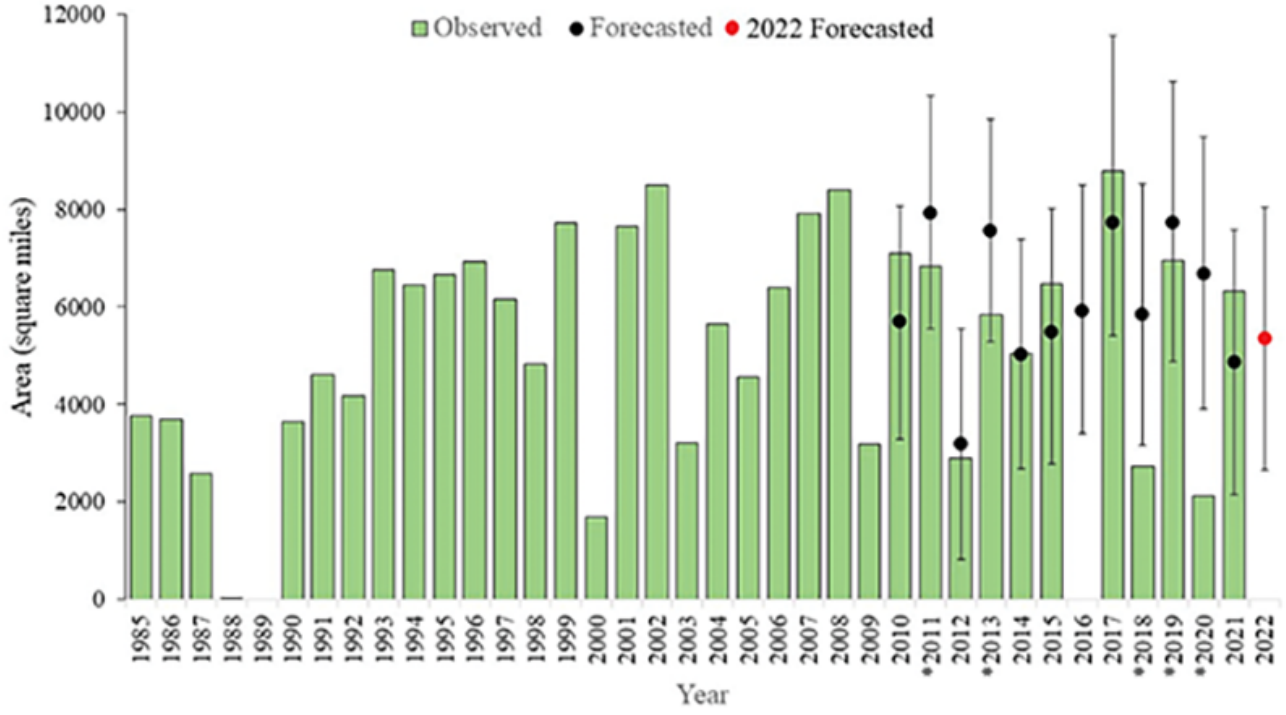
Science Societies

Gulf of Mexico hypoxia 2022: What's the role of plant nutrition?

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Hypoxia in the Gulf of Mexico is an environmental issue connected to agricultural crop management in the Mississippi River watershed. Programs

to improve nutrient stewardship in this watershed aim to improve nutrient use efficiency and reduce losses of nitrogen and phosphorus. Trends since the 1980s show increases in both crop production and the size of the hypoxic zone while the trends in nitrogen surplus have neither increased nor decreased. Provisional flow-normalized river loads of nitrogen are decreasing. While improvements in adoption of 4R management of applied fertilizers and manures have been noted, opportunities for improvement also remain. While 4R practices will not solve the issue on their own, they can make an important contribution when integrated with soil conservation practices and changes to whole farming systems.

This article is part of a series from The Fertilizer Institute, highlighting some of the latest 4R research.

In the hypoxic zone in the Gulf of Mexico, the concentration of oxygen in the bottom waters falls too low to support fish and other marine life. The area of the hypoxic zone in the Gulf of Mexico in 2022 is forecast by NOAA (**2022**) to be approximately 5,364 mi ^{2}, about average for the 35-year history of measurements. While smaller than the area observed last year, and smaller than the past five-year average, it still would exceed by 2.8-fold the reduction goal of 1,930 mi^2 (Figure **1**).

What Are the Concerns, Economic Impacts of Hypoxia?

Hypoxia in the Gulf is a serious environmental concern, but much remains to be explored on its economic, social, and ecological impacts. The low oxygen levels near the bottom of the zone cannot support most marine life. Fish, shrimp, and crabs often swim out of the area, but animals that are unable to swim or move away can be stressed or killed. The northern part of the Gulf contains almost half the nation's coastal wetlands, and it supports commercial and recreational fisheries generating more than $2.8 billion annually. This area has undergone profound changes due to nitrogen and phosphorus loads from the Mississippi River watershed. When hypoxia occurs, fishermen catch more smaller shrimp and fewer large ones. While the total quantity of shrimp caught could remain the same, a reduction in the highly valued large shrimp would lead to a net economic loss (USEPA, **2021**).

The USEPA Hypoxia Task Force is a partnership established in 1997 to work collaboratively on reducing nutrient loads from the watershed to the Gulf's hypoxic zone. Members and collaborators include five federal agencies, 12 states bordering the Mississippi and Ohio rivers, and the National Tribal Water Council on behalf of tribes. Multi-state sub-basin committees and a land grant university consortium are also key partners. The task force adopted a Gulf Hypoxia Action Plan in 2001. It lays out specific steps needed to reduce, mitigate, and control hypoxia in the Gulf and improve water quality in the Mississippi River/Atchafalaya River Basin. From this, states have developed individual state-level plans for nutrient reduction.

What Are the Drivers of Hypoxia and What Do We Know About Them?

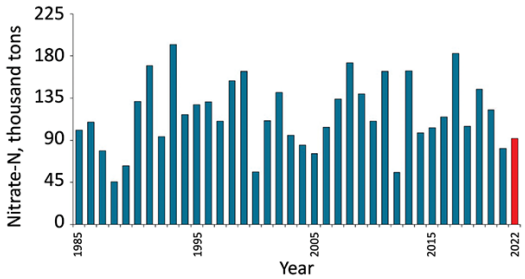


Figure 2, *USGS estimate of the May load of dissolved nitrate nitrogen to the Gulf of Mexico from 1985 to the present. The 2022 value is highlighted in red (NOAA, **2022**).*

One of the main drivers of the size of the zone is the nutrient load carried by the Mississippi River. The nitrogen loads delivered in May relate most strongly, and most of the models involved in making the forecast are based on either dissolved nitrate or total nitrogen load. At least four of the six models in the current ensemble do not even include phosphorus as a driving variable, but those based on nitrogen alone adjust for an apparently increasing sensitivity; that is, the size of the hypoxic zone per unit of nitrogen load increases over time (Obenour et al., **2015**). The May 2022 load of nitrate-nitrogen is estimated by USGS at 93,000 tons, 23% below the long-term average (Figure **2**). No increasing or decreasing trend in May nitrogen loading is evident over the time period 1985 to 2022. The 2022 load of phosphorus is 17% above the long-term average.

The USGS also reports a 26% reduction in the flow-normalized annual loading of total nitrogen, from the 1980–1996 baseline period to 2021. About 40% of this reduction occurred in the past 10 years, according to a provisional estimate that applies to annual rather than May loads. The decreasing trend suggests that farm management practices, including 4R nutrient practices, may be contributing to reduced nitrogen losses.

In 2007, the Hypoxia Task Force received a scientific assessment that estimated that a 45% reduction in both nitrogen and phosphorus loads would be needed to meet the size reduction goal, set in 2001. In 2015, the Hypoxia Task Force extended the time to reach the 45% loading reduction to 2035 with an interim target of a 20% reduction by the year 2025. The load reduction goals are relative to the baseline load from 1980–1996. It has been more recently suggested that a greater reduction in nitrogen load—59%—is needed to meet the hypoxic area reduction goal (Scavia et al., **2017**).

The Mississippi River watershed drains a large proportion—68%—of the nation's cropland. Water flow (surface runoff and subsurface drainage) from this vast area varies from 2 inches per year in the arid west to 2 ft per year in the east (Robertson & Saad, **2021**). The delivered incremental yield of nutrient (load per unit of watershed area) is greatest where crop production covers the greatest proportion of the watershed and where rainfall and water runoff is high (Figure **3**).

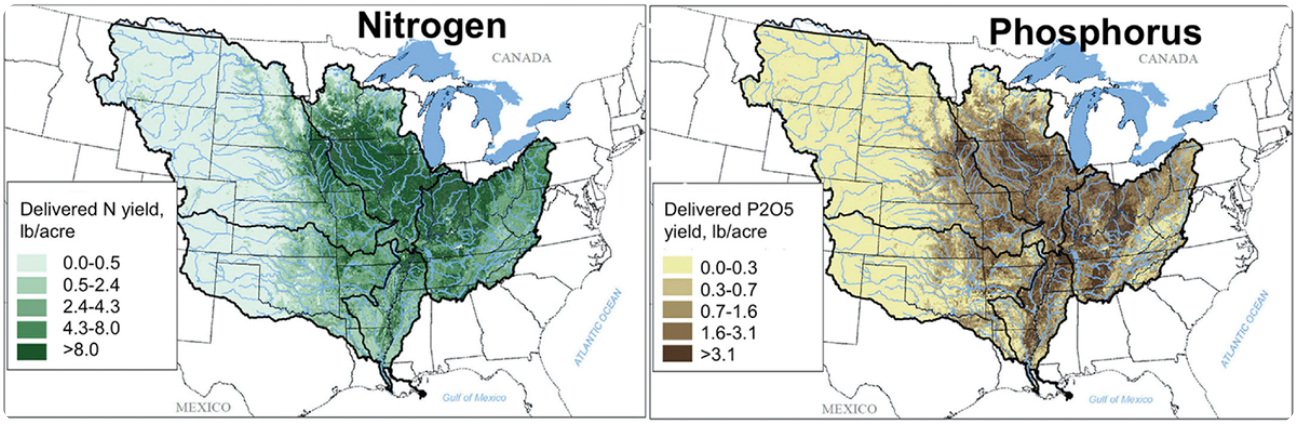


Figure 3, *Delivered incremental yields of nitrogen and phosphorus per acre of watershed land area. Adapted from (Robertson & Saad, **2021**).*

What Is the Agricultural Contribution to the Nutrient Loads?

Around 2016, the agricultural land in the watershed received 72% of the nation's fertilizer, for both nitrogen and phosphorus. As crop production has intensified over the past decades, both the inputs and the harvested crop removal of these nutrients have increased. Nutrient losses from cropland combine with nutrients from urban wastewater effluents and other sources to increase the nutrient load in the river.

One tool used to estimate sources of nutrient loads is the SPARROW (SPAtially Referenced Regressions On Watershed attributes) model. It relates attributes of catchments, including a limited set of management practices, to measured nutrient loads. In the 2012 SPARROW model (Robertson & Saad, **2021**), fertilizers account for 26% of the nitrogen load and 38% of the phosphorus load, respectively. These loads

attributed to fertilizers amount to 3.6% of the nitrogen and 11% of the phosphorus applied as fertilizers. Manure accounts for 29% of the nitrogen delivered to the Gulf of Mexico, as compared with 16% in the earlier versions of the model, owing to a change in the model recognizing that much of the atmospheric deposition (around 40%) arises from manures. The 2012 version also recognizes natural soil sources of phosphorus loading, which greatly increased the loadings from Kentucky and Tennessee, relative to earlier versions of the model. It does not, however, separate out the role of streambank erosion, shown in Iowa to account for for 31% of the total P exported in the Mississippi river (Schilling et al., **2022**).

In the 2012 SPARROW model, four states—Iowa, Illinois, Indiana, and Missouri—contributed half the annual delivered total nitrogen load of 1,710,000 tons (Table **1**). Illinois, Kentucky, Iowa, and Missouri contributed 43% of the delivered phosphorus load (Table **2**). Watershed-wide, agricultural sources were estimated to contribute 73% of the nitrogen loads and 56% of the phosphorus load. The total nitrogen load delivered from the watershed amounts to 19% of the fertilizer N applied there, and the equivalent proportion for phosphorus is 16%. When loads are expressed per unit of watershed area, they are called "yields"—but note that they may be higher per unit of cropland area than per unit of watershed area.

Table 1. Total annual nitrogen load and yields, delivered to the Gulf of Mexico, for the four states contributing the largest load, and the entire Mississippi River watershed. Percentage attributed to each source by the SPARROW model calibrated for 2012 inputs and loads (Robertson & Saad, **2021**)

Area	Delivered N load	Delivered N yield	Source distribution				
			Urban	Fertilizers	Manures	Fixation	Non-ag atmospheric deposition
	thousand tons	lb per watershed acre	%				
Iowa	258	18	2	35	34	21	9
Illinois	252	18	11	36	15	25	13
Indiana	198	24	6	36	18	26	15
Missouri	150	8	7	21	34	18	21
Mississippi River watershed	1710	5	7	26	29	18	20

Table 2. Total annual phosphorus load and yields, delivered to the Gulf of Mexico, for the four states contributing the largest loads and the entire Mississippi River watershed. Percentage attributed to each source by the SPARROW model calibrated for 2012 inputs and loads (Robertson & Saad, 2021)

Area	Delivered P load	Delivered yield	Source distribution			
			Urban	Fertilizers	Manures	Natural losses
	thousand tons P_2O_5 equivalent	lb P_2O_5 per watershed acre	%			
Illinois	61	4.2	32	46	7	16
Kentucky	52	5.1	14	29	15	42
Iowa	50	3.5	13	47	25	16
Missouri	46	2.6	20	41	24	16
Mississippi River watershed	490	1.6	21	38	18	23

While the SPARROW model provides an estimate of the amounts and proportions of the nutrient load that arise from each of the major sources in Table 1, it provides little in the way of assessment of the impact of management practices, particularly timing and placement, on load reduction.

What Are the Trends in Agricultural Nutrient Balance on Cropland?

Nitrogen inputs to cropland exceeded crop removal over the period from 1987 to 2016, but the surplus did not increase, despite rising amounts of fertilizer applied (Figure 4). During the same period, the deficit of phosphorus inputs relative to crop removal grew considerably. Projections to 2021 (not shown) indicate that these trends continue; since 2016, crop yields and nutrient removals continue to increase more than inputs. The reason why the role of manure appears small in Figure 4 is that only applied (recovered) manure nutrients are shown while the SPARROW model results shown in Table 1 include all the nutrients in manure as excreted—large portions of which are lost to the air (particularly nitrogen in the form of ammonia) and/or to water (from storage) and/or deposited on pasture or rangeland.

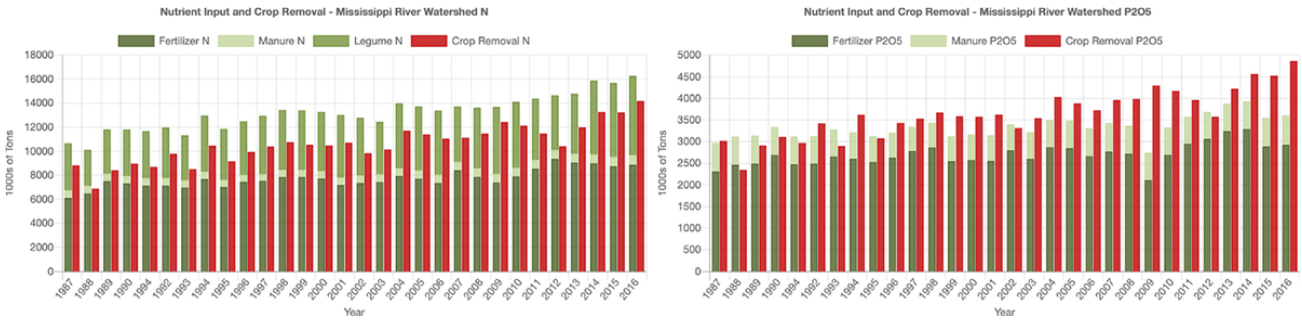


Figure 4, *Cropland nitrogen and phosphorus balances of the Mississippi River Watershed. Inputs include fertilizer and applied manure and fixation of nitrogen by legumes crops. Outputs include harvested crops, including hay and silage. (TFI, **2021a**).*

The spatial distribution of nutrient balance is also important. Parts of the watershed can be in surplus or deficit of nutrients, regardless of the whole watershed status in a given year (Figure 5). The **NuGIS** online tool (TFI, **2021a**) allows exploration of this spatial distribution at the scale of counties or eight-digit hydrologic units.

What Management Practices Can Contribute to Mitigation?

The Conservation Effects Assessment Project (CEAP) recently released a report (USDA-NRCS, **2022**) evaluating conservation trends on cropland and their effects, comparing surveys from 2013–2016 to those from 2003–2006. It notes a number of trends affecting the losses of applied nutrients.

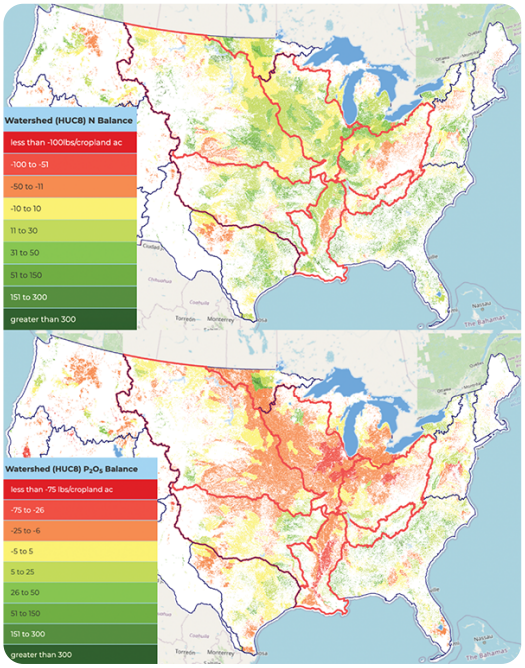


Figure 5, *Spatial distribution of cropland nitrogen and phosphorus balances for crop year 2016. Balance = inputs (fertilizer, applied manure, and legume fixation) minus outputs (harvested crop removal). Watersheds outlined in red are part of the Mississippi River watershed. (TFI, **2021a**).*

The area of cropland on which variable-rate technology (VRT) was used to apply nutrients increased from 12.7 to 52.2 million acres. This trend seems consistent with the increasing trend in agri-retailers offering VRT services (see Figure 14 in the 2020 report of the Purdue–CropLife dealership survey at **https://bit.ly/3RRHitK**). Variable-rate application can increase crop uptake of applied nutrients (by better matching rates applied to crop demand) and reduce losses that result in loads to rivers.

The post-planting application of nitrogen increased from 2 million to 3 million tons. This increase is a positive trend, indicating that farmers are increasingly using delayed and/or split applications to fine-tune amounts applied to more closely match season-specific crop demand.

The cropland area on which enhanced-efficiency fertilizers were applied increased to 74 million acres. The increase is consistent with current industry sales data.

The use of soil testing increased modestly from 56% to 60% of the cropland area. Past industry surveys of soil test laboratories indicate a greater increase in total samples analyzed, from about 4.5 million samples in 2005 increasing to 10 million samples by 2015 (TFI, **2021b**). The greater increase is possibly explained by an increase in sampling intensity on the cropland that already practiced soil testing. Thus, there likely remains considerable land area that could benefit from increased soil sampling.

The proportion of applied nitrogen that was incorporated into the soil declined from 70 to 60% nationally. This trend is consistent with reduction in tillage as more conservation tillage and no-till methods were adopted since it is more difficult to apply nutrients with subsurface placement or incorporation in these systems. Depending on nitrogen source and timing, this change in placement may represent a risk of increased nitrogen losses.

The amounts of phosphorus applied without incorporation increased. While consistent with the reduction in tillage, there is concern that phosphorus fertilizer, left on the soil surface, is more likely to contribute to increased loads of soluble P (dissolved reactive P) in runoff if applied during parts of the year with substantial runoff risk.

The SPARROW modeling results in Table **1** suggest that neither the 59% nor the 45% nitrogen loading reduction targets can be achieved by better management of fertilizer alone. This is confirmed by in-field experiments such as those in Iowa (Waring et al., **2022**), which evaluated fertilizer application timing and concluded that while split application produced modest reductions in nitrate concentration in subsurface drainage discharge, fertilizer nitrogen management alone could not be enough to

reduce nitrate load to surface water systems. Continued efforts to improve nitrogen use efficiency can nevertheless make further contributions to controlling the size of the hypoxic zone in the Gulf of Mexico.

Improved practices for 4R management of applied fertilizers and manures need to be integrated with changes to whole-farm systems and improvements in soil conservation (SPRPN, **2022**). To more effectively reduce nutrient losses, farming systems need to transition towards improving circularity from a nutrient perspective (Spiegal et al., **2020**). This may include technologies and livestock production systems that reduce nutrient losses from manure between excretion and land application and better capture of those nutrients in forms that can be transported long distances and readily applied as fertilizer.

Soil conservation practices can be improved by changing crop rotations to extend green cover on the soil with tillage systems that maintain soil residue cover and soil health. Structural practices that control and trap soil erosion can be effective in reducing nutrient losses, particularly those of particulate phophorus. Edge-of-field installations such as wetlands, bioreactors, and saturated buffers can also be effective in reducing nutrient loads, particularly nitrate. All these practices complement each other, but the starting point in nutrient loss reduction is when the nutrients are applied. Thus, 4R Nutrient Stewardship remains important.

Acknowledgments

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