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Policy Brief

Evaluating Alternative Options for Managing Nitrogen Losses from Corn Production

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Policy Challenge

Widespread and intensive agricultural activity, particularly corn production, has resulted in large amounts of nitrogen (N) loading to surface and groundwater[1,2]. Elevated N levels in streams and rivers causes a spectrum of different problems including biodiversity loss, crop yield loss, and negatively affecting human health[3]. Nutrients transported through the Mississippi River Basin (Figure 1) have been blamed for what are referred to as the "dead" zones (low oxygen water) formed in the Gulf of Mexico[4,5]. According to the United States Environmental Protection Agency (US-EPA) Hypoxia Task Force, the 2017 hypoxic zone measured 8,776 square miles, and reducing this size to a more acceptable level by 2035 will require at least a 45% reduction in the N load exported by the Mississippi and Atchafalaya Rivers[6,7]. This Policy Brief explores some alternative means of achieving this abatement target.

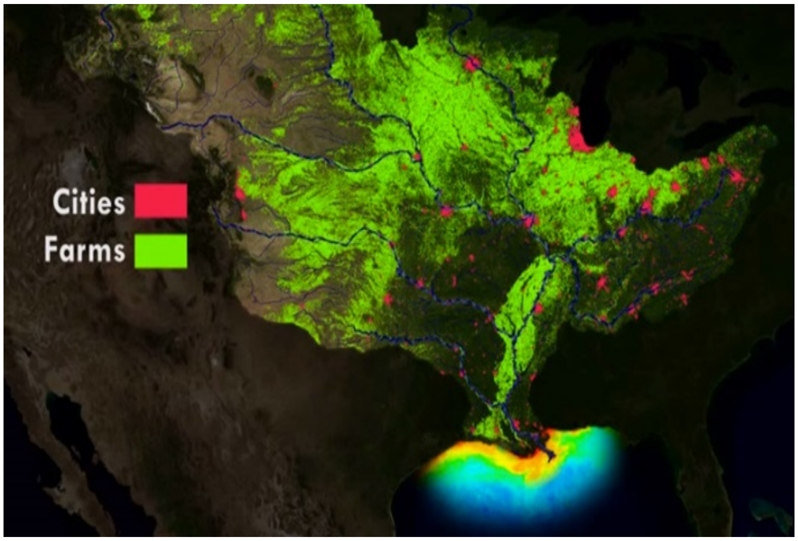

Figure 1. The Mississippi River and its tributaries drain 41 percent of the U.S. and carry N nutrient that fuels the annual dead zone. Fertilizer use on farms (green) is a more significant source of nutrient loss than urban wastewater (red). Source: NOAA Environmental Visualization Lab.

Key Findings

45% N leaching reduction is feasible using different approaches—some more painful than others	In-field N reductions coupled with wetland restoration are the most effective strategy	Local policies can have consequences for global markets

Policy Options

A variety of conservation practices have been suggested to abate loading from farming, including both N-management and N removal practices. However, a growing consensus suggests that no single practice is sufficient to meet the water-quality goals[8–10]. Furthermore, most of these conservation activities are voluntary and the adoption has been minimal to date[11,12]. As a consequence, market-based reduction strategies are now being considered. This might entail establishing a cap on total nutrient loading, and allowing farmers, as well as industry, to 'trade rights'. Farmers implementing a conservation practice might be compensated by selling the ensuing leaching rights to another farmer or to industry. In the absence of sufficient point sources to allow for a healthy trading market, a leaching charge could be levied on producers. Economists advocate this kind of policy, as it encourages least cost abatement with the marginal cost equated across farms.

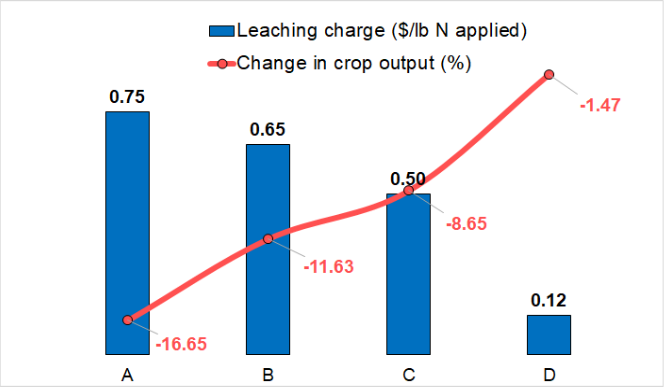

Figure 2. Leaching charge and change in crop output under alternative conservation strategies: A) Rate reduction, B) A+ Split N, C) B+ Controlled drainage, and D) B+ Wetland restoration.

Implications of Policy Alternatives

In analyzing a variety of abatement options, we started out by asking how large a leaching charge would have to be to achieve agriculture's contribution to the -45% target established by the Hypoxia Task Force *if all of the abatement were to come from reductions in fertilizer application rates.* We find that the resulting charge under this rate-reduction-only strategy (A in Figure 2) is extremely high, namely the equivalent of 75 cents per pound of N fertilizer applied, which is roughly 130% of the N fertilizer price. Furthermore, such a 'rate reduction' strategy would have an adverse impact on yields, reducing US corn output by about 17% and raising prices sharply. Improving nutrient management through techniques such as fall/spring split applications of N fertilizer (B in Figure 2) can reduce the necessary leaching charge by about 10 cents per pound of N applied, but this is still very high and the ensuing output reduction remains above 10 percent. Further reductions in the pollution price can be obtained if farmers were to simultaneously implement controlled drainage[13] (C in Figure 2) in those locations where this practice, which involves installing water table control structures at the outlet of subsurface drainage systems in order to limit drainage during some parts of the year, is deemed feasible (Figure 3). However, the biggest impact on the leaching charge is obtained when wetland restoration (D in Figure 2) is introduced.

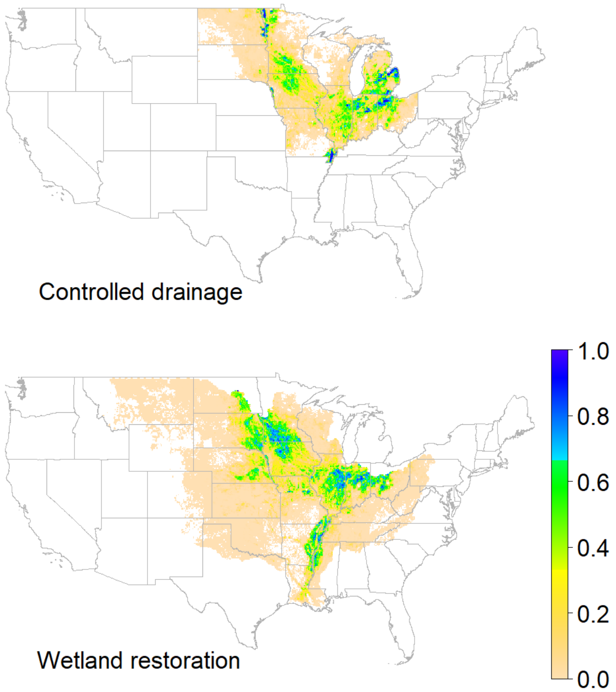

Figure 3. Feasible sites for edge-of-field management (fraction of each grid-cell) based on Gridded Soil Survey Geographic Database and Hydric Soils layer from Natural Resources Conservation Service USDA, and Cropland Data Layer from National Agricultural Statistics Service USDA.

As can be seen from Figure 3, there are many sites throughout the Corn Belt (upper Midwestern US dominated by farming) where wetland restoration is feasible[14,15], and this is expected to be a very effective strategy for N removal. Combining comprehensive restoration of wetlands with split applications of N and a much more modest leaching charge (22% of the price of N applied) throughout the Corn Belt can achieve the 45% leaching reduction target for agriculture while reducing corn output by just 1.5%. Furthermore, even if it were impossible to incentivize rate reductions (a zero 'leaching charge' in Figure 2), comprehensive wetland restoration paired with improved N efficiency would still deliver a 40% reduction in N leaching.

Linking Local Actions to Global Drivers

In order to arrive at these findings, we employed a novel sustainability framework which captures global drivers of local sustainability stresses, as well as feedbacks from local actions to the national and international economies. Dubbed 'SIMPLE-G-US'[*], it incorporates the local responses of corn yields to N fertilizer applications, as well as the predicted nitrate leaching rate based on local soils, weather and management practice. These agronomic relationships are based on the Agro-IBIS[**]modeling framework developed at the University of Wisconsin-Madison by Chris Kucharik and his collaborators[16,17]. Higher spatial resolution to capture local effects is critical since nitrate leaching rates – as well as the potential conservation actions to limit leaching – vary greatly across the Corn Belt.

The pair of maps in Figure 3 illustrate the tremendous variation in suitability for these particular conservation practices. However, fine spatial resolution is not enough to allow a complete analysis of these policy packages. As shown in Figure 2 (red line), restricting N use across the Corn Belt can have significant impacts on corn output and prices. Capturing this feedback to national and international markets is a key contribution of our framework.

Spatial Consequences of Alternative Policies

While each of the policy scenarios in Figure 2 achieves the same 45% aggregate reduction in leaching from farming, the spatial patterns are quite different (Figure 4). Local variations in farming practices, weather and soils, as well as feasible conservation practices, result in very different leaching reduction rates. For example, controlled drainage would be more effective for Illinois, Indiana, and Ohio, whereas wetland restoration would be more effective for Nebraska, Iowa and Minnesota.

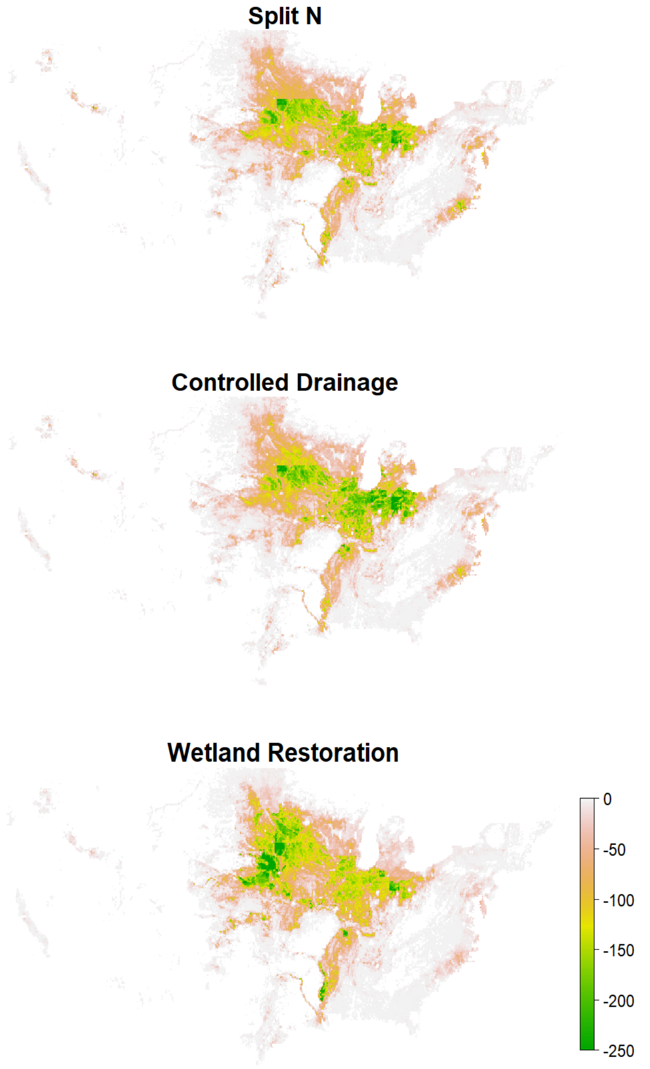

Figure 4. N leaching reduction (tons per grid-cell) under Strategies B, C and D.

Figure 5 shows this decomposition for the two policies involving wetland restoration and controlled drainage. From it can be seen that the relative importance of in-field (blue bar shows rate reduction

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[*] SIMPLE-G-US stands for a Simplified International Model of International Prices Land use and the Environment – Gridded over the United States. For more detail and to explore these results online, visit GLASS on Purdue University's GeoHub: https://mygeohub.org/groups/glass

[**] Agro-IBIS is a process-based terrestrial ecosystem model adapted from the Integrated Biosphere Simulator (IBIS) to simulate the dominant U.S. Corn Belt agroecosystems.

and split-N) and edge-of-field (red bar shows contribution of N removal) conservation practices varies greatly across states. Overall, in-field reduction is a more dominant component of the leaching reduction when controlled drainage management (strategy C) is adopted, as opposed to wetland restoration (strategy D).

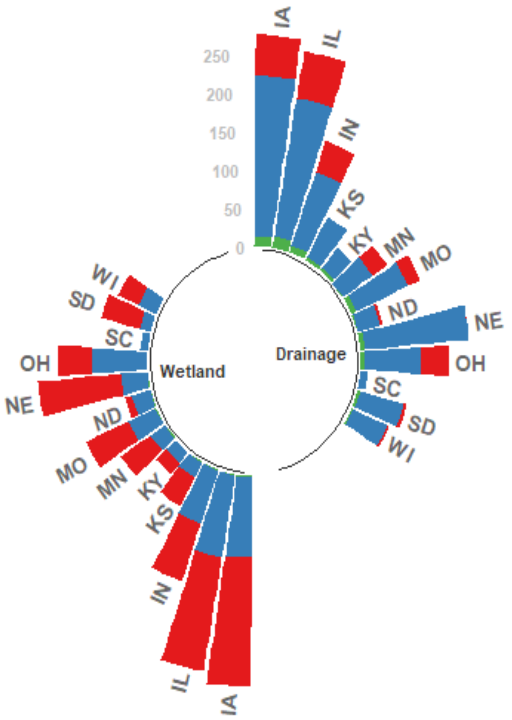

Figure 5. Total reduction in leaching (1000 tons) by state, under strategies C and D from Figure 2. Contributions of in-field reductions in blue, edge-of-field practices in red and cropland area change in green.

Limitations of the Analysis

As with any quantitative analysis of sustainability, our study has important limitations which should be borne in mind. Firstly, the policies are ‘best case’ scenarios representing implementation of the conservations practices across all feasible locations. Scaling up these policies to such an extent will surely pose significant challenges, including the site-specific availability of low lying areas for wetland restoration. Secondly, we have only focused on nitrate pollution from corn production. While this accounts for a large share of total nutrients flowing into the Gulf of Mexico, a comprehensive analysis would also consider other sources of pollution and a realistic assessment of the potential trading opportunities between farm and non-farm activities. Another important limitation is that we have only focused on N in water – which pertains to nitrates leaving the root zone where the corn is produced. We do not consider the emission of nitrous oxide – an important contributor to greenhouse gas emissions[18]. Furthermore, we have not yet evaluated how much of the leached nitrates end up in the Gulf of Mexico. This will depend on local hydrological and biogeochemical processes[17]. Recent evidence[19] suggests that it may still take two decades to achieve the 45% leaching reduction goal even if agricultural N use is 100% efficient (zero N surplus). We aim to address these limitations via ongoing collaborations with hydrologists and biogeochemists.

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