Imperfect Substitutes: The Conditional Effect of Agronomic Practices on Nitrogen Fertilizer Demand

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Imperfect Substitutes: The Conditional Effect of Agronomic Practices on Nitrogen Fertilizer Demand

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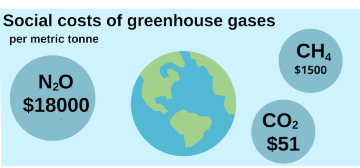
Background

Nitrogen fertilizer is a critical input for the dramatic increases in crop yields necessary to feed a growing global population (IFA 2025; Zhang et al. 2015). However, this success has come at significant environmental costs.

Harmful algal blooms
Source: EPA



Source: Interagency Working Group

A central paradox for sustainable agriculture: while practices such as crop rotation, cover cropping, and manure application are widely encouraged for their potential to provide alternative nitrogen sources and improve nutrient cycling, adoption of cover crops (4%) and manure (8%) remains low.

Research Question

Do alternative nitrogen management strategies, proven to reduce the need for synthetic inputs at the field level, actually reduce fertilizer consumption by profit-maximizing farmers in practice?

Data

- USDA Fertilizer Use and Price: Fertilier Price
- NuGIS Fertilizer Data: Estimated Synthetic Fertilier Consumption and Manure Consumption
- USDA Cropland Data Layer (CDL): Land Use Change
- USDA NASS Quick Stats: Corn Yield

Alternative Nitrogen Srouces

Manure: livestock waste

- Beneifts: Provides crop nutrients (N, P, K)
- Challenges: 1) High Transportation Cost: limits its use as a fertilizer source but more as a waste management issue; 2) Imbalanced N-to-P Ratio: leads to phosphorus overapplication, causing nutrient loss.

Soybean-Corn Rotation

- Beneifts: 1) N Fixation: Soybeans add N to the soil through biological nitrogen fixation (BNF), providing a N-credit; 2) Improved Soil Health: Crop rotation enhances nutrient cycling and soil organic matter.
- Challenges: Opportunity Cost.

Cover Crops & Double Cropping

- Beneifts: 1) N Fixation: Legumes fix atmospheric nitrogen, providing a N-credit; 2) Nutrient Recycling: Other cover crops scavenge and hold residual soil nitrogen, preventing loss.
- Challenges: 1) High Upfront Costs. 2) Delayed Payoff. 3) Increased Complexity: Requires more intensive, year-round farm management.

Method

Panel Fixed Effect Model

$$\log Q^D_{ct} = \alpha + \beta_1 \log P_{ct} + \beta_2 \log M_{ct} + \beta_3 \text{CornShare}_t + \phi_1 \log M_{ct} \times \text{CornShare}_t$$
$$+ \beta_4 \log \text{SoyCorn}_{c,t-1} + \beta_5 \text{After2010}_t + \phi_2 \log \text{SoyCorn}_{c,t-1} \times \text{After2010}_t$$
$$+ \beta_6 \log \text{MajorCrop}_{ct} + \mu_c + u_{ct}$$

where for county c in year t, Q^D_{ct} is the quantity of N synthetic fertilizer consumed, P_{ct} is the N fertilizer price, M_{ct} is the quantity of manure nitrogen consumed, CornShare_t is the county's corn acreage as a share of major crop acreage, serving as a proxy for local N demand, $\text{SoyCorn}_{c,t-1}$ is the acreage of soybean-corn rotation from year t-1 to year t, After2010_t is a dummy variable for the post-2010 "ethanol boom" era, MajorCrop_{ct} is the total planting acreage of major crops, and u_c is the county fixed effect.

We incorporate interaction terms to capture the conditional nature of farmer behavior. For instance, the value of manure as a nitrogen substitute depends on local crop demand. In a county with extensive corn production, the high nitrogen requirement of the crop makes manure a valuable substitute for costly synthetic fertilizer. Similarly, the nitrogen credit of a soybean-corn rotation may be overshadowed by economic incentives. During periods of high corn prices, a profit-maximizing farmer may be incentivized to apply nitrogen at higher rates to ensure yield is not limited, potentially negating the savings from the agronomic credit.

Results

	log(N Fert. Demand)	log(N Fert. Demand)
log(N Fert. Price)	-0.169*** (0.041)	-0.188*** (0.042)
log(Manure N Consump)	0.033 (0.021)	0.031 (0.022)
Corn Share	0.661*** (0.168)	0.673*** (0.181)
log(Manure N Consump) × Corn Share	-0.082*** (0.032)	-0.083** (0.034)
log(Lagged Soy-Corn Rotation)	-0.009* (0.005)	-0.009* (0.005)
After2010	0.036** (0.018)	0.033* (0.018)
log(Lagged Soy-Corn Rotation) × After 2010	0.012*** (0.002)	0.013*** (0.002)
log(Major Crop Acreage)	0.011 (0.016)	0.011 (0.016)
log(Lagged WinterWheat-Soy DC)		0.005 (0.003)
log(Lagged WinterWheat-Sorghum DC)		0.007** (0.003)
log(Lagged WinterWheat-Corn DC)		-0.002 (0.003)
log(Lagged WinterWheat-Cotton DC)		-0.006 (0.006)
log(Lagged Oats-Corn DC)		-0.001 (0.001)
log(Lagged Soy-Oats DC)		-0.003 (0.004)
log(Lagged Barley-Corn DC)		-0.028*** (0.010)
log(Lagged Corn-Soy DC)		-0.008*** (0.003)
log(Lagged Barley-Soy DC)		0.015*** (0.004)
Country FE	Yes	Yes
Observation	15,255	15,255

Discussion

Our findings confirm an inelastic N fertilizer demand, with the own-price elasticity ranging from -0.169 to -0.188.

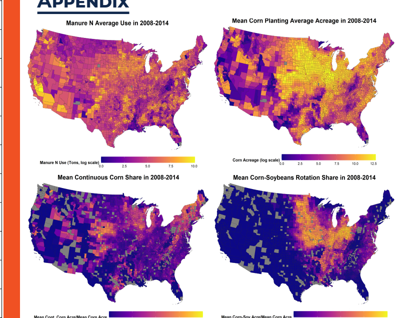
Manure becomes a significant substitute for fertilizer only in corn-heavy areas. A 10% increase in manure use can decrease synthetic N demand by 0.29% in these counties.

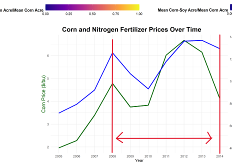
The effect of soy-corn rotation on N fertilizer use flipped from negative (-0.009) before 2010 to positive (+0.003) during the high-price "ethanol boom".

Specific double cropping systems, like Barley-Corn, are linked to significant fertilizer reductions. A 10% increase in such land use can decrease synthetic N demand by 0.28%.

Our summary statistics indicate that, on average, synthetic N use is 4,191 tons, manure N use is 486 tons, corn plants at 30,733 acres, barley plants at 736 acres, and barley-corn double cropping plants at 11 acres. This gap reveals a significant potential to reduce synthetic fertilizer reliance by expanding the use of alternative practices.

Appendix





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