Evaluating Alternative Options for Managing Nitrogen Losses from US Corn Production

Background

Widespread and intensive agricultural activity, particularly corn production, has resulted in large amounts of nitrogen (N) loading to surface and groundwater (Turner and Rabalais, 1991). Elevated N levels in streams and rivers causes a spectrum of different problems including biodiversity loss, crop yield loss, and negatively affecting human health (Tilman et al., 2002). Nutrients transported through the Mississippi River Basin have been blamed for what are referred to as the "dead" zones (low oxygen water) formed in the Gulf of Mexico (Diaz and Rosenberg, 2008). 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 (USEPA, 2013). This paper evaluates the potential of alternative options to mitigate Nitrogen loss from US corn production.

Method

Assessing the costs and benefits of reducing N-loss requires knowledge of yield response to N fertilizer use and the resulted nitrate leaching. In order to capture the spatial heterogeneity in these relationships, a grid-resolving model SIMPLE-G-US-CS is developed. SIMPLE-G-US-CS is a global partial equilibrium model where the U.S. is downscaled into 5 arcmin resolution grid-cells and each of the fifteen non-US regions is represented by an individual 'grid'. It is a gridded version of the SIMPLE model that has been widely employed to study long run sustainability issues in agriculture (Baldos and Hertel, 2014; Hertel et al., 2014; Liu et al., 2017). The increasing regional demand for food is shaped by growing population, income per capita, biofuels demand and total factor productivity. On the supply side, crop production follows a CES function but each grid cell has a distinctive cost structure and an elasticity of substitution between Nitrogen fertilizer and other inputs.

Cost shares and elasticities are derived from a set of transfer functions that are separately fitted based on the simulated yield responses to Nitrogen use from a biophysical agroecosystem model Agro-IBIS. These grid-specific transfer functions significantly improve the representation of local biophysical characteristics in the economic model. Given that Agro-IBIS is geographically confined to Mississippi Basin and simulates only major field crops in this area, SIMPLE-G-US-CS focuses on two dominant crops -- corn and soybeans. Their combined planted area accounts for 54% of total area planted in the U.S. in 2017. Corn and soybean production also plays a critical role in shaping the long-run sustainability of agriculture given the bio-energy goals and the diet transition by the middle of the century. In terms of nitrate leaching, corn specifically 'requires the most nitrogen per acre' according to USDA. To validate the model's ability to generate a forecast, we use year 2006 as the base year and validate a back-cast to 1990. We calibrate the model such that the simulated changes in cropland area, nitrogen use and price changes in nitrogen fertilizer reasonably follow historical observations.

Experimental Design

Four policies are examined, namely A) leaching charge, B) splitting N application between fall and spring, C) controlled drainage, and D) wetlands restoration. In experiment A, a nationwide leaching charge ($/leaching) is combined with leaching intensity (leaching/N use) to incur an additional cost attached to the uniform market price of fertilizer. Farms with high leaching intensity thus will expect high penalty for pollution and try to avoid the excessive use of N fertilizer. Strategy B of changing the timing of N application reduces not only the leaching from late fall fertilization but also the amount of N required for spring fertilization. This strategy is implemented in the model by a 10% increase in the productivity of N fertilizer. Strategy C and D lower N leaching rate from installing controlled drainage and restoring wetlands respectively. Both are implemented in the model by shifting downward the leaching response function. The magnitude of the shifter is informed by agronomic models.

Key findings

#**1. Neither of the four strategies alone will be sufficient to achieve the Hypoxia Task Force Goal** (i.e. the 45% reduction goal) (Figure 1). Wetland restoration appears to be the most effective policy among the four, but can only achieve one third of the goal. Combining strategy A, B and D can significantly increase total mitigation but still unable to hit the target.

#**2. Most effective leaching reduction policy varies by location and by state (Figure 2).** For example, in the heartland corn belt, controlled drainage and wetland are typically more effective than leaching charge and splitting N application, in contrast with northeast and southeast US where leaching charge should be considered mostly. At the state level, the winning strategy also varies.

#**3. The spatial pattern of N leaching reduction varies across strategies (Figure 3).** While the aggregated leaching reductions between strategy A and B are comparable, the spatial pattern shows clear difference. For controlled drainage and wetland restoration, N leaching could increase due to the indirect effect transmitted by markets.

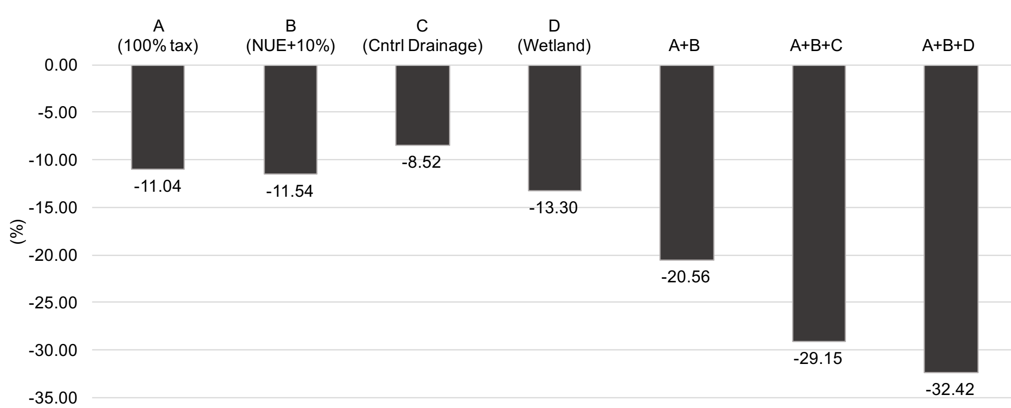

Figure 1. Total N leaching mitigation differs across strategies.

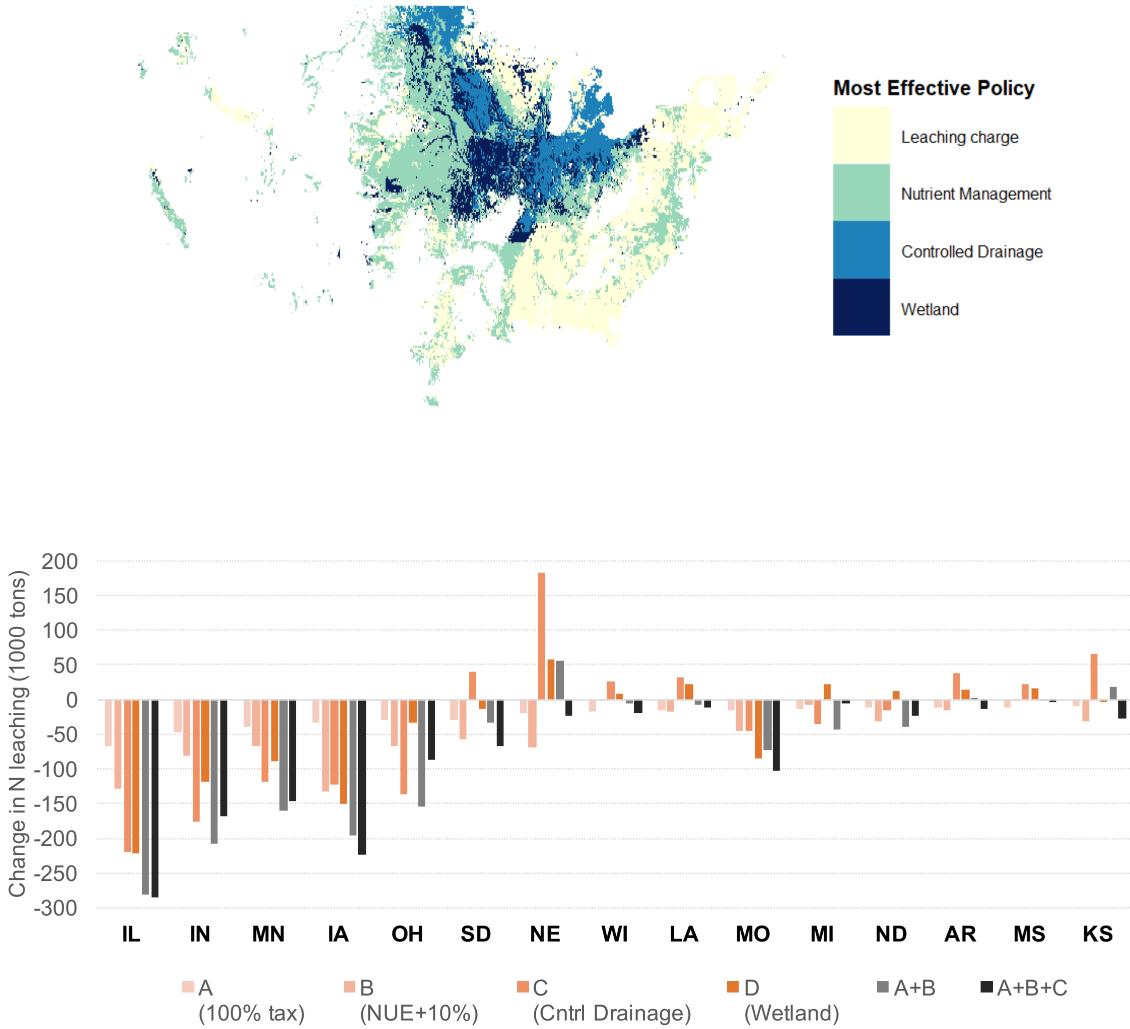

Figure 2. Most effective leaching reduction policy varies by grid-cell (above) and by state (below).

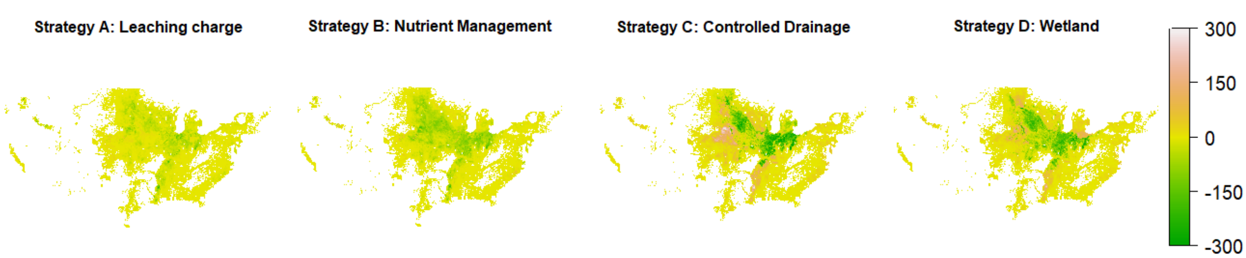

Figure 3. Change in N leaching at the grid-cell level. Unit is tons per grid-cell.