Understanding the Dynamics of Nutrient Management and Runoff from Plant Farms in the Potomac Watershed

Take Example of Nitrogen Management in Corn Planting of Frederick

By

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Abstract

In this paper, we focus on nitrogen load from corn planting in Frederick, in order to explore a generalized system dynamics structure and policy indications for nutrient pollution from agricultural planting in Potomac watershed. The structure contains two sections: commodity production structure and nitrogen application structure, which separately focus on two core variables as planting acreage and nitrogen application. We find leverage points from structure analysis, simulation results and literature. Nitrogen application control is most efficient method for nitrogen load reduction while soil quality preservation is most significant and has long-term effect for the whole system. Manure application shows more problems than fertilizer application while manure management and transportation are seen as important for manure application control. We further analyzed related best management practices and compared implementation feasibility for each policy. The system dynamics model has reproduced the reference mode, passed sensitivity test and robustness test. The test of soybean planting in commodity production structure indicates the structure can be generalized to similar agricultural products.

Keywords

Nitrogen load, corn planting, nitrogen application, soil quality, manure application, best management practices, Frederick, System Dynamics

Table of Content

List of Acronyms

BMP: Best Management Practice

CAST: Chesapeake Assessment Scenario Tool

CBWS: Chesapeake Bay Watershed

CLD: Causal Loop diagram

ESL: Edge of Stream Load

NASS: National Agricultural Statistics Service

PWS：Potomac Watershed

RUSLE: Revised Universal Soil Loss Equation

SD: System Dynamics

SFD: Stock Flow diagram

USDA: Department of Agriculture

WIP 2025: Watershed Implementation Plan 2015

N: Nitrogen

P: Phosphorous

NY: New York

PV: Pennsylvania

MD: Maryland

VA: Virginia

MD: Maryland

WV: West Virginia

1. Introduction

1.1 Background Information

Estuary water nutrient pollution shows a rising problem partly due to a rising socio-economic activity in the watershed and the ever-increasing climate change. According to the EPA (2016), 46% (about 546,000 miles) of U.S. streams and rivers are in poor condition in terms of their phosphorous (P) levels and 41% (about 495,000 miles) are in terms of their nitrogen (N) levels based on sampling results from almost 2,000 sites bench marked against conditions represented by a set of least-disturbed sites. Excessive nitrogen and phosphorus in the water creates health problems and damage land and water along the riparian area. When the nutrient moves and accumulates in estuary water, it would persistently be harmful to water environment, ecological balance and resident health. Although the social cost of pollution in the context of water quality has received less attention than the social cost of carbon in the context of climate change (Metaxoglou & Smith, 2022), the pollution can lead to a huge damage on economy and society.

The Chesapeake Bay Watershed (CBWS) is the largest estuary in United States and the third largest in the world. The bay is a vital ecological and economic resource. It supports more than 18 million people who live, work, and play within the watershed (10 M of these live along or near the Bay's shores). More than 150 major rivers and streams flow into the Bay's 64,299-square-mile (166,534 km2) drainage basin, which covers parts of six states, New York (NY), Pennsylvania(PV), Delaware, Maryland(MD), Virginia(VA), and West Virginia(WV), and all of Washington, D.C. The largest of these are Susquehanna, Potomac, Rappahannock, York, and James rivers (Chesapeake Bay Program, 2023a).

The bay and its tributaries have been degraded for decades by excessive nitrogen and phosphorus delivery into the waterways that cause harmful algal blooms and decreased water clarity, submerged aquatic vegetation, and dissolved oxygen. A myriad of factors affects the sources and transport of N and P in the CBWS. Human land-use practices, mainly due to agricultural practices and urbanization, as well as natural hydro-geologic and soil conditions are among the prominent factors (Chesapeake Bay Program, 2023b; CAST, 2018c).

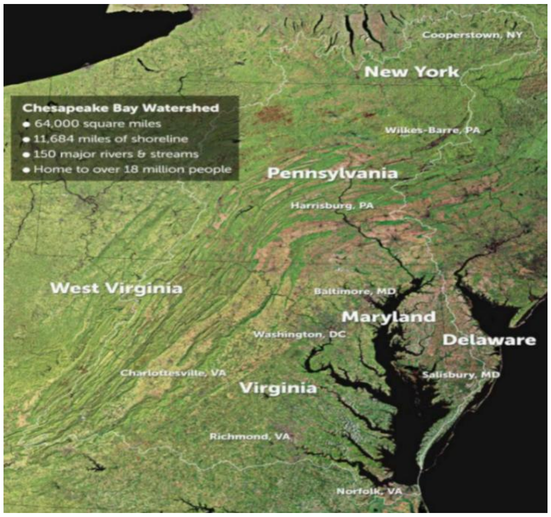

Figure 1 Chesapeake Bay Watershed (Chesapeake bay Program, 2023a)

With decades of work on improving nutrient management practices, nutrient loads delivered to bay has shown a decline (Figure 2). However, the delivery loads of N and P were above the target levels till 2021 and it is very unlikely to meet 2025 Watershed Implementation Plan (WIP)[1]

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[1] The 2025 Watershed Implementation Plan (WIP) Outcome is off course since BMPs are not in place to achieve the 2021 target for nitrogen and phosphorus. The 2021 target is essentially 80% of the needed nitrogen, phosphorus, and sediment pollution load reductions to attain water quality standards (the difference between the 2009 pollution load and the 2025 pollution load). While BMPs are in place to achieve 80% of the needed sediment load reductions, marking the sediment goal complete; because the pollution control measures are not in place to achieve the 2021 target for nitrogen and phosphorus loads, the 2025 WIP Outcome's outlook is off course.

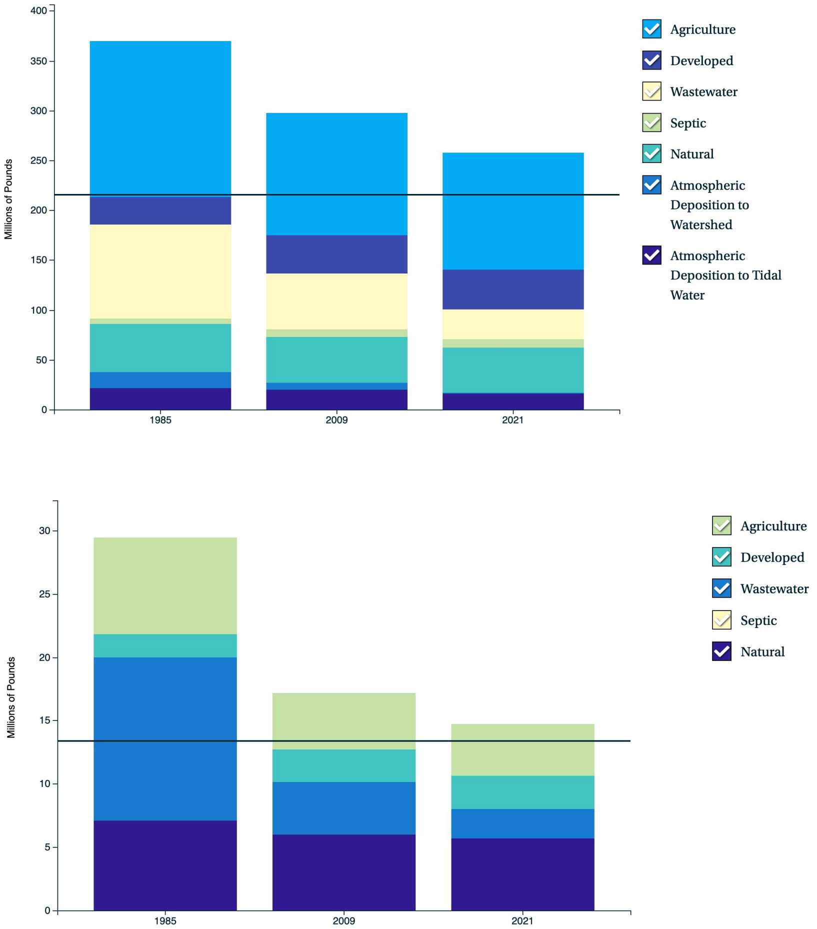


Figure 2 Simulated Nitrogen (upper) and Phosphorous (bottom) Loads Delivered to the Bay by Source* (million pounds/year)(Chesapeake Progress, 2023)

The data of nitrogen loads delivered to the bay by sources is : 156.28 million pounds (1985), 123.02 million pounds (2009), 117.05 million pounds (2021). The 2025 Planning Target for Nitrogen: 214.88 million pounds (dark line in upper picture). The data of phosphorus loads delivered to the bay by sources is: 7.638 million pounds (1985),4.467 million pounds (2009), 4.076 million pounds (2021). The 2025 Planning Target for Phosphorus is 13.315 million pounds (dark line in bottom picture)

Loads simulated using CAST19 version of Watershed Model and wastewater discharge data reported by Bay jurisdictions.**The Natural sector contains the following load sources: CSS Forest, Harvested Forest, True Forest, CSS Mixed Open, Mixed Open, Shoreline, Stream Bed and Bank, Headwater or Isolated Wetland, Non-Tidal Floodplain Wetland, and Water

1.2 Problem Formulation and Study Area

To clearly understand the interaction of causal factors that affect the current nutrient management practices in the CBWS and policies that help minimize the nutrient load, we choose Potomac watershed as a case study area. The Potomac River is the second largest tributary to Chesapeake Bay. Its watershed is approximately 38,000 km2 and spans parts of four states MD, PV, VA, WV and Washington, D.C. The tidal Potomac begins just upstream of Washington, D.C. at the boundary of the Coastal Plain and Piedmont (Figure 3)(American Rivers, 2023).

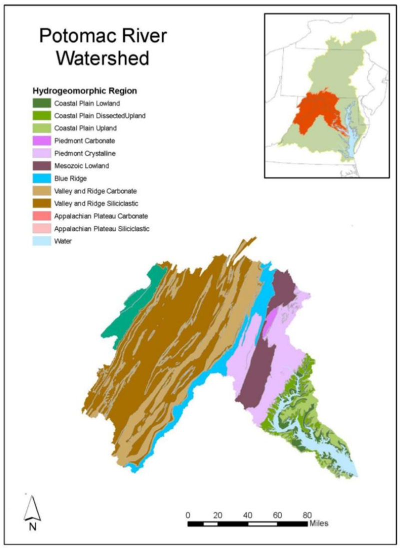


Figure 3 Distribution of physiography in the Potomac River watershed (Keisman et al., 2020).

Land use has a direct effect on nutrient and sediment load. Figure 4 shows the change of the distribution of land uses in Potomac River watershed since 1985. The Potomac River watershed is dominated by (61%) natural areas (Keisman et al., 2020). In general, developed lands have expanded to 1.5 times the values in 1985. Agricultural lands have stayed steadily as the second largest area with 23% since 2009. These indicate that developed land and agricultural land could be main sources for nutrient and sediments load and thereby for the nutrient pollution in the watershed.

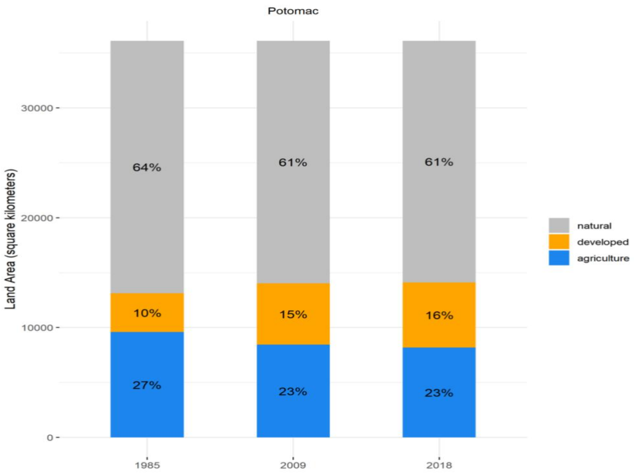


Figure 4 Distribution of land uses in the Potomac River watershed (Keisman et al., 2020).

Next, Figure 5 supports the above assumption that developed land and agricultural land are the main causes for nutrient load in the watershed. In Figure 5 we can see that the expected long-term average loads of N, P, and sediment from different sources to the tidal Potomac. Nutrient load from developed land shows increase which corresponds to the expanded developed area in the past. The nitrogen and phosphorus load from agriculture took the largest (over 30%) in the total load from all sectors in 1985. Although it showed some reduction between 1985 and 2009, it remained almost same thereafter. In contrast, the N and P load from wastewater showed major reduction from 1985 to 2018, even if sediment load from wastewater only showed slight improvement in the same period.

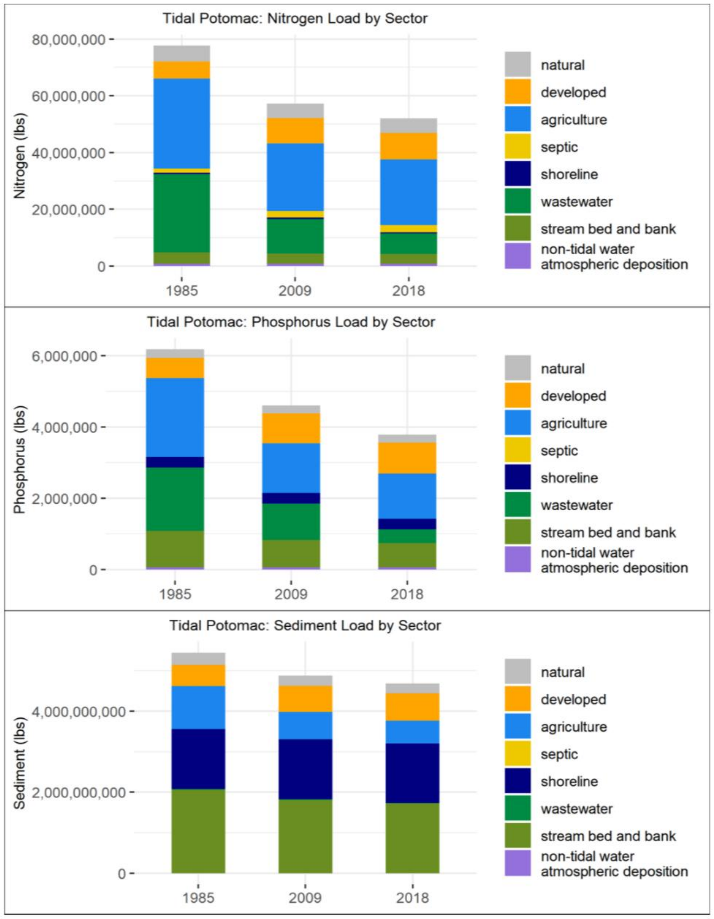
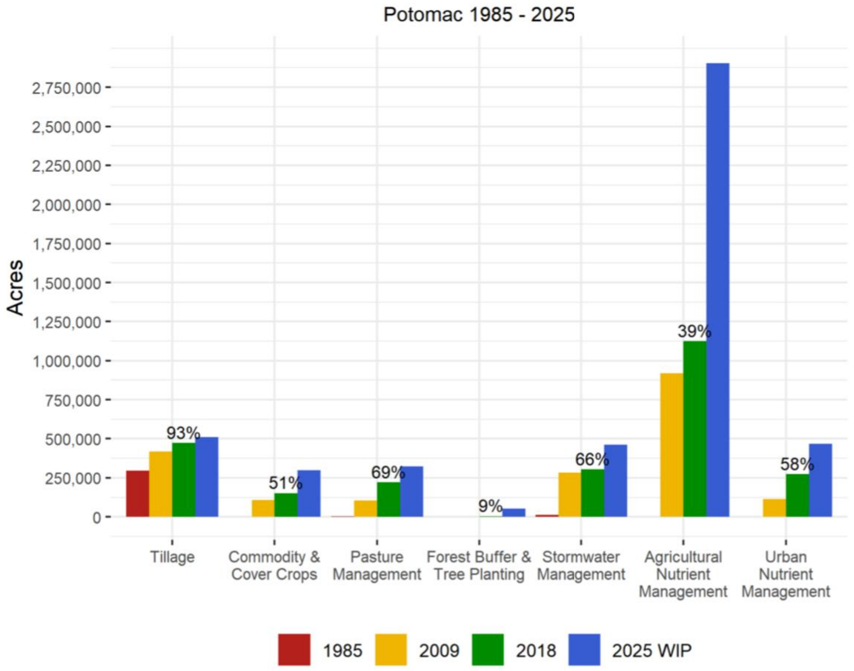


Figure 5 Expected long-term average loads of nitrogen, phosphorus, and sediment from different sources to the tidal Potomac, as obtained from the CAST (2018a). Data shown are time-average delivered loads over the average hydrology of 1991-2000, once the steady state is reached for the conditions on the ground, as obtained from the 1985, 2009, and 2018 progress management scenarios (Keisman et al., 2020b).

Hence, Figure 5 indicates that we need to focus agricultural and developed land if we have to reduce the nutrient load in Potomac watershed.

Since large of work has been done to achieve the load reduction in 2025 Watershed Implementation Plan (WIP) in Potomac watershed. Figure 6 shows an overview of BMP implementation achievement in the area from 1985 to 2018.



Values above the 2018 bars are the percent of the 2025 goal achieved.

Figure 6 BMP implementation in the Potomac watershed (Keisman et al., 2020c).

We can see implementations on Tillage, Commodity & Cover Crops, Pasture Management, Storm water Management and Urban Nutrient Management have shown a relatively effective achievement from 51% to 93%, excepted for the Forest buffer and Tree Planting, which is completed only 9%. (Tillage is the largest as around 500,000 acres and Forest Buffer & Tree Planting is only around 60000 acres). As a contrast, Agricultural Nutrient Management has been completed only 39% while the target is over 2,850,000 acres, which is highest in target area and even larger than sum of others. This indicates Agricultural Nutrient Management should be a significant concern for the study of nutrient load in Potomac watershed.

Metaxoglou & Smith (2022) shared the concern of nutrient load from the agriculture sector by citing the works of CENR (2000) , “fertilizer runoff from agricultural crops has been estimated to contribute somewhere between 50% of the annual nitrogen riverine export from the MRB2 to the GoM[3] fueling a hypoxic ("dead") zone[4]" p2.

Narrow Study Area Though we have decided agricultural nutrient management in Potomac watershed as study focus, there exist various agricultural types and complex load conditions due to the different watershed physiography. We purposefully choose three counties (see Figure 3 & Figure 7) along Potomac watershed: Frederick, Shenandoah and St. Mary's. They represent for varied physiography of Piedmont as Mountains and Valleys (Frederick), Valleys and Ridges (Shenandoah) and Coastal Plain (St. Mary's)[5] (Keisman et al., 2020).

Due to time restriction, we further narrowed our study area to Frederick county, which is the largest agricultural County with the most number of farms (1,300) and farmland acres (over 181,500 acres). Since the county has been harvesting revenues in agriculture longer than any other industry, agriculture remains an important industry and has far reaching effects on their economy and quality of life (Frederick County Government, 2023a). The Piedmont Plateau and mountain terrain has benefited the developed animal grazing industry and boosted the feeding crops planting, which are both closely related to nutrients load in the area.

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[2] MRB, Mississippi River Basin

[3] GoM, Gulf of Mexico

[4] "Dead zone" is a more common term for hypoxia, which refers to a reduced level of oxygen in the water. Less oxygen dissolved in the water is often referred to as a "dead zone" because most marine life either dies, or, if they are mobile such as fish, leave the area.

[5] The introductions for three counties, also see "Frederick country"(2023); "Shenandoah county" (2023); "St, Mary's county" (2023).

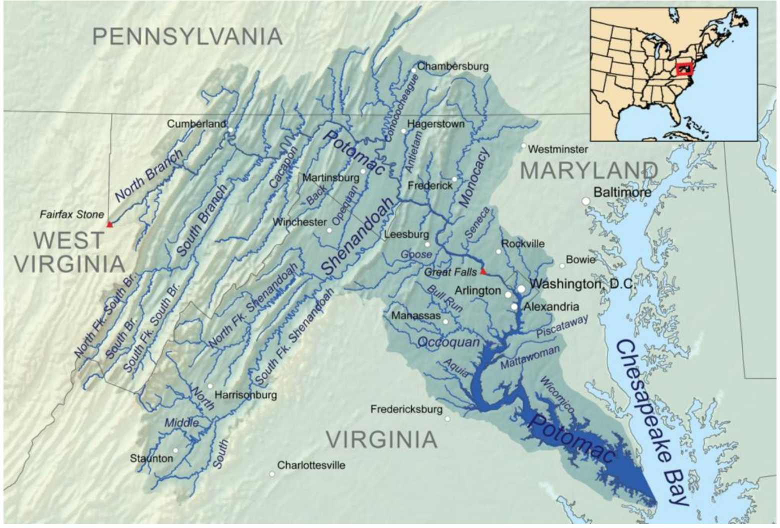

Figure 7 Potomac Watershed Basin. (American Rivers, 2023)

1.3 Research Objective: Corn, Nitrogen, Frederick

The goal of the paper is to develop a system dynamics model that can recognize underlying structure on how agricultural planting effect nutrient load to watershed, as well as to understand interactions of current nutrient management practices in the CBWS and find best leverage points for future policies to reduce nutrient load.

The paper has chosen the nitrogen load from planting of corn for grain (corn planting[6]) in Frederick MD[7] as a typical study object, which is located in the outlying section of Washington metropolitan area (Figure 7). Nitrogen is the most important nutrient in soil organic matter from the economic standpoint (Saysel, 2004). Nitrogen load from sources is chosen as focus as it is much higher than phosphorus and nitrogen load (Figure 2). Corn is chosen as a focused crop because it is the most fertilizer intensive crop in the country (Metaxoglou & Smith, 2022). Besides, Corn and soybeans are the nation’s most prevalent crops and the predominant source of feed grains used in cattle, dairy, poultry, and hog production. United States also produces 41% of the world's corn (Schlenker & Roberts,

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[6] Corn planting, in this paper corn planting means planting of corn for grain, which does not include corn for silage use.

[7] Frederick MD means area of Frederick county that belongs to Maryland.

2009). These indicate corn planting has taken a significant role in agricultural planting in the country and would continue this trend for many years. Finally, the structure is expected to be generalized to other plants types (especially for animal feeding crops) and other areas.

1.4 Research Questions

1.4.1 Reference mode

Figure 8-11 show dynamics scenarios as reference mode by data from CAST[8] Source Data, (2023). They consist of general dynamics for our focus in Frederick county.

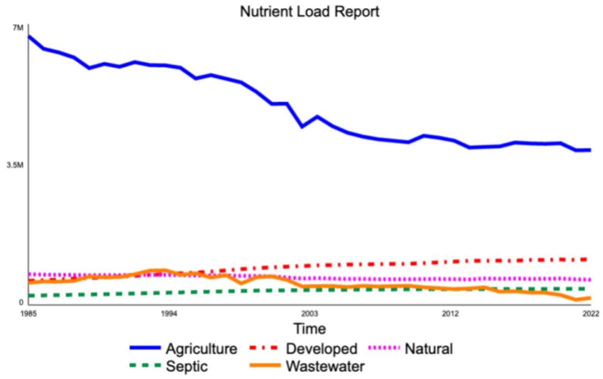

Figure 8 Nitrogen Load Report from different sources in Frederick MD in 1985 to 2022 (CAST Source Data, 2023)

Figure 8 shows agriculture contributes the largest part of nitrogen source since 1985. Though with a general decrease in the past decades, the reduction has slowed down in recent years.

Figure 9 shows Surface total nitrogen data in the Tidal Fresh Potomac River in Maryland. Due to the location of Frederick county, we choose stations of TF2.1 - TF 2.4 on the section of tidal fresh of Potomac River because this is the nearest part to the upstream with the

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[8] Chesapeake Assessment Scenario Tool (CAST) is a web-based nitrogen, phosphorus and sediment load estimator tool that streamlines environmental planning. Users specify a geographical area, and then select Best Management Practices (BMPs) to apply on that area. CAST builds the scenario and provides estimates of nitrogen, phosphorus, and sediment load reductions. The cost of a scenario is also provided so that users may select the most cost-effective practices to reduce pollutant loads.

confluence of waterways from Frederick and would best capture the effect from agricultural nutrient load from Frederick county, compared with other monitoring stations. The graph shows a similar dynamic nitrogen change in Potomac river upstream in the past decades, compared with nitrogen load trend from agriculture in Frederick MD (Figure 8). It indicates the choice of agriculture nitrogen load in Frederick MD is meaningful for the concern of nutrient pollution in Potomac river.

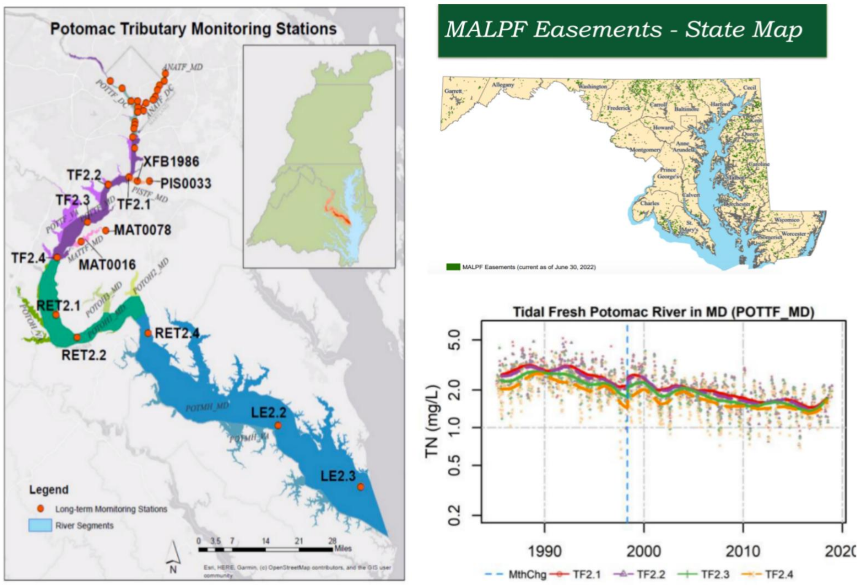

Figure 9 Map of Maryland State (Maryland Department of Agriculture, 2023); Map of tidal Potomac River segments and long-term monitoring stations (Left); Tidal Fresh Potomac River in MD (Bottom). Colored dots represent data corresponding to the monitoring station shown indicated in the legend; colored lines represent mean annual GAM estimates for the noted monitoring stations. Vertical blue dotted lines represent timing of changes in laboratory and/or sampling methods (Keisman et al., 2020d-e).

Figure 10 shows scenarios on planting acreage of Corn & Grain[9] in Frederick MD, St Mary's MD and Shenandoah VA from 1985 to 2022. Frederick MD shows a much higher corn planting than the other two counties.

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[9] Corn & Grain used in the scenario means corn planting both for grain and silage.

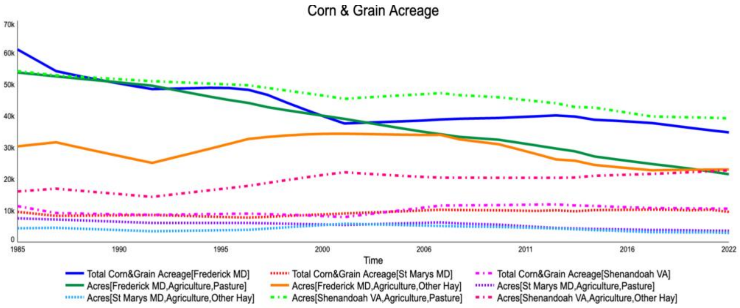

Figure 10 Corn & Grain Acreage in Frederick MD, St Mary’s MD and Shenandoah VA, in 1985 to 2022(CAST Source Data, 2023).

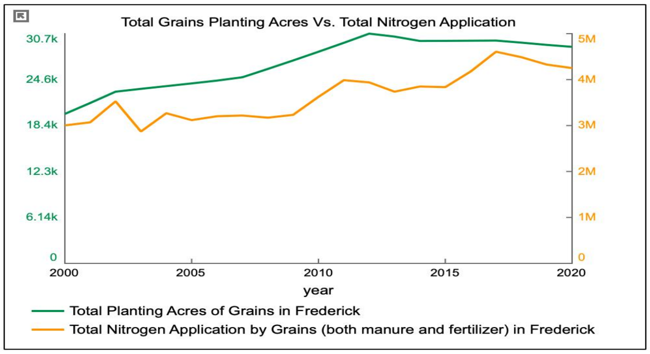

Figure 11 Total Grains Planting Acres and Total Nitrogen Application (CAST Source Data, 2023). The graph describes the total planting acres of Grains and total nitrogen application in Frederick County, both containing grains with manure and fertilizer applications, obtained from source data of Chesapeake Bay Assessment Tool.

In figure 11, we have total grains planting acreage in Frederick and total N application by grains. Grains planting increases from 20,000 acres in 2020 to around 30,000 acres in 2013 then slowly decreases to 28,900 acres by 2020. Total N application from grain planting shows quite similar trend. According to USDA (2023b), the major feed grains in U.S. are corn, sorghum, barley, and oats. Corn is the primary U.S. feed grain, accounting for more than 95 percent of total feed grain production and use. Hence, we can assume 95% if grains planting in Frederick is corn planting. The total N application in corn planting should be quite close to the total N application in grains.

These dynamic scenarios supply us a comprehensive reference mode for study of nitrogen management and load from crop planting in Frederick.

1.4.2 Research Questions

The paper describes the structure hypothesis with two sections that respectively focus on two core variables: planting acreage and nitrogen input. Research questions are raised around them.

1. What are the main factors and structrue that effect changes on corn planting acreage?
2. What are the main factors and structurethat effect nitrogen application and nitrogen load from corn planting?
3. How do existing policies (best management practices) (BMPs[10]) contribute to nitrogen load?
4. What are most important leverage points[11] for policy the system? What policy should be given more concern in the future?

1.5 Methodology

The paper would rely on System Dynamics(SD) as main methodology and explain the principle for assumptions, test as well as analysis based on a system dynamics modeling, which contains a multiple modeling property as conceptual, mathematical and simulation model. System dynamics is an approach to understanding the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, table functions and time delays (MIT, 2013).

Ford (2010) defined system dynamics as :

> *"System Dynamics is a methodology for studying and managing complex systems that change over time. The method uses computer modeling to focus our attention on the information feedback*

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[10] BMPs, best management practice in Chesapeake Bay Watershed, for more, see CAST BMP (2020).

[11] Leverage points, see Meadows (1999).

loops that give rise to the dynamics behavior. Computer simulation is particularly useful when it helps us understand the impact of time delays and nonlinearities in the system." (p3-4)

For our study of dynamics of different factors on planting acreages, nitrogen management and load, system dynamics modeling can capture the varied delays and describe the nonlinearity between those factors and dynamic behaviors.

Ford also stated, system dynamics will be most productive with simple category of models and recommend the goal should be to deliver improved integration across the different sectors of the system. Study in this paper on terrestrial nitrogen management is part of the nutrient study of CBW, which contains terrestrial input, hydrologic dynamics, water quality and estuarine environment. System dynamics modeling is powerful to describe how nutrient transmit across these different sectors. Finally, system dynamics is expected to contribute to estimate former policy achievement and evaluate policy implementation. As Forrester (1987) says, "The power and utility of system dynamics is best achieved by going beyond a model to implications and generalizations that can be drawn from the process of modeling."

1.6 Data Source and Literature Review

Data Source The data in this paper mainly comes from CAST, USDA, Frederick Government and literature. Parameters in the model partly come from historical data and literature. Part of parameters are estimated by principle in literature and historical data calculation, sensitivity test and optimization on Stella. Description for all the data source and parameters for model are included in documentation in Appendix A. Sensitivity test and optimization are included in Appendix B .

Literature Principles for model formulation, structure assumptions, analysis and policy discussion largely rely on existing literature. Table 1 shows main literature and data source for structure of commodity production and nitrogen management. The complete list of literature is included in Reference.

Author	literature	Main Principle or Indications
Sterman, 2000	Business Dynamics	Commodity structure: principle and logic, Commodity delays and nonlinear relationships
Meadows, 1971	Dynamics of Commodity Production Cycles	Commodity structure: principle and logic, delays, production capacity and utlziation capacity, robust test on different products
Bach, N. L. and K. Saeed (1992)	Food self-sufficiency in Vietnam: a search for a viable solution	Nitrogen Application Structure: principle and logic, nonlinear relationships, soil structure
Saysel, A. K. (2004)	System dynamics model for integrated environmental assessment of large scale surface irrigation	Nitrogen Application Structure: general principle and logic for SD model in agriculture
Foth, H. D. (1990)	Fundamentals of Soil Science	Nitrogen Application Structure: princile and logic of humus structure; nitrogen cycles for corn planting
Ford (2000)	Modeling the environment	Nitrogen Application Structure: principle and logic for structure, delays, high turnover stock, dynamics model from planting pollution
Metaxoglou & Smith, 2022	Nutreint pollution and U. S agriculture	Causal effects for nitrogen polluation, nitrogen problem in corn planting, climate effects, important reference parameters and data
Schlenker, W. AND M. Roberts (2009)	Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change	Influence from Climate and weather conditions; comparison of corn and soybean
MacDonald, Robert &Newton, (2018)	Three Decades of Consolidation in U.S. Agriculture	Influence from farm level decision
Edmeades, D.C (2003)	The long-term effects of manures and fertilisers on soil productivity and quality	Principle and logic on manure use
University of Minnesota Extension website, (2021)	Crop residue management	Principle for corn residue return, crops cover, proportion calculation
Charles et al., 2019,	Nutrient Management Suggestions for Corn	Principle for nitrogen uptake by corn, nitrogen application demand calculation from yield
Medows, 1999	Leverage points	Structure analysis and Policy analysis
David Wheat	Profit-cost analysis	Policy implemtentation feasibility Analysis
Keisman et al.	Potomac river report	Problem formulation
Frederick County Government		Information of Frederick: physiography, history, agriculture and land preservation
CAST, Phase 6	Watershed model documentations	Structure principle and logic, reference data, concepts decription, calculation methods
CAST, Data Source		Data source, BMP achievement calculation
USDA		Data source and Agricultural information

Table 1 Main literature for structure formulation

2 Hypothesis

In Hypothesis, we continue to discuss causal factors to problematic behavior, recognize important feedback loops and underlying structure, and explain assumptions mainly with Causal loop diagram (CLD). All hypothesis and model conceptualization rely on existing literature and historical analysis to get structure validity. Finally we will deliver Stock-flow diagram (SFD), a simulation system dynamic model, in order to reproduce reference mode and further test structure validity.

2.1 Structure of Corn Planting in Commodity Production Cycles

The whole structure hypothesis contains two sections: Commodity production and Nitrogen management, which are mapped around core variable respectively: Planting acreage per year and Nitrogen application per acre per year. They both decide total nitrogen application.

*Total nitrogen application = Nitrogen application/acre/year * Planting acreage*

Planting acreage is defined as the amount of corn acreages planted in Frederick every year. Previous study shows the positive and statistically significant effects of corn acreage on nitrogen pollution (Metaxoglou & Smith, 2022) .They state that:

> *"...Acreage is much better measured than fertilizer use. We observe nitrogen fertilizer sales by county, but we do not know in which county or year that fertilizer was applied to a field. In contrast, we observe annual acreage by county..." (p8)*

In their working paper, they picked up corn planting as typical plant for study of water pollution and its relationship to U.S. agriculture. They used regression analysis to establish causal links and particularly estimated the causal effects of corn acreage on nitrogen concentration in the country's water bodies using alternative empirical approaches, based on the average stream flow of the Mississippi River at the Gulf of Mexico. They find a 10% increase in corn acreage causes an increase in nitrogen concentration in water by at least 1% (Metaxoglou & Smith, 2022).

In order to capture the nitrogen application and load from corn planting in Frederick, we consider “nitrogen application/acre/year” as a second core variable. as it is main source for N load. These two variables have taken farmer’s most important decisions that relate to total N application and N load.

2.1.1 Commodity Production Cycles

Farmers’ planting decisions are based on the expected post-harvest crop price and expected costs (Metaxoglow & Smith, 2022). The principle behind this sentence is the essence of commodity production of planting. Corn planting is substantially production process inside commodity production cycles of corn.

Meadows has described this structures in his book of Dynamics of Commodity Production Cycles and raised the essentials of that structure are two coupled negative-feed-back loops, consumption and production, each acting to adjust inventory coverage to the desired level (Figure 12) (Meadows, 1971).

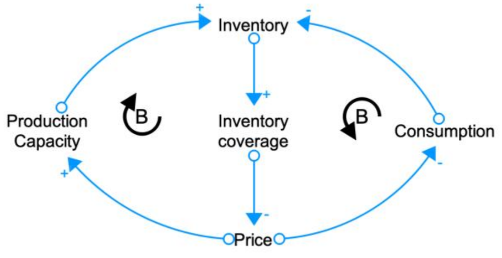

Figure 12 Feedback loop structure of production cycles (Meadows, 1971a).

Based on this structure, Meadows has built a generalized dynamic commodity cycle model and tested it in hog and chicken system, and concluded, with appropriate managerial and biological coefficients the model yields the typical cattle and chicken cycles (Meadows, 1971).

However, for this study, we only focus on the part from Price to Production, instead of bringing in the whole structure. There are two reasons: 1. the production of corn in Frederick is effected by change of market price and cost. However, the change of inventory or inventory coverage of Frederick county is not sufficient to effect the whole market price. The study area we focus are not applicable to reproduce the whole commodity cycles structures. 2. our final target is to study the relationships between N load and N management in corn planting, but not commodity production cycles or commodity stabilization policies. Price setting is seen to offer one of the most difficult formulation challenges in economic modeling (Sterman, 2000a). It can be effected by endogenous structure in commodity cycles and exogenous factors or emergencies from other system. Thus, It is impossible for us to capture price change precisely and the uncertainty would largely interfere our final simulation target. Hence, We set a boundary inside commodity production structure. We use external data from USDA for corn price and cost, to formulate how price and cost would effect production capacity and capacity utilization. This can raise structure validity and prevent much deviation on simulating planting acreage and total N application.

Sterman (2000) has dedicated a generic commodity market model in his book of Business Dynamics, which describes the underlying feedback structure responsible for the commodity cycles. In this paper, we will explain our commodity structure hypothesis for corn planting, referring to the generic structure and theory from both Meadows and Sterman.

2.1.2 Commodity Production Structure of Corn Planting

Figure 13 gives an overview of our structure assumption on corn planting[12].

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[12] The principle comes from Meadows (1971b); Sterman (2000a).

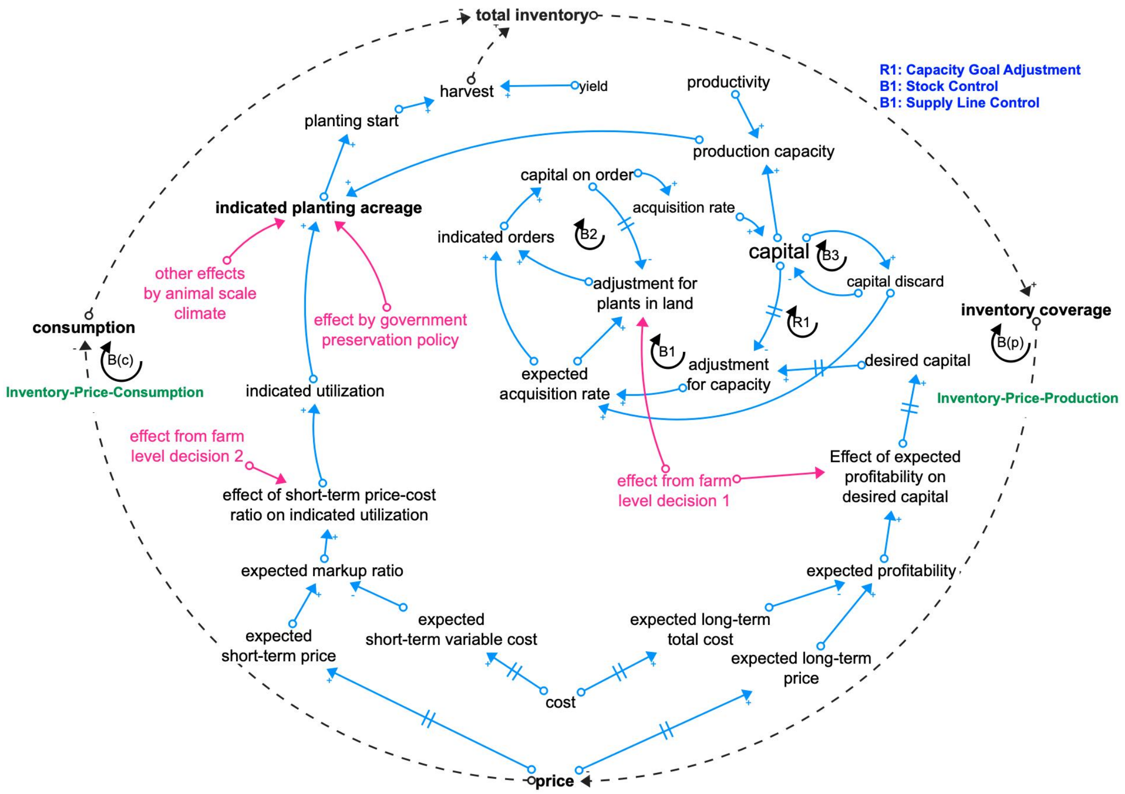

Figure 13 Commodity Production Structure Overview -- Corn Planting

The blue lines represents for basic structure of commodity production for corn planting. The red part shows external factors that effect capacity adjustment and utilization rate. The dotted lines shows the hinted part of commodity cycles that we do not include in our structure, like structure for inventory, consumption and price.

The CLD shows how planting acreage is decided by adjustment of capacity and utilization rate They separately come from long-term expectation of profitability (from market price and total cost) and short-term expectation of markup (from market price and variable cost). Besides, the adjustment processes and planting acreage are effected by external factors, including farm size level, government preservation policy and animal scale.

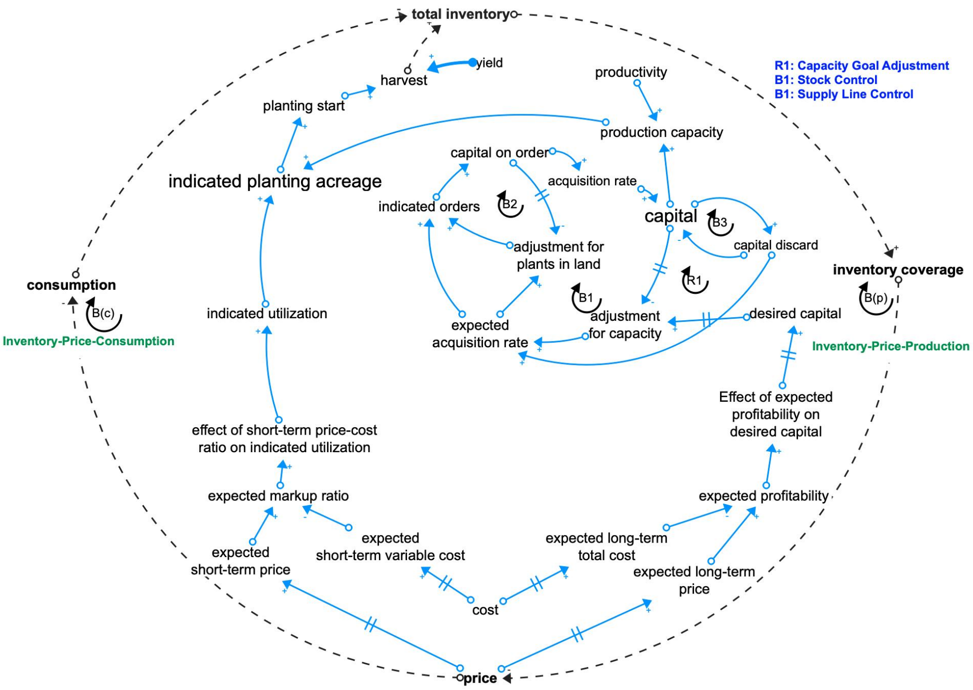

Figure 14 Basic Structure of Commodity Production of Corn Planting

The basic part of commodity production structure (Figure 14) describes how production capacity[13] and production utilization decide planting acreage without consideration of external effects. Main feedback loops are listed as following.

R1 (Capacity goal adjustment loop): Capacity Stock → + Capital discard → + expected capital acquisition rate→ + indicated orders → + capital on order →+ acquisition rate → + capacity stock.

B1 (Stock control loop): Capital Stock → - Capital stock adjust → + expected capital acquisition rate → + indicated orders → + Capital on order→ + acquisition rate → + capacity stock.

B2 (Supply line control loop): Capital on order → - Capital adjust for plants in land → + indicated order → + order rate → + Capital on order

B3 (Capital discarding Loop): Capital stock → + Capital discard → - Capital Stock

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[13] Production capacity is the rate of output generated at full utilization by existing plant and equipment (Sterman, 2000c).

Assumption on Capacity Adjustment The adjustment of production capacity is practised by a change of capital investment to corn production industry. Capital decision makers[14] get expected profitability from long-term expectation based on market price and total cost[15]. The equation is:

Expected profitability = (expected long-term price - expected long-term cost) / expected long-term price

This expected profitability would have an direct effect on desired capital for decision makers. The desired capital level would be compared with present capital level and adjusted by a proper time delay. This process is described as adjustment for capacity because the change on capital is realized on the change of capacity. The adjustment for capacity can be positive or negative, meaning they increase or decrease capital stock. The final adjustment of capital (capacity) does not only contain the adjustment demand from market change, but also include supplementary part of capital discharging. The discarding comes from equipment and tools scrapping, capital value shrinking and other reasons that deplete capital value. It depends on the general lifetime of capacity resources. Thus, capital stock adjustment and supplementary of discarding of capital consist of expected acquisition rate, which drives the increase rate for capital on order. Since capital stock adjustment can be negative, which might lead to a negative expected acquisition. However, in SD modeling, we do not use negative inflow to capital stock but set it as 0 when expected capital acquisition is negative. It means no new capital would enter the industry.

The indicated order rate comes from two parts: expected acquisition rate and adjustment for plant in land. Adjustment for plant in land is explained as the processing inventory on supply line. When we decide new order, we have to consider the processing inventory, which is still under production but will be transformed to capital later. Corn in land is like processing

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[14] Capital decision makers can be the same to producers or different people who only invest into the industry.

[15] Total Cost contains both fixed cost and variable cost.

product on assembly line, which need time to become mature, on sold and change to capital. It is the adjustment for the gap between capital in order (value of present plants in land) and expected acquisition rate with expected acquisition delay time. Farmers need time to adjust plants in land to an expected amount and other resources. Finally, capital on order moved to capital stock, the capital would be transformed to production capacity with capital productivity[16] before they are depleted by discharging rate.

Assumption on Capacity Utilization Adjustment The left part of CLD describes how producers or farmers decide their production capacity utilization by effect of expected markup, which is shaped by ratio of expected short-term price and expected short-term variable cost[17].

It is important to note here: In capacity adjustment, expected profitability for desired capital relies on long-term expectation on price and total cost. But for utilization rate, producers only rely on short-term expectation on price and markup ratio with variable cost (or operational cost) for decision of capacity utilization.

Markup Ratio = Expected short-term price / Expected short-term variable cost

This "short-term" price expectations by farmers has been referred and discussed by Meadows (1971) in description of hog cycles:

" A 1940 study of hog price expectations in a declining market also suggested that bout 80% of the producers were averaging recent prices to estimate prices nine months in the future (cited by Meadows, 1971 from Schults & Brownlee;pp. 494-495). We know that the producers' response to price for hogs is similar to that for other agricultural commodities. Changes in livestock (hog) numbers on farms show the same general type of response to antecedent prices received by producers as do changes in corp acreages(cited by Meadows, 1971c from Bean, L.H., op. Cit. P. 370)" (p 47)

As a contrast, an expected long-term price is used in the shape of desired capital from

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[16] See Sterman (2000a); Meadows (1971b).

[17] Variable Cost is described as operational costs in this paper.

expected profitability, discussed by Sterman (2000):

> *"Long-run price forecasts are formed by first-order adaptive expectations. The time constant governing the price expectations driving investment decisions is longer than that used in the utilization decision. Producers must be confident a change in price will persist long enough for investment undertaken today to be profitable when it comes on line." (p810)*

The structure also captures important delays in the behavior of real commodity system. For example, adjustment time for capital, adjustment time for plants in land, adjustment time for indicated utilization and smooth time for expected price as well cost. All these delays have influence period of corn commodity production, which is the attribute which most differentiates one commodity's production cycle from another (Meadows, 1971). Although we do not expect the exact periodicity to suit a real-commodity cycle of corn, we concern these delays and test their sensitivity in Appendix. We try to dedicate a valid and robust structure for corn planting with valid principle, parameters and reasonable range.

2.1.3 External Influence on Commodity Production Structure

The commodity production structure is effected by external factors (red variables in Figure 13). We have captured three effects to corn planting increase, based on literature, data analysis from USDA and CAST. They are introduced in hypothesis and tested in Analysis.

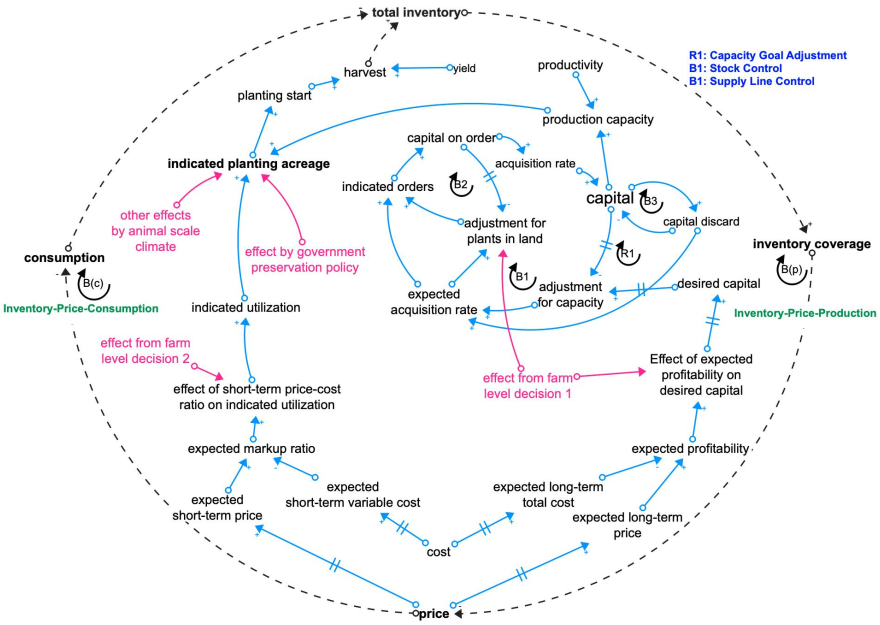

Figure 13 Commodity Production Structure -- Corn Planting

Effect of Farm level decision

In the U.S. agricultural production has shifted to much larger farming operations over the last three decades, even as the number of very small farms grows. Consolidation of acreage and production has been persistent, widespread, and pronounced in crop production (MacDonald et al., 2018). Compared with small farms, larger farms have advantages on capital, technology and production efficiency, to afford advanced equipment, workforce, fertilizer and other resource. We have captured the effects on capital adjustment and utilization decision in our commodity structure .

Firstly, we need define farm and farm measurement. The U.S. Department of Agriculture (USDA, NASS, 2017) defines a farm as any place from which $1,000 or more of agricultural products were sold or would normally have been sold during a given year. Farm size can be measured in several ways: a farm's land area, the number of animals (for livestock operations); or the dollar sales of the farm business (Sumner, 2014). As we consider about corn planting, we measure farm size by land area.

How does farm level effect capital desire? By MacDonald et al. (2018), the consolidation in crop production is pronounced, nearly ubiquitous across commodities and States, and persistent over time. They also stated,

> *"Large farms are not just larger. While most are family-owned and operated, large farms encompass a wide range of legal structures and ownership patterns. They use leases and rental agreements to access land and capital, and they often hire custom service providers and labor contractors for some farm tasks, freeing the operators to specialize. Some large farms are part of firms that own multiple farms and operate them as integrated businesses. In short, large farms embody a range of distinctive organizational strategies and business practices." (p8)*

Thus, these large farms are often operated by Multiple-Farm Business of Firms. Their production needs to meet commitments to retailers. The range of locations allows the firm to better meet contractual commitments with retailers by harvesting and delivering fresh products over a longer time period, and by better tying product attributes (MacDonald et al., 2018). Besides, MacDonald also show these firms link operations across farms in the same business and conduct other business like cattle feeding, integrated hog and poultry firms. And these integrated changes have effects on corn planting, which is seen as major livestock feed (USDA, 2023a).

The trend of farm consideration and multi-business type can improve the ability for farms to resist risks from market change. A better cooperation with retailers also make them less willing to change plants type in land as quickly as small farm. Hence in the structure, we assume the larger farms tend to be less sensitive to the expected profitability and they spend longer time to adjust plants type in lands as the contract limit or volume limit.

How does farm level effect capacity utilization? Sterman (2000c) has referred to this effect when he describe the relationship between expected makeup ratio and indicated capacity utilization.

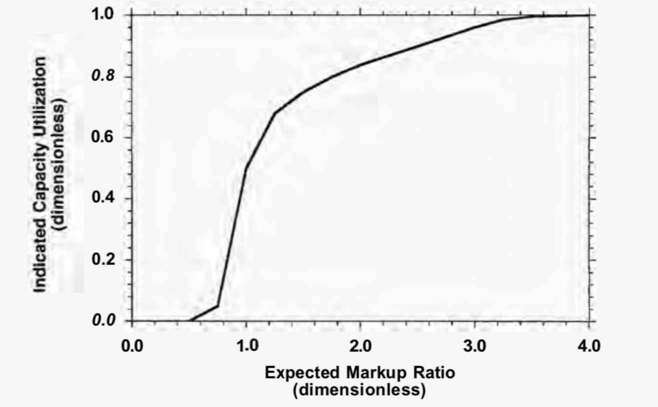

Figure 15 Dependence of indicated capacity utiliation on the expected markup (Sterman, 2000c)

As we discussed in 2.1.2, farmers or producers would decide capacity utilization by the effect of expected markup, which depends on producers' expectation s for price. Sterman (2000) describes an interesting thing in Figure 15,

"utilization is greater than zero even when the average expected markup ratio is less than 1. When the markup is low, only the most efficient plants, and the producers with the most optimistic expectations, find it worthwhile to operate." (p804)

Larger farms, with their advanced technology, equipment and other resources, can produce more efficiently than smaller farms, for example they can continue corn planting when markup is less than 1. In the structure, we assume a different graphical function for the larger farms, which effect final utilization with a proportion of large farms.

Effect by Government preservation policy

USDA have conducted conservation programs to help agricultural producers to adopt best management practices in crop production by land-retirement and working-land programs since 2002(Metaxoglou & Smith, 2022). The program of land-retirement has an direct influence on planting acreage in commodity production structure. By Metaxoglow & Smith, in this program, landowners receive payments in exchange for taking land out of active agricultural production and putting the land into perennial grasses, tress, or wetland restoration.

By the information of Frederick County Government (2023b), the preservation programs offered through Frederick County, the State of Maryland, and the federal government, provide many opportunities to the farmers of Frederick County to protect the future of their farmlands and promote natural resource industries. There includes different programs and achievements respectively: Agricultural Preservation (over 3500 acres since 2009), Critical Farms (over 5100 acres since 1994), Installment Purchase Program (over 20,700 acres since 2002), Maryland Agricultural Land Preservation Foundation (MALPF) (over 23,300 acres since 1980), Rural Legacy (over 6700 acres since 1997) and Conservation Reserve Enhancement Program(CREP)(over 3,500 acres since 2009)[18].

The preservation programs have restrictive effect on total agricultural planting in Frederick. We capture it by an effect on indicated corn planting with a proportion estimation for corn in all planting.

Effect from Animal Scales

Corn is the primary U.S. feed grain, accounting for more than 95 percent of total feed grain production and use. Feed use, a derived demand, is closely related to the number of animals (cattle, hogs, and poultry) (USDA, 2023a). Though when we use market price as external data, it has contained the interactions between inventory and consumption, some farms plant corns mainly for their own animals. Those farms decide corn planting with consideration of the change of animal scale. Hence, we assume indicated corn planting can be effected by the relative change of animal scale, especially when the scale in the county is shrinking (More discussion in Analysis part).

Effect from Climate Factors and Weather Conditions

Former study shows monthly precipitation in March to May to control for the effect of

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[18] See Frederick County Government, (2023b), Division of planning and permitting, conservation and preservation.

pre-planting weather conditions on corn acreage in the U.S. They argue that a wet spring can make it difficult from corn to be planted on time, and hence, corn acreage might be switched to soybean acreage. (Cited by Metaxoglou & Smith, 2022 from Miao et al., 2015)

Since our study horizon only cover latest twenty years, it is very difficult to capture the effect from change of climate or weather conditions. In the model formulation, we ignored the effects from temperature on yield and effect from precipitation condition to planting shifting between corn and soybean. We would capture precipitation effects on soil erosion and yield in N application part. And we some discussion on the long-term effect of climate change to nitrogen pollution in Limit part.

2.2 Structure of Nitrogen Application

Structure of Nitrogen Application concerns main questions in corn planting: what are the causal factors to nitrogen application by manure and fertilizer? What a role has soil quality played for N application and N load?

2.2.1 Structure for Nitrogen Application

The essence of nitrogen application and transform in Corn Planting belongs to nitrogen cycles[19] [20]. In Figure 16, a simple structure shows the dominant interactions for nitrogen in agricultural planting. Generally, N input damage soil quality, which stimulates farmers to apply more N for plant growth (R1). A fading soil quality also leads to high erosion and N load, which take away more nutrient and further damage soil quality (R2). More fertilizer input causes a low uptake efficiency and surplus N load to waterways (R3).

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[19] The nitrogen cycle is the biogeochemical cycle by which nitrogen is converted into multiple chemical forms as it circulates among atmospheric, terrestrial, and marine ecosystems.

[20] See Fowler et al. (2013), the global nitrogen cycle in the twenty-first century.

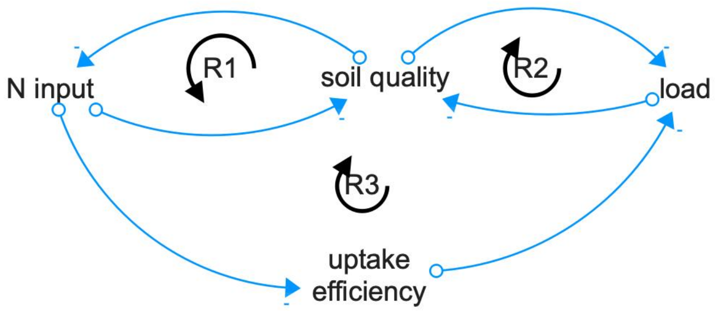

Figure 16 Simple Structure for Interactions of Agricultural factors in corn planting

Based on the simple structure, we have CLD in Figure 17, which describes underlying structure and interactions amont N application, N uptake, N load, soil quality and yield. It also includes external effects from fertilizer price, manure supply and climate change. Besides, existing related agricultural management practices (BMPs) are included in explanatory and expanded to future policy.

In the model, we distinguish N application between land with manure and land without manure. Land with manure are applied with manure and fertilizer. We use two stocks to represent for soil quality[21]: surface nitrogen and humus, for soil nutrient level and other properties for soil, like texture, structure and organic.

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[21] Soil quality in this paper shares the same meaning to the health condition for soil on physicochemical and biological properties.

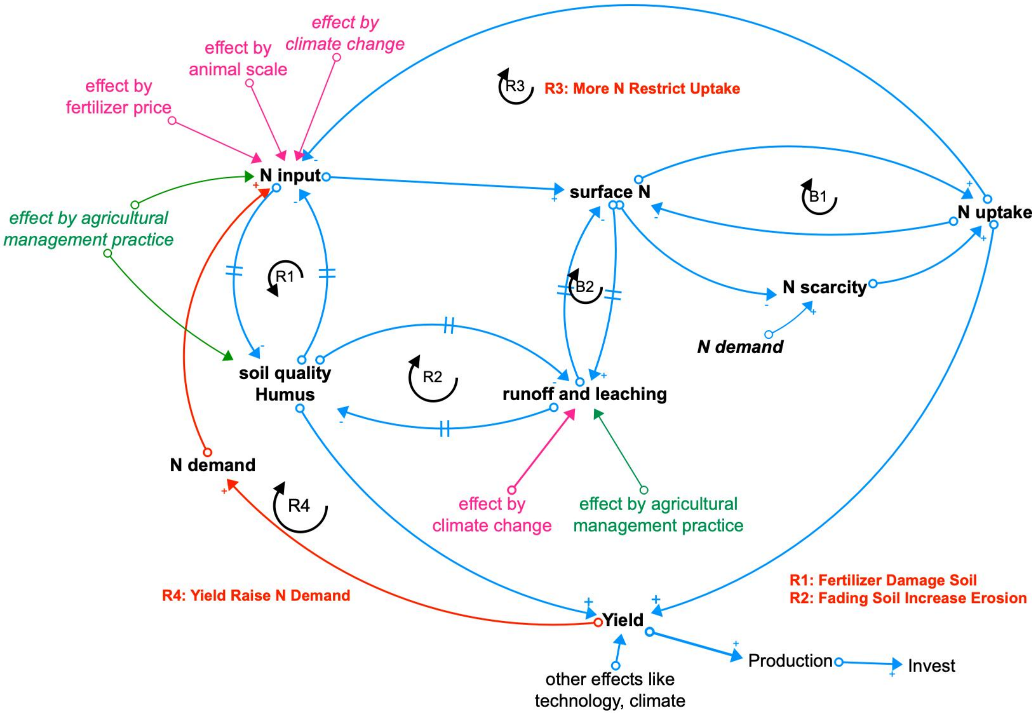

Figure 17 Structure of Nitrogen Application and Transmit[22]

For this section of structure, we will introduce feedback loops with main assumptions.

B1 (Uptake deplete N balancing loop): Surface N → + uptake by plant → - surface N

B2 (Loading deplete N balancing loop): Surface N → +runoff and leaching → - surface nitrogen

R1 (N damage soil reinforcing loop): N input increase → - soil quality → - N input increase rate

R2 (soil and load reinforcing loop): Soil quality → - runoff → - soil quality

R3 (N application and scarcity reinforcing loop): Nitrogen input → + surface nitrogen → - nitrogen scarcity → - uptake → - nitrogen input

R4 (Yield pushes N demand reinforcing loop): Yield → + high expected yield → + N demand → +N input → + N uptake → + yield

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[22] The principle comes from Saysel (2004); Foth (1990); Bach, N. L. and Saeed (1992).

These loops contains main assumptions for N application structure. Balancing loop B1 and B2 tell most familiar nutrient transmit routines for in planting: both N uptake and N load deplete surface N[23]. B1 shows N uptake increases by higher surface N. However, plant uptake is not only decided by surface N level but also the effect from N scarcity to plants' absorption ability. N scarcity is the ratio of proportional N demand to surface N. Though surface N support uptake for plants, a surplus surface N can restrict uptake level[24] with lower scarcity. That is important principle for our assumption 1.

Assumption 1: how does Surplus N restrict Uptake and gives High load in Manure land by Loop R3

In reinforcing loop R3, when surplus N gives lower scarcity, plants' uptake ability would be restricted. When farmers observe uptake effectiveness lower than their expectation, they tend to increase N uptake by adding more N to land. This would further strengthen balancing loop B1 and B2. Plants' uptake effectiveness stays lower with high input and more surface N is lost by running off and leaching. Saysel (2004) shared the viewpoint,

"inappropriate placement and poor scheduling of fertilizer application would result in less uptake and more leaching, while an appropriate fertilization practice would result in more uptake and less leaching." p18

We use reinforcing loop R3 to simulate the farmers' assumption on N application, especially on how farmers make the decision for surplus fertilizer N application in land with manure N. Metaxoglou & Smith (2022) described farmers' behavior on N application in corn planting:

"In corn planting, farmers are willing to apply more fertilizer, as the shape of the crop production function implies that fertilizer application in excess of agronomic recommendations does not reduce yield, which provides an insurance motivation to use extra fertilizer This is referred to the firm of

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[23] In the model, we assume nitrogen loss only by running off/leaching and volatilization and ignore other N loss.

[24] The principle comes from Saysel (2004); Foth (1990); Bach & Saeed (1992).

Insurance Nitrogen[25]". p8

Compared with fertilizer, the speed for manure to lease N is slower. It takes longer time for plants to absorb N from manure, which gives an lower effectiveness in the early days after manure applied. This stimulates farmers to apply more fertilizer to raise surface N and ensure plant can uptake enough N . But this further restricts plants' absorption ability. As inorganic N would be absorbed preferentially, this leads to more remnant manure in land, which causes N load and soil pollution. Metaxoglou & Smith (2022) stated, "total nitrogen losses were highest for acres receiving manure (56 Ib per acre per year)."

Hence, the assumptions around B1, B2 and R3 described how farmers apply surplus N to land and why land with manure gives higher N load. We would further discuss and test the assumption in Analysis 3.1.

Assumption 2: Interactions between Humus and N Application & N load by R1 and R2

We just discussed the relations between soil nutrient level (surface N) and N application. Assumption 2 focus on interactions between soil health condition and N application & N load, which is controlled by R1 and R2. The health of soil is regulated by soil properties, physicochemical and biological properties. Hence, in the structure, we use surface N and humus to capture the multiple properties of soil. It is referred to the structure of Bach & Saeed (1992), which is cited by Saysel (2004):

"It is required in very large quantities and since inorganic nitrogen does not build up in soils but disappears through leaching, it is most likely to be the limiting agent in crop development (Foth 1990) p. 186. Second stock variable Humus stands for other soil attributes supporting plant growth such as

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[25] Insurance Nitrogen, Specifically, many farmers choose to err on the liberal side when making decisions on nitrogen rates. This extra nitrogen is often called "insurance" nitrogen Besides, soil quality fading would decrease productivity of plants(Metaxoglou & Smith, 2022)

micronutrients, structure and texture. This two stock representation of soil nutrient dynamics. (Bach and Saeed 1992) which analyzes food sufficiency in a national context." p17

Crop yields are often directly proportional to the nitrogen released from organic matter (Saysel, 2004). Though Insurance Nitrogen does not reduce corn yield, however, continuous utilization of chemical fertilizers is responsible for the decline of soil organic matter (SOM) content coupled with a decrease in the quality of agricultural soil (Pahalvi et al., 2021).

So the fading of humus can lead to yield reduction and this drives farmers to apply extra N, which further decrease health condition of soil. In the model we formulate it as effect from humus change to N application and another effect from N application to humification (inflow of humus). As Saysel stated, N leaching is also influenced by Humus. Humus fading can increase soil erosion and leads to an extra use of insurance N. The surplus N will eventually find its way to lakes, rivers, and streams, contributing to nutrient pollution (Metaxoglou & Smith, 2022).

Our study focus, N load, is defined as Sediment edge-of-field loads, which are determined based on the Revised Universal Soil Loss Equation (RUSLE)[26](CAST, 2018b). So we formulate N load as normal loading proportion of surface N and effect by soil erosion. For this study, we concern the effects from soil condition, precipitation and BMPs, while assume the plant type and slope conditions are steady as constant.

Assumption 3: Humus Structure & Distinguish land with manure and without manure

Soil health management is vital for the maintenance of biodiversity and safeguarding sustainable agricultural production (Pahalvi et al., 2021).

In the nature, humus are shaped by natural humification process and lost by natural oxidation, decomposition and erosion. But humus in planting land is largely effected by

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[26] The RUSLE equation ($A = R * K * LS * C * P$) provides an estimate of net erosion rate at the edge of field (EOF) in units of tons per acre per year. The R factor (hundreds of foot-toninches per acre per hour) is the rainfall erosivity factor; the K factor (ton-acre-hours per hundred foot-tons per inch) is the soil erodibility factor; the LS factor (dimensionless) is a topographic factor that takes into account slope length and steepness; the C factor (dimensionless) is a crop/vegetation management factor; and the P factor (dimensionless) represents the support practice factor(CAST, 2018b).

agricultural activities and need human’s preservation to maintain its property and power. However, the complex change in soil is beyond our study purpose. In this paper, we focus more on the relationships between humus and N management.

Hence, we simplify hummus stock with an inflow of humification rate and an outflow of humus oxidation-decomposition rate. All the effects from N application and management practices are formulated as effects to the inflow or outflow. Specifically, humification is based on normal humification rate and effected by residue return rate to land and N application. A long-term fertilizer use can damage soil PH, natural texture and other properties for planting. Farmers add residue return to land to replace the natural humification process from plants or animals decayed. The residue return also covers the land and prevents part of soil erosion. The outflow of oxidation and decomposition rate is formulated as product of normal proportional oxidation-decomposition rate and the effect from implementation proportion of preservation tillage. Traditional tillage would largely damage soil texture and increase humus loss speed. Besides, for land with manure, the humification rate is also effected by manure input as manure can partly benefit humification process with its organic and microorganism[27].

In the model, we also distinguish humus for land with manure and land without manure, in order to see their difference of interactions between on humus condition and N application & N load. N management are also distinguished between manure and fertilizer as they have quite different effects on soil. Inorganic nitrogen does not build up in soils but disappears through leaching, it is most likely to be the limiting agent in crop development (Foth, 1990). Besides, manure can benefit humification process as it supplies organic matter and microorganism. So there is an extra effect from manure use to humus. It is assumed a different fading speed on humus in two types of land, then different polices are indicated to practice.

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[27] The principle comes from literature: University of Minesota Extension (2021); Edmeades (2003); Saysel (2004).

Assumption 4: High Yield Expectation pushes High N Application by R4

In the whole structure, besides the dominant reinforcing Loop R1, R2, R3, there hints another reinforcing loop R4. It describes higher yield expectation can push farmers to apply more N to achieve target yield. This further strengthened other three reinforcing loopsand leads to more serious N load as well as soil fading. With a rising advanced technology on planting skills and biology, the traditional important role of soil quality on yield is largely weakened. This just meets the citing by Saysel (2004) from Mannion (1995),

"increased fertilizer application masks decreasing soil fertility due to oxidation of soil organic matter by intensive tillage and loss of organic material by wind and water erosion."p16

Hence, a seeking for high production and high yield can be fundamentally harmful to the ecosystem of agricultural planting, which also prevents the establishment of sustainable agricultural planting system. We would continue this discussion in Analysis 3.1 and Policy.

2.2.2 External Influence on Nitrogen Management Structure

In the structure, we capture the main external influence on nitrogen management from animal scale, fertilizer price, climate change (weather condition), and management practice achievement (BMPs).

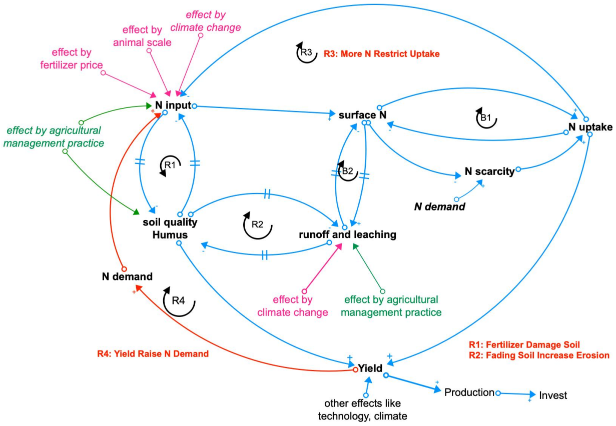

Figure 17 Structure of Nitrogen Application and Transmit

Effect from Animal Scale; Fertilizer Price

According to the data from CAST, there is steadily around 40% of corn planting land having applied manure in the past over 20 years though the change of manure application and planting acreage. This indicates manure application is more restricted to the farms that have animals to support manure. Hence, we capture the change on manure application with an elasticity of manure application to change of main animal scale in Frederick.

Besides, we consider the effect of fertilizer price on indicated fertilizer application. We have referred to a basic elasticity of fertilizer demand to change on fertilizer price, which is discussed by Metaxoglou & Smith (2022).

Effect from Climate Change and Weather Conditions

Metaxoglou & Smith (2022) have discussed on effects from weather conditions on plant growth, yield, fertilizer input and nitrogen pollution, especially precipitation and temperature. Precipitation directly effect N load as the amount of surplus nitrogen that enters waterways is determined in part by precipitation. Farmers also would like to use more fertilizer in wetter and warmer days. Schlenker & Roberts (2009) find out that high temperature over 29° C is harmful for corn yield. Since more fertilizer input does not decrease field, it is plausible that farmers may compensate for the loss in yields by fertilizing more, or that reduced take-up of nitrogen fertilizer by crops would leave more nitrogen in the soil to be leached into waterways. Hence, we concern weather conditions as external factors because temperature and precipitation are correlated with both acres planted and nitrogen concentration (Metaxoglou & Smith, 2022) as well as large influence to yield (Schlenker & Roberts, 2009).

However, we could not include all these effects properly into structure as the limit of resource in Frederick and uncertainty on measurement. We would mainly capture precipitation effects on soil erosion and yield.

Effect from Existing Preservation Policy

Farmers have practiced on farming land for centuries and preservation policies for reduction of load in the watershed have been conducted for decades of years. We include achievement of preservation policy into our explanatory model. Those agricultural BMPs all benefit N load reduction. In our structure, we mainly include nutrient management, cover crops, conservation tillage and buffer that are most related to agricultural planting. With the different humus for land with manure and without manure, we expect to compare the change rate of soil conditions in two type of lands with the same implementation of policies. The government working-land policy is assumed to combine with BMPs as payment support.

2.3 Modeling Overview

Based on hypothesis above, we have formulated the system dynamics model with two sections: Commodity Production and Nitrogen Application. Here is a structure overview and all the documentations are included in Appendix A.

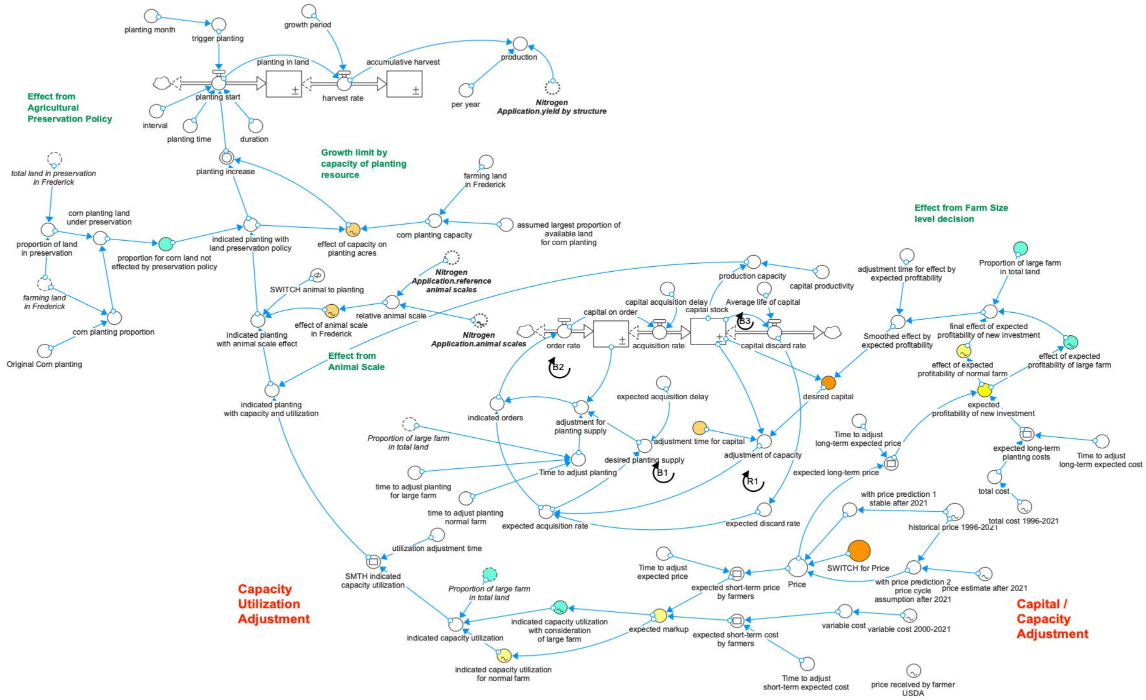

Figure 18 Modeling Overview - Commodity Production

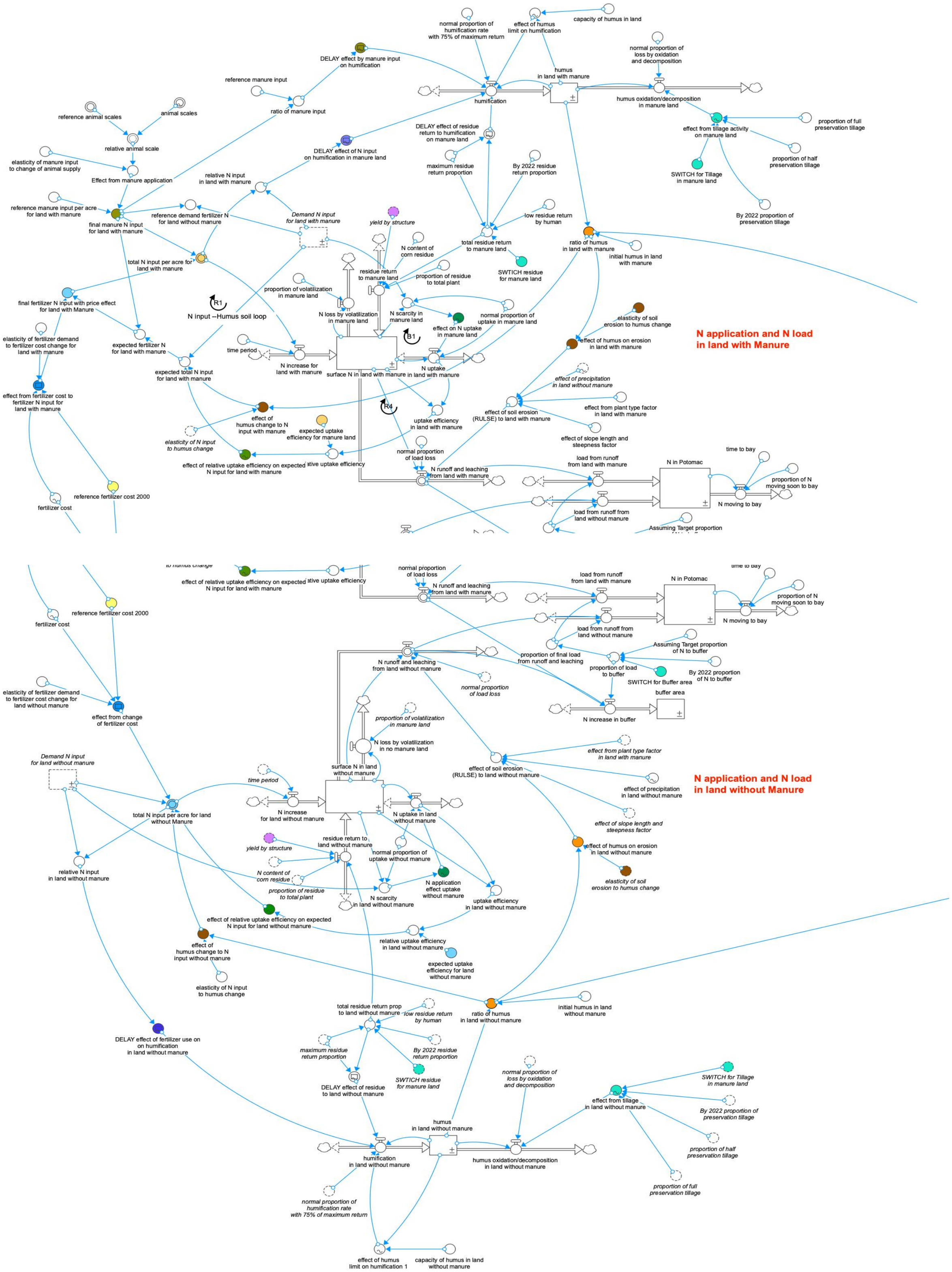

Figure 19 Modeling Overview: Nitrogen Application and Load in land with manure (upper) and land without manure (bottom)

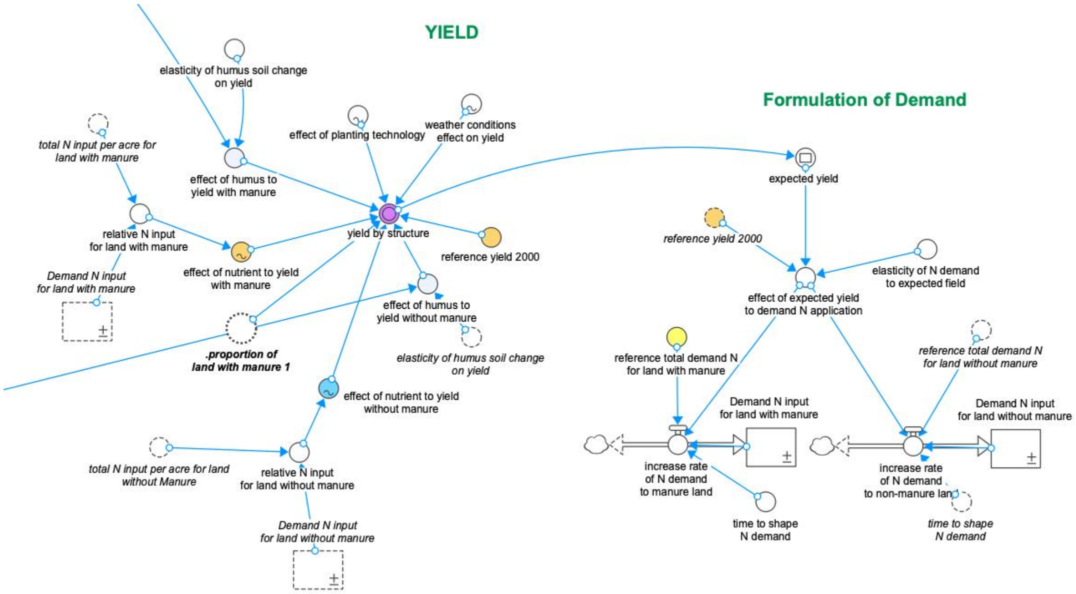

Figure 20 Structure of N application: Yield - Demand

2.3.1 Reproduction of Reference mode

Planting Acreage and Total Nitrogen Application In the problem part, we have chosen planting acreage and nitrogen application (grain) as main reference mode. Figure 21 shows how the simulation results reproduce reference mode on corn planting acreage and total nitrogen application.

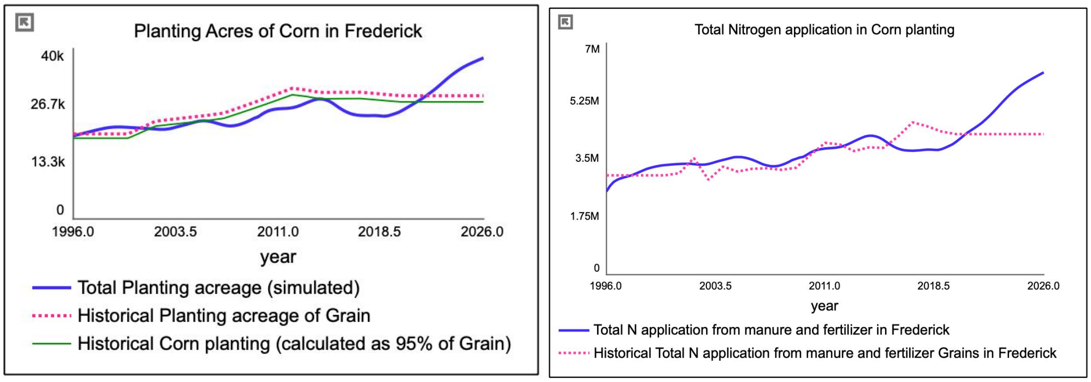

Figure 21 Simulating planting acreage Vs. Historical planting acreage (left); Simulating total N application Vs. Historical total N application (right)

Historical data source: CAST Source Data (2023). In the figure of planting acre, the pink line represents for the historical grains planting acreage in Frederick. The historical data covers the period of 2000 to 2020. As discussed in Problem, we have assumed the corn planting and nitrogen application in Frederick shows a similar dynamics and approximately 95% of the amount on the total Grains planting. It is shown as the green line in left figure.

In left figure, total planting acreage simulated by model shows slight waves but similar trend to historical data. The waves comes from structure of commodity production cycles. Though the historical data does not include the practical change after 2020, the simulation planting acreage indicates an increasing trend after 2018. It slows down after 2022 and is assumed to reach its peak after 2026.

In right figure, total N application to corn planting shows a similar and smooth growing trend to historical data from 2000 to 2020. The simulation result indicates total N application from corn planting would continue rising in the coming years.

Total N Application in Land with/without Manure In Figure 22, the total N application of corn in Frederick county largely corresponds to the shape of planting acreage. As we concern final N load from corn land, it is essential to understand the change of N application per acre during the time. We formulated the variables N application per acre. Figure 22 shows comparison of simulated N input per acre and historical data from CAST. The simulation results gives similar trend from 2000 to 2020. It shows slight decreasing from 2000 to 2011, then gradually increased to similar level slightly as 2000. The simulation trend of total N input for land without manure shows more discrepancy from historical data. This may be caused by a higher effect from humus fading and N efficiency. The discrepancy might also comes from the uncertainty to parameters and simplified structure for humus. However, with a reasonable range of parameters, the simulation N application has reproduced the main trend of reference mode, which indicates the validity of this part of structure for further analysis.

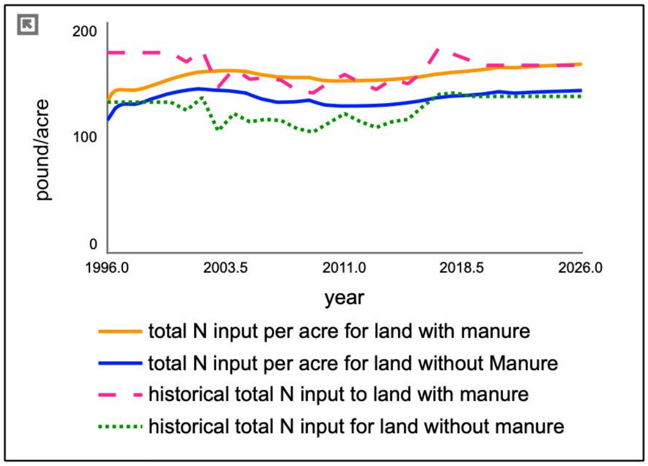

Figure 22 Total N application for land with manure and without manure. Historical data source: CAST, Source Data (2023). The historical data covers the period of 2000 to 2020.

Final Load from land with/without Manure

Expect for the reproduction of reference mode on N application, Figure 23 shows N load per acre is close to the average N load value from grain land supplied by CAST, Source Data (2023). Load from land without manure shows slightly higher than normal load amount given by CAST. The load gap partly comes from discrepancy on N application in Figure 23 and might be also effected by humus effect on soil erosion. Generally, the simulation of N load further indicates the validity of structure and parameters for N application and N load. This benefits our target study on N load reduction.

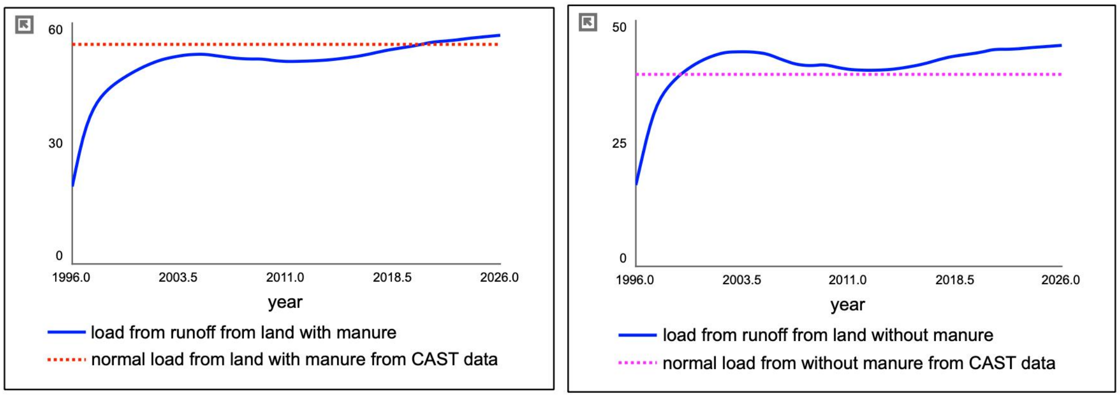

Figure 23 N load per acre per year from land with/without manure. Historical data source:CAST, Source Data (2023)

The load from land with manure is given as 54.7lb/acre/year and load from land without manure is given as 39.07lb/acre/year. The data is applicable for the Chesapeake watershed.

Nitrogen Demand

The total yearly N application to land is formulated as the product of demand N and effects from changes on N uptake efficiency, soil quality and fertilizer price. N Demand per year is seen as core variable for total N application. Historical N demand has used approximately constant as 140lb/acre/year for land with manure and 130lb/acre/year for land without manure from 2000 to 2020. N demand is important variable in the structure forscarcity and uptake efficiency. Hence, we include it in endogenous structure, by formulating it as product of reference N demand and effect from expected yield. The elasticity of N demand to yield change is calculated with an assumption that: yield has take 60% of plant (dry weight); plant consisted of yield and residue and both of them share the same N content[28]. In Figure 24, the simulated N demand shows fitness to historical Demand N application from CAST, Source Data (2023).

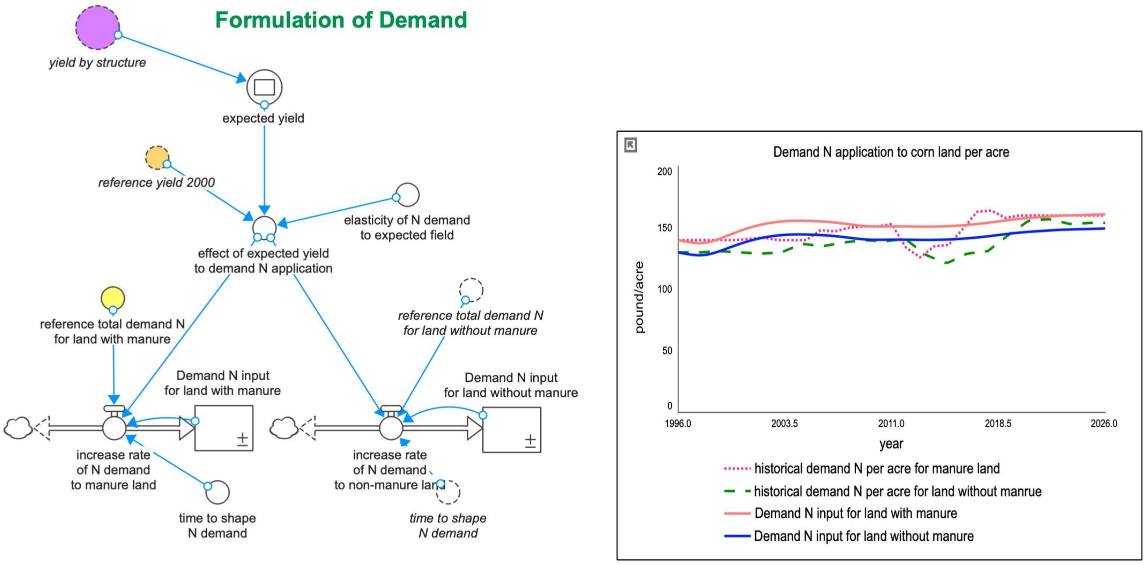

Figure 24 Structure on formulation of N Demand(left); Demand N application to corn per acre (right).

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[28] The principle comes from Charles et al (2019).

Source: CAST, Source Data (2023)

2.3.2 Parameter Validity

In the commodity production section, parameters are mainly about adjustment time in the commodity production cycles. These delays play important role in shaping the period and amplitude in production. Though we cannot find all specific values for these delays in corn production, we have estimated them in most reasonable range, relying on related discussion on literature, historical data analysis, sensitivity test and optimization on Stella.

For optimization on Stella, we use it more for comparison rather than values estimation. Because we consider the gap between our simulation and historical data as the ignorance of other important factors in the system. A high matching by target pursuing can mask the true sensitivity of model and prevent us finding out valuable results.

In the section of nitrogen application, more parameters are used to estimate elasticity and delays of effects throughout N transportation. We rely more on literature for parameter estimation for this section. Uncertainties of parameters are mainly on humus and yield, such as elasticity for effects. However, considering out target, the relative comparison by simplified structure is qualified for this study. So we give tolerance to uncertainty on parameters in humus structure and yield but we include more tests and discussion on it in Appendix A - sensitivity test.

2.4 Conclusion for Hypothesis

This part further discussed causal factors to problematic behaviors and explained validity for the structure hypothesis. Main assumption and feedback loops have been explained for both commodity production and nitrogen application structure. Based on these hypothesis, we have formulated our system dynamics model. It successfully reproduced the reference mode and other important behaviors we concern.

As we have included many assumptions for two structures in hypothesis, we would like to include more model formulation descriptions in Analysis part as they are closely related to scenarios analysis. By this we can prevent confounding among assumptions and test targets.

3 Analysis & Test

In Analysis part, we will test main assumptions on feedback loops, including important equation descriptions and findings discussion based on simulation model. Both CLD and SFD are combined to explain dynamics of underlying structure and how it has shaped the problematic behaviors. The explanatory model has contained the results of existing policies (BMPs). In order to ensure the coherent description for each assumption, analysis part would include much policy discussion. Hence, there would be some cross coverings and jump analysis between Analysis and Policy part. Analysis also includes sensitivity test and uncertainty test for essential parameters and structures. Soybean is used to test robustness and generalization for commodity production structure.

3.1 Nitrogen Application: Hypothesis Test and Findings

In Hypothesis, we have described the dominant effects and interactions among reinforcing loops: R1 (soil quality - N application), R2 (soil quality - N load), R3 (N application- uptake) and R4 (yield - N application). They all contributes to final N load as we concern. N application is main source for N load and in the structure N application joints all reinforcing loops. In the model, we formulate total N application:

total N application per acre per year = N demand per acre per year * effect from uptake efficiency * effect from humus change * effect from fertilizer cost.

There exist other factors while we consider these factors are most important.

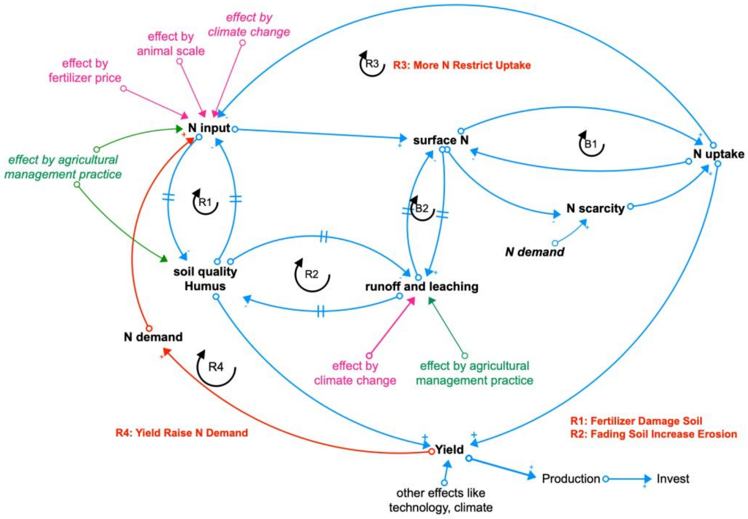

Figure 17 Structure of Nitrogen Application and Transmit

3.1.1 Uptake Efficiency and Nitrogen Application

Figure 25 shows proportional relationship between total N input and N load. There is gap that land with manure use gives higher N application and N load than land only using fertilizer. These indicates our assumption is meaningful to reduce N load by controlling N application.

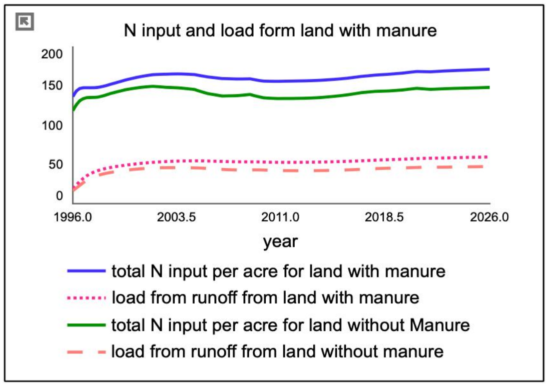

Figure 25 Nitrogen Application and Load in land with/without manure

Then, Figure 26 shows an comparison of N uptake amount by plants and uptake efficiency. Usually manure needs a longer time to lease N for plants absorption but it can stay effective longer in soil as organic nitrogen. By contrast, commercial inorganic fertilizer can lease N much faster for plants absorption but it cannot be stored in soil and easily lose by runoff or leaching.

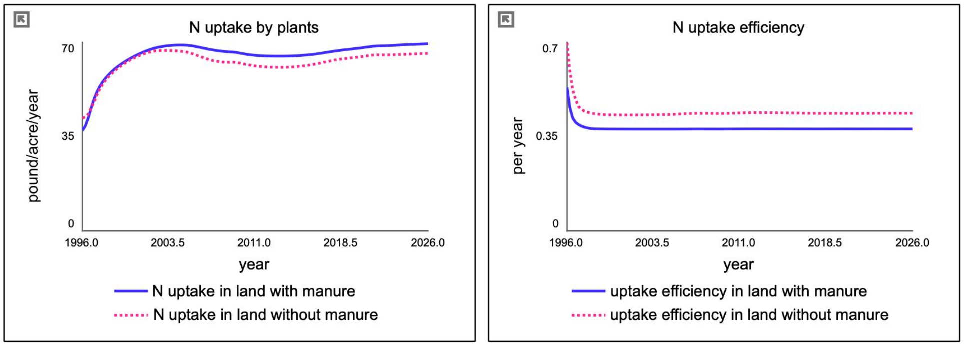

Figure 26 Nitrogen uptake and Uptake efficiency

In the model, we have captured this feature by setting normal N uptake proportion in land without manure as 0.5, and for land with manure slightly lower as 0.45[29]. The equation contains the logic that effective time or lifetime of manure is longer than fertilizer. we set the gap between them for our further test on their N uptake efficiency.

In Figure 26, plants in land with manure shows a higher N uptake amount (left graph) but lower N uptake efficiency (right graph) than land only using fertilizer. This corresponds to the total higher nitrogen application in manure land. It indicates land with manure use has applied more N to plants but with lower uptake efficiency, then the surplus N which is not absorbed by plants would causes more N load to waterways and soil pollution.

Assumption Test on R3 (Uptake and N application. Surplus N application in land with manure) In Hypothesis Part, we have described Assumption 1 about farmers' decision on N application by reinforcing loop R3. There are many uncertainties on farmers' assumptions, and here we raise an assumption story like this:

when farmers observe their plants do not show expected growth or some factors would influence N uptake (like more precipitation, from study of Metaxoglou & Smith, 2022), they would worry about their corn plants can not absorb enough N. With the concept of

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[29] The principle of proportions come from Debruin & Butzen (2023); Cornell University Cooperative Extension (2017).

"Insurance Nitrogen", they would increase N application and surface N to guarantee the level of uptake and yield goal.

In practice, farmers might toughly estimate the growth condition of plants and how much fertilizer or manure N they have applied, compared with conditions of recent years or other farmers' plants. It is very difficult to give a general standard to their expectation, so in the model we use "expected N efficiency" to describe this standard in their mind, which is equal normal proportion of N uptake from surface N in soil (specifically 0.45 for land with manure and 0.5 for land without manure). It would be compared with practical uptake efficiency, which is the ratio of uptake and Surface N in soil. When the practical uptake efficiency is lower than their expectation, they would increase N application, as surplus N would not harm corn yield but raise it to some extent[30].

The puzzle or misunderstanding of farmers can be also explained as farmers have to ignore the restriction effect on plants' uptake ability by surplus N but rely more on surface N to increase N uptake by plants. Uptake by plants is the product of surface N in soil, normal uptake proportion and effect from scarcity.

*N uptake by plants = surface N * effect of scarcity to uptake.*

When there is higher N in soil, scarcity level falls down, it has an effect to restrict plants' uptake[31], though final uptake level might still show increase with a larger soil N value. However, farmers might do not recognize this truth, or they can do nothing else to help the plants absorption. With a affordable consideration of cost, they would finally refer to "Insurance Nitrogen" and add more nitrogen.

If we put this assumption on land with manure, it would be more reasonable and interesting . Since it takes longer time for plants to uptake N from manure, farmers might show less

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[30] See principle of "Insurance Nitrogen" by Metaxoglou & Smith (2022).

[31] Here we are not sure how the specific process that scarcity restrict plants' absorption. It may effect directly on plants absorption system, or it effects the soil condition which finally effects the plants' uptake of nitrogen.

satisfied to growth of plants in land with manure. With the assumption we described above, farmers would apply more fertilizer as supplementary N to guarantee the uptake of plant. It leads to a higher surplus N in land with manure. These might explain why land with manure shows higher surplus N input and N load, compared with land only using fertilizer.

Based on this assumption, we have a test on the relationships between total N application and uptake as well as N efficiency. We have a sensitivity test for it : By adjusting expected uptake efficiency from 0.3 to 0.8 (original value as 0.45), we are going to see a changing total N application and how N uptake and uptake efficiency would react to the change.

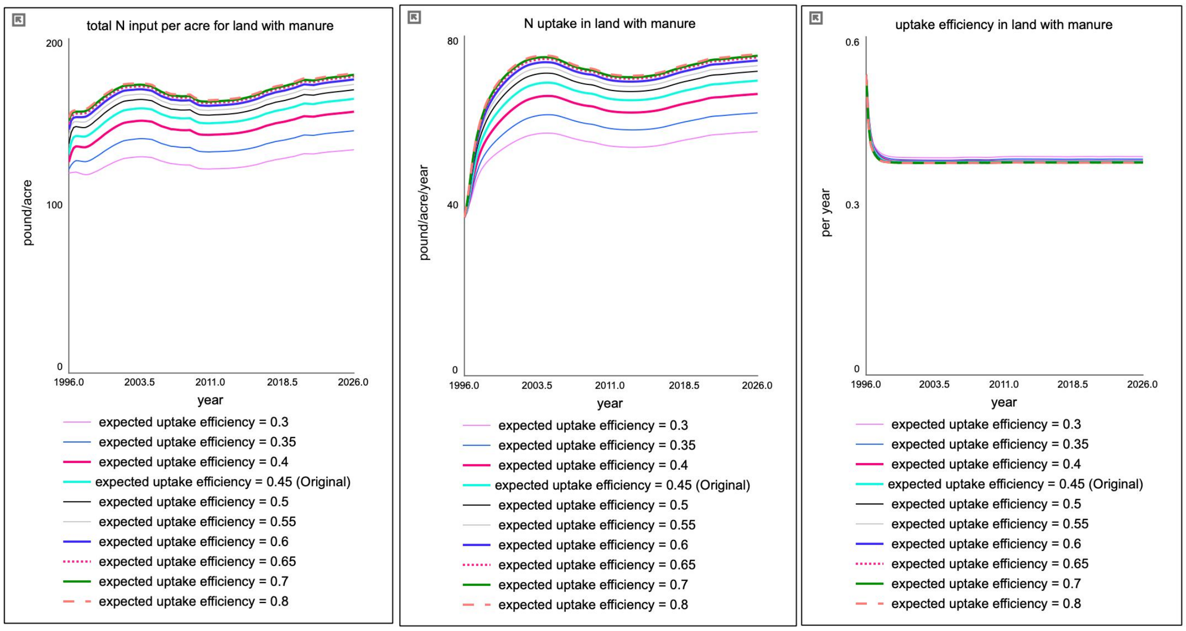

Figure 27 Sensitivity test of N application, N uptake and N uptake efficiency to a changing Expected uptake efficiency

Figure 27 shows only N application and N uptake is sensitive to the change on expected N uptake efficiency by farmers. However, practical uptake efficiency is not sensitive at all as it is the proportional ratio of the other two. The steady uptake efficiency explains that N uptake increases proportionally by the increase of total N input to land, but it would not show a higher increasing rate than N input with the restriction effect from scarcity. In practice, under a higher N input, the uptake efficiency can be even lower. The slight change in third graph shows corresponding efficiency line to the highest N application is lowest. Hence, farmers can increase N uptake amount by adding more N into land, but this only increase part of uptake amount and decrease uptake efficiency slightly. This causes more N waste especially as manure in land (as plants would absorb N from fertilizer faster than manure) and leads to more N load and soil pollution.

Figure 27 also gives another indication. Original lines (bright green) for N application and uptake correspond to an expected uptake efficiency of 0.45. When we adjust the expectation above or below the original value, neither N application nor N uptake graph shows a symmetrical distribution around the original line. Specifically, When expected uptake efficiency is moving below 0.45, the corresponding N application and uptake lines are reacting more sensitive. When expected uptake is moving higher than 0.45, N application and uptake are less sensitive and the corresponding lines are laid more intensive in the graph. This indicates farmers' expectation on higher N application would face more restrictions by effecting factors like fertilizer cost. However, farmers still have a possible range on adjustment of N application to for their expected uptake by plants.

In summary, this part has tested the rationality for assumption of reinforcing loop R3 and the structure shows validity and robustness under adjustment. This test and discussion is very important for our study on final N load. It has tested our assumption on farmers' use of surplus N application when they are not satisfied with plants growth. Although it can increase N uptake amount by plants, it is not an efficient method, shown from the non-sensitive and slightly decreasing practical uptake efficiency. It will raise planting cost and more N load. Besides, manure is considered as beneficial N sources, but the not decomposed manure can be "a dangerous product capable of causing serious environmental pollution" (Annicchiarico et al., 2011). These indicates N application in land with manure shows more urgency.

3.1.2 Interactions between Humus and N Application & N Load under BMPs

In Hypothesis, we explained assumption 2 on interactions of humus condition between N application & N load with reinforcing loop R1(soil quality- N application) and R2 (soil quality - N load). In this section we further test the assumptions under BMPs in land with manure and without manure.

Firstly, we have assumed an equilibrium scenario for humus with the same normal proportion for humification rate and oxidation-decomposition rate as 0.05 per year[32]. The normal proportion for humification rate (inflow) can be reached when the residue return reaches 75% of maximum residue return[33]rate while for oxidation/decomposition rate (outflow) preservation tillage can be reached when preservation tillage is covered as 100% or there is no tillage. These polities have been conducted for many years and included in our explanatory model.

Then, we have a few scenarios to compare how humus conditions would change under different policy implementation assumptions.

Scenario 1: In figure 28, when the switch = 1, it gives the scenarios under present policy by 2022 and residue return (0.045 of residue proportion) and preservation tillage cover rate (0.91).

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[32] This is an estimating proportion in order to simulate our model and compare the different conditions as well as related effects. As we cannot find any exact value from literature, the practical proportion can be much lower.

[33] Maximum residue return means the effective residue return in crop land is 0.09. The principle comes from study findings of University of Minesota Extension (2021).

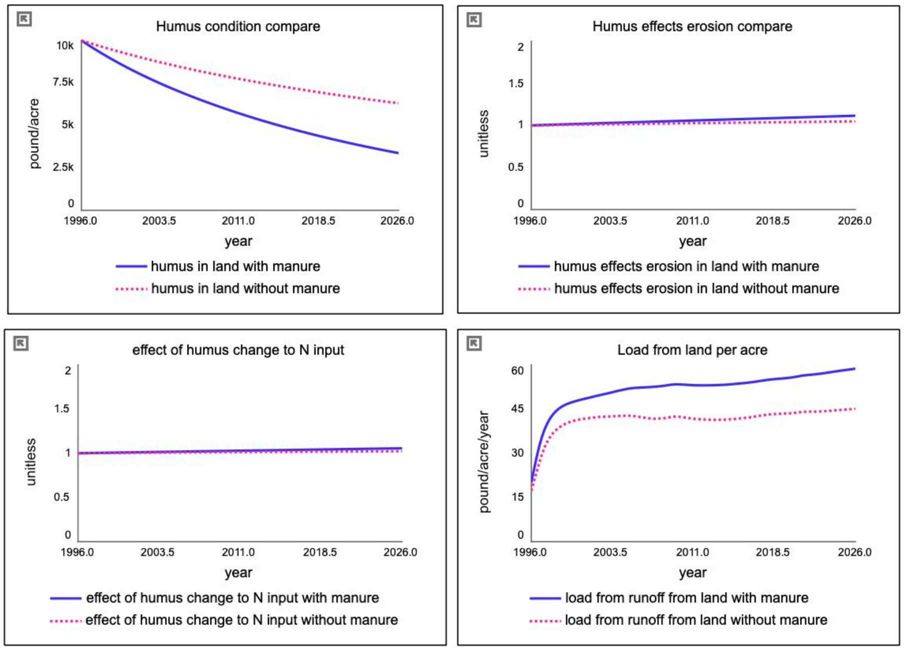

Figure 28 Scenario 1: Humus condition and effect of humus on soil erosion. Switch=1, scenario with management practice process by 2022. Residue return rate = 0.045, Tillage of preservation proportion = 0.91. All scenarios contain 0.01 of N runoff and leaching moving to buffer area.

In Figure 28, both two humus stocks shows fading. Humus in land with manure shows faster fading speed as visible exponential decay. Humus in land without manure shows slower fading speed. Note the gap between them only represents for the simulation results with the original parameters we set, but not the practical discrepancy. With humus fading, both two type of lands show increasing N application and faster soil erosion. These both broaden the gap of N loads between two types of lands. By the end of simulation as 2026, the N load reaches 58.7 lb/acre/year and 45.1 lb/acre/year separately from land with manure and land without manure.

Analysis of scenario 1: The scenario has simulated a second farmer's assumption on N application. Farmers have some knowledge on the relationship between soil quality and yield. When they observe the risk of yield reduction by soil fading, they would add more N to guarantee yield. However, increased N application masks decreasing soil fertility due to oxidation of soil organic matter by intensive tillage and loss of organic material by wind and water erosion (Cited by Saysel, 2004 from Mannion, 1995).

This parameters for scenario a is set to suit the residue return policy and preservation tillage cover implementation til 2022[34]. Though the graphs might not fit the practical status as the simplified structure and uncertainty on original parameters. However, it delivers two important results to us:

1. Humus fading can stimulate N application and increase soil erosion. These both lead to more N load. The simple structure has tested the rationality of relative or changing dynamics between humus and N application as well as N load.

2. Land with manure shows a faster humus fading though manure has some beneficial effect to humification rate. This can be further tested if we have better research materials or resource to measure how much manure prompts humification rate and how much N application restricts humification rate. The simulation indicates, land with manure use faces a more serious fading problem, though it is sometimes thought as opposite. Study from Edmeades (2003) shared similar viewpoints,

"It is concluded therefore that it cannot generally be assumed that the long-term use of manures will enhance soil quality – defined in terms of productivity and potential to adversely affect water quality – in the long term, relative to applying the same amounts of nutrients as fertilizer".p1

Scenario 2: In order to see the effects of BMPs implementation, in Figure 29 -31, we further test humus change under different BMPs implementation with residue return and tillage policy. In Figure 29, by turning switch = 0, we have scenario 2 when low residue return rate is 0.01, only by roots left in soil, and preservation tillage is 0.5 with the other half as traditional tillage.Compared with scenario 1, both two humus stocks are fading very fast and shows strong exponential decay. Land with manure shows worse results. Effect of humus change on N application is higher than scenario 1. The slope on effect to soil erosion shows obviously larger than scenario 1. N load shows a visible rising trend. By the end of

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[34] Policy parameters are calculated or estimated from BMPs implementation results from CAST Data Source (2023); study findings on residue return by university of Minesota Extension (2021).

simulation year of 2026, it increases to 70.5 lb/acre/year and 53.7 lb/acre/year separately from land with manure and land without manure.

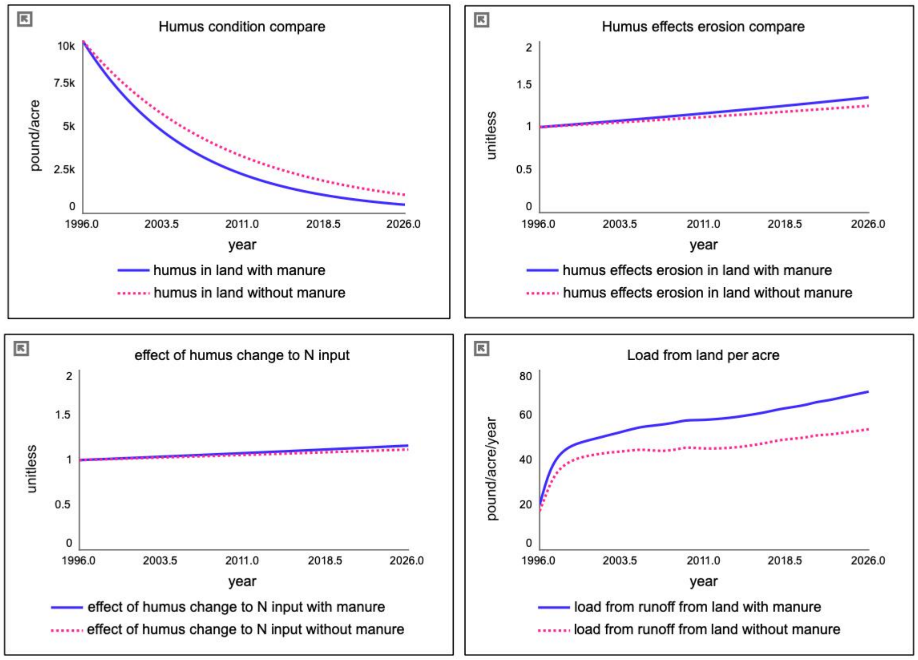

Figure 29 Humus condition and effect of humus on soil erosion -- Scenario 2. Switch=0, scenario with management practice process by 2022. Residue return rate = 0.01, Tillage of preservation proportion = 0.91. All scenarios contain 0.01 of N runoff and leaching moving to buffer area.

Analysis of Scenario 2: This scenarios have described an very extensive or primitive agriculture type, when farmers continuously plant crops with high fertilizer and manure and half proportion of planting relies on traditional tillage. They do not give necessary residue return to increase humification rate or cover surface soil. These cause a very fast fading on soil condition. The fading of humus will push farmers to rely more on fertilizer input and fading humus gives a higher soil erosion effect. This would largely increase the planting cost. In practice, the effect of seriously soil fading to planting condition is a continuously deteriorating process which shows a nonlinear change on effect. This is the limit of description ability for our simplified structure.

Scenario 3: We hope to see if the humus condition can be improved by enhanced policy implementation. By setting switch=2, we have scenario 3 when residue return rate reaches the maximum return rate as 0.09 and the preservation tillage is covered by 100%[35]. In Figure 30, with better BMP implementations, both humus in two type of lands shows obvious improvement. humus in land with manure shows a little fading while humus in land without manure shows almost constant. By data from simulation, humus amount in land without manure gives slight increase during the time horizon.

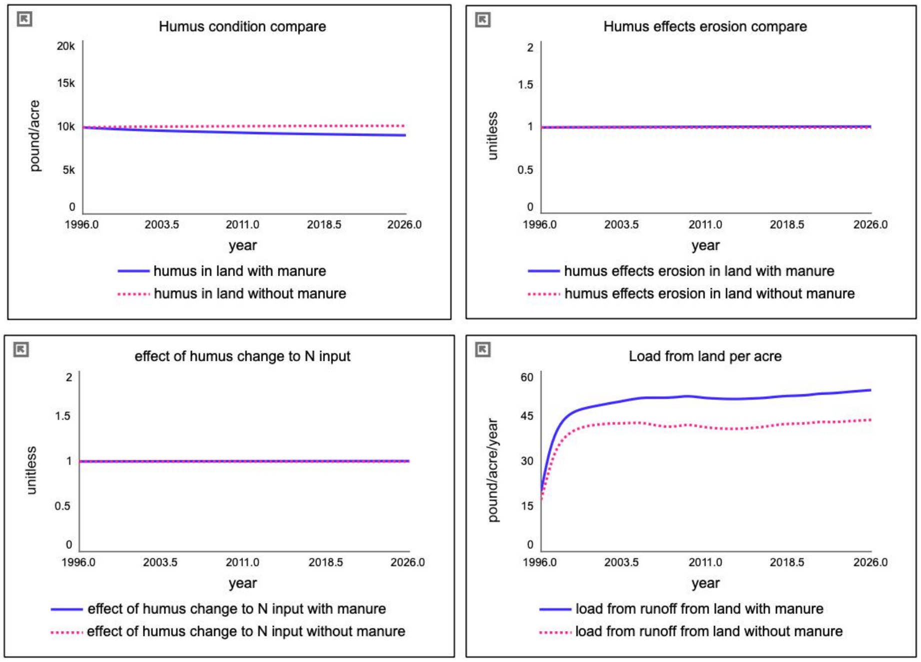

Figure 30 Humus condition and effect of humus on soil erosion -- Scenario 3. Switch=3, scenario with better management practice process . Residue return rate = 0.09 (maximum return rate), Tillage of preservation proportion = 1. All scenarios contain 0.01 of N runoff and leaching moving to buffer area.

As a result, effect of humus change to N input stays as constant. When farmers observe a steady soil quality level, they can decrease the fertilizer cost for supplementary nutrient to plants. The effects from humus to soil erosion also stays as constant as 1. For a few years in land without manure, effect from humus to soil erosion shows slight improvement as 0.999. N load shows more steady trendy and generally lower level than scenario 2. By the end of simulation year 2026, it would decrease to 52.2 lb/acre/year and 42.6 lb/acre/year from land

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[35] Both these two maximum implementations are close to the WIP 2025 (CAST Data Source, 2023; Keisman et al., 2020).

with manure and without manure.

Analysis of Scenario 3: The scenarios in Figure 30 gives us two indications:

1. with a better management practice implementation, the humus condition can be improved. Notice here we did not combine the policy implementation by 2022 and maximum policy implementation together in scenario 3. Because our aim is to use this simplified structure to test the possibility of better results under different policy implementation. However, it is not suitable to simulate the practical implementation results from 2022 to 2026 because all the original values and parameters are assumed for their relative relationships but without practical reference.

2. with the maximum residue return and 100% preservation tillage, here is still a fading for humus in land with manure. We can assume the gap exists even larger in practice and also in the land without manure. Except for the effect from residue return and preservation tillage, we also tested the effect of N application to humification rate. Hence, we have Figure 31 as combination of scenario 3 and a decrease of total N application.

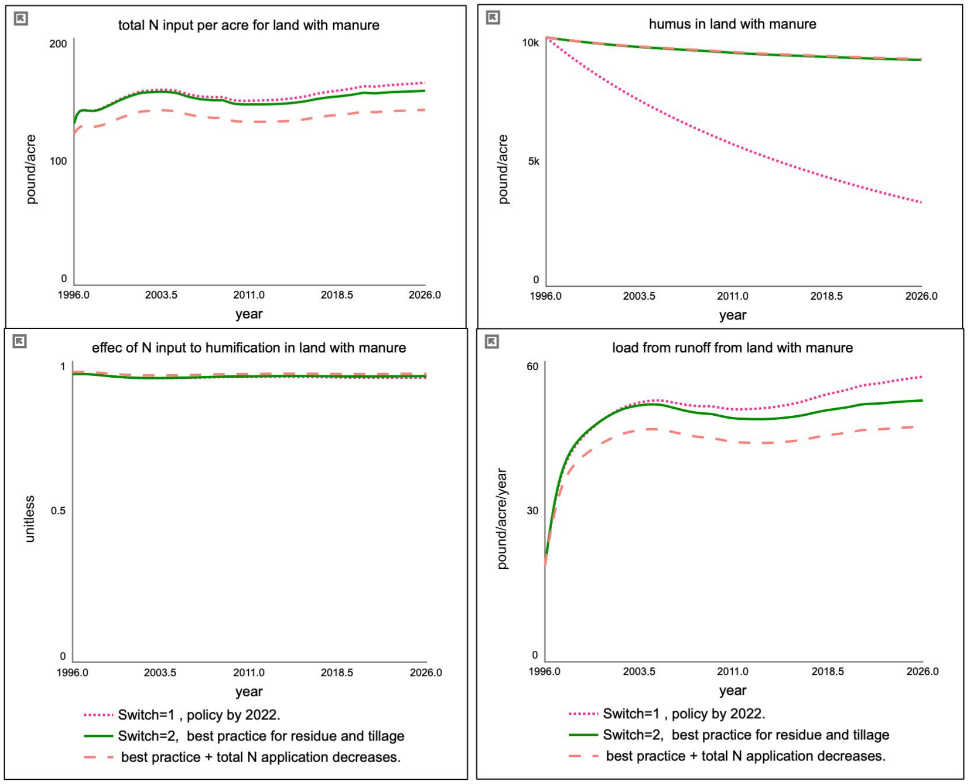

Figure 31 total N input effects humification (policy by 2022 is residue return = 0.045, preservation tillage = 91%; best practice: residue return =0.09 (maximum), preservation tillage = 100%). All scenarios contain 0.01 of N runoff and leaching moving to buffer area.

Generally, the decrease of N application gives slight improvement effect on humification. The effect is not obvious as in practice the change for soil happens during a very long delay that is not captured by parameters in the model. However, from the comparative lines in Figure 31, we can clearly see the differences on the total N application as well as N load between the policy implemented by 2022 and best practice (dotted pink line and green line in graph 1 and graph 4). This further indicates a better management practice can prevent fast humus fading and decrease total N application. These would finally contributes to N load.

In summary, this part has tested Assumption 2 as well as how the key variables react under different BMPs implementation. Though the structure is simplified, the interactions between key variables show robust under test by different scenarios..

The scenarios indicate: both nutrient level (surface N) and other properties of soil (humus) are important for planting and would effect N application and final N load. A fading humus can stimulates farmers to apply more N in land and fading soil conditions can increase soil erosion. Both these leads to a higher N load. Finally, relevant study and simulation scenarios indicate that the soil (humus) fading in land with manure can be faster than land without manure. This partly contributes to the higher N load from land with manure than that from land without manure.

3.1.3 Burden-Shifting Structure on Soil, Yield and Nitrogen

With qualified tests on main assumptions around N application and humus change, the structure is indicated with rationality and some robustness. We would like to explore the assumption on R4 (Yield - N input) to a wider thinking on relationships among soil - yield - N relying on structure analysis. Firstly, we have a simplified structure to describe their relationships in Figure 32.

The structure tells a story: the primitive agriculture relies yield on soil quality. When production cannot achieve expected yield, farmers apply nutrient to land. With a higher yield expectation and advanced technology on fertilizer and production type, the original role of soil quality has been gradually weakened.

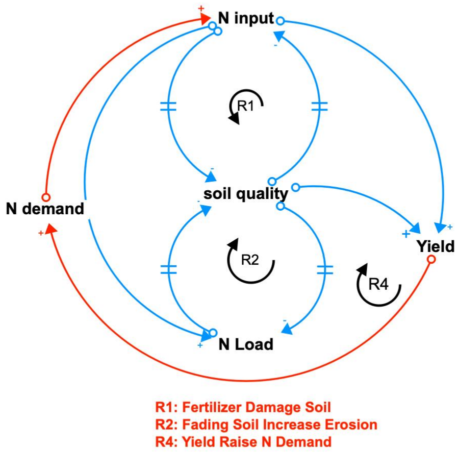

Figure 32 A simplification of structure of Soil - Yield - N application.

In the market surroundings where economic interests are pursued, the production target gives higher requirement to yield. The reinforcing loop R4 has continuously pushed more N application and drives a stronger R1 and R1, which both damage soil quality. Hence, the combination of reinforcing loop R1, R2 and R4 as well as R3 (not shown here) have taken the dominant positions in the system.

Soil is non-sustainable resource and the shaping of soil takes millions of years. Finally, the whole structure consists of a comprehensive vicious circle, which is not only restricted in corn planting system. This might be the most powerful strength underlying the whole system that have caused most of the problems in agricultural environment today. We are far from powerful to influence the market preference, but we can get some indications from the structure for problem settlement.

Let us further transform the structure to its original type. In Figure 33, balancing loop B3 and

B4 consist of an archetype of burden-shifting (Braun, 2002). When original structure of soil occurs, the system is completed.

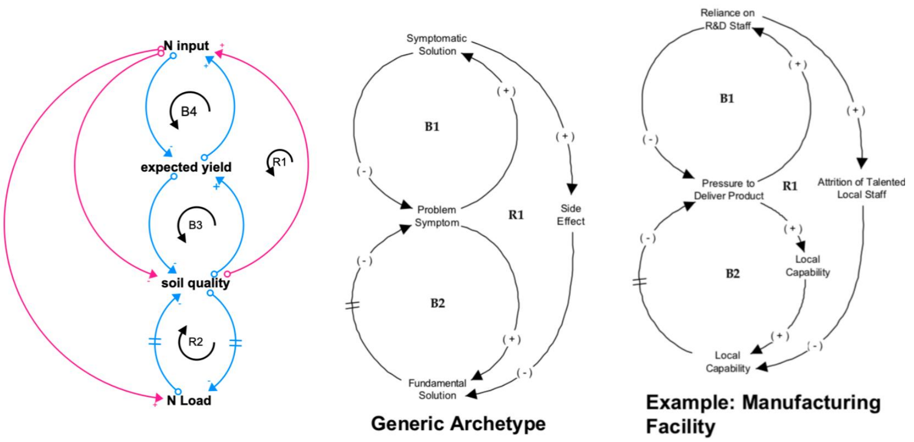

Figure 33 Structure of burden-shifting(left); Generic Archetype(middle); Manufacturing facility (Braun, 2002)

Seen from structure, the occurrence of N application, loop B4 is considered as an external structure that comes later to assist loop B3 for expected yield. The development of loop B4 has gradually weakened the underlying structure of loop B3. Meanwhile, N application directly damage soil quality, which also reinforcing loop R2 by a rising N load and this further weakened original structure of loop B3. The structure has described that N load is like an important side product of N application, by both direct running off and higher soil erosion from damaging soil structure. In the whole system, the strength of soil quality is continuously restricted and weakened by all the other loops: R1, R2, R4 (yield - N input), B4. The whole system falls into vicious circle.

This finding on structure gives important indications for our policy direction, or leverage points (Meadows, 1999). For our target of N load reduction, the primary and most efficient policy is the control of N application to land, especially the surplus N input, which is absorbed by plants and finally turns to be load. Secondly but fundamentally, preservation of soil quality is necessary and should be conducted for long term, as the importance of soil health for maintenance of biodiversity and sustainable agricultural production (Pahalvi et al., 2021).

The essence of soil quality is easily ignored by people's preference to see short-term interest than long-term return. The application of fertilizer makes soil preservation less imperious as it is. It takes much longer time til preservation on soil conditions to show its benefits. All the simulations on humus conditions we have in the model are set to simulate faster than practical situation. In practice, policies on soil never give fast return even under a well implementation. This is one advantage that system dynamics model enable us. We avoid building models with slow simulations. Rapid simulations are essential if we are to encourage interactive simulation and discussion (Ford, 2010).

With such slow return from soil preservation, should we still consider soil quality as most important factor and conduct BMPs on it? The answer is absolutely yes. In the burden-shifting structure, soil quality holds the basic underlying structure for the whole system. While reinforcing loop R1 and R2 are continuously weakening basic underlying structure, soil quality fading speed is increasing increasingly, later it would shift to exponential decay til final exhaustion. During the process farmers have to rely more on N application. This would cause a higher product price and commodity market depressed. Furthermore, the effect of N application relies on the existence of soil and all the system has its growth limit including the effectiveness of N. If soil system is too weak to allow the external structure to work on yield, the whole system collapses. If we continue to ignore soil preservation and just rely on more external N input, that is the final story.

The consolation is that farmers are aware of some importance of soil and preservation methods are carried on since traditional agriculture time. For our concern of N load, in the past decades of years, different best management practices (BMPs) have been conducted. We will continue the discussion in Policy Part.

3.2 Uncertainty and Robust Test for Commodity Production Structure

In this paper, our problem focus is the nitrogen load from corn planting to Potomac river. Though we discussed more on N management section, it is also important to capture the general changing trend for corn planting in the county. We have used commodity production structure to capture this trend and successfully reproduce the reference mode. However, there are some uncertainties that we need to test on if they would effect validity of structure. We leave uncertainty of delays in Appendix B as they are mostly from literature, data and practical business behaviors. Here we focus two important uncertainty from external influences: farm level decision and animal scale in the county. We also had a robust and generalized test for our commodity production structure, in order to see if the structure can be generalized to other crop plants.

3.2.1 Uncertainty Test on Farm Size level decision

As we described in Hypothesis - External influence, the agricultural production in U.S. today has been largely effected by the past decades of agricultural consolidation and this trend is shown as pronounced in crop production. In the model, we formulates it as 70% of farms have been like middle or over middle sizes[36], according to the estimation of MacDonald et at. (2018) for the crops production of U.S. However, we are not sure the specific proportion of farms in Frederick that are for corn planting. Hence, we have adjusted the proportion to see how much it would effect the desired capital and final planting acreage.

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[36] See MacDonald et al. (2018). In this paper, we use "large farms" to represents for the farms that have size of middle and over middle and "normal farms" to represents for the farms that have size below middle size.

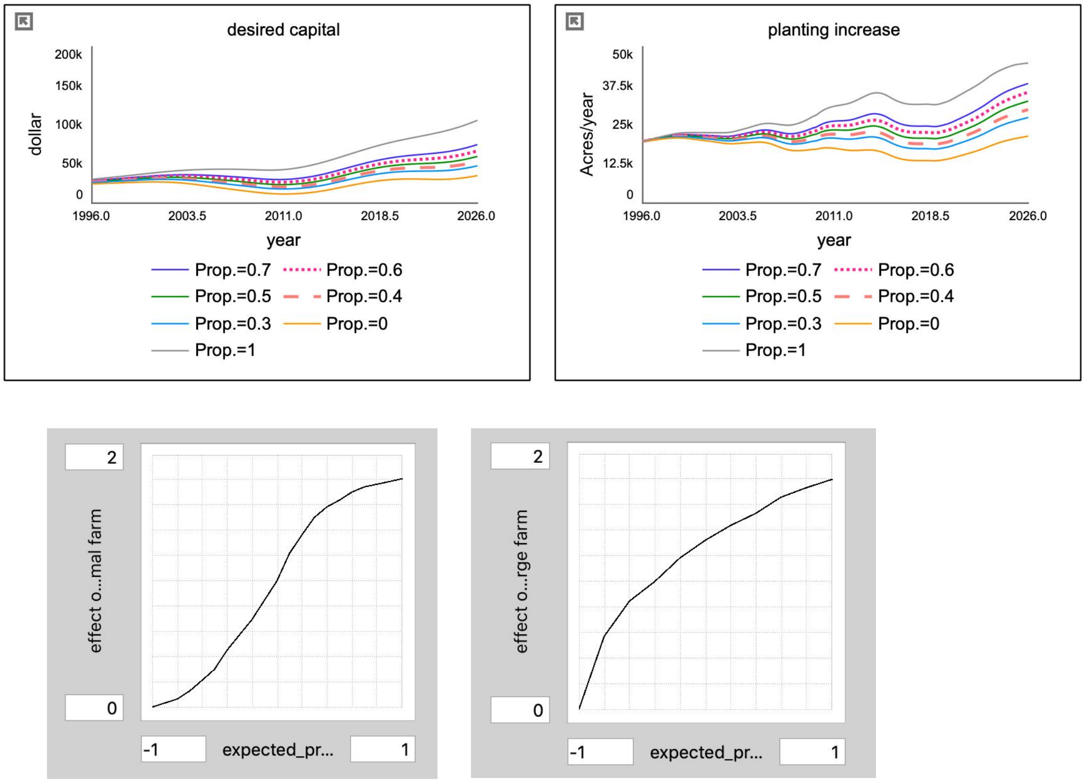

Figure 34 Sensitivity test for effect from proportion of large farms. The proportion is set as 0.7 (original), 0.6, 0.5, 0.4, 0.3, 0.2 and two extreme proportions as 0 and 1. Graph function (left): effect of expected profitability to desired capital for normal farms; Graph function (right): effect of expected profitability to desired capital for large farms.

In Figure 34, we could see that with a lower proportion of large farms than 0.7, the desired capital level would be generally lower than original level. This is caused by the different nonlinear effects from expected profitability to desired capital on different farm size level (see graph functions). As a result, the planting increase shows a decreasing to the change. However, we can find out that general changing trend of capital and planting increase rate is not changed. By the end of simulation horizon, scenarios from all proportion give an increasing trend. As a comparison, with a lower proportion of large farms, the graphs shows a more obvious falling during increasing years, while when there is higher proportion of large farms, it just shows more steady as approximate equilibrium, then in the increasing years, it rise up quickly. This corresponds to the difference of sensitiveness to expected profitability between large farms and small (normal) farms. When expected profitability is lower, small producers would decrease investing willing , while larger producers could continue the normal investment. When expected profitability is falling to negative, small producers would withdraw capital and leave the market, while large producers would stop adding investment to the industry but continue their production, because they have a higher production efficiency by more advanced technology, capital input and robust risk resistance by closely cooperation with retailer company.

In summary, the uncertainty on proportion of large farms would not bring unexpected effect to the trend of planting increase rate and the result meet our former assumptions and analysis.

3.2.2 Uncertainty Test on effect from Animal Scale

In Hypothesis - External influence from animal scale, we have discussed why we consider animal scales as one main external influence to corn planting in the county, though we have taken price as external data for this commodity production structure, which partly contains the effect of corn consumption. Based on the information from USDA and data from CAST, we have calculated the main three cattle in Frederick, which has take up 70% of animal unit in Frederick: dairy, beef and other cattle. Figure 35 shows how we capture the effect from a relative change of animal scale with a reference animal scale as starting year of simulation.

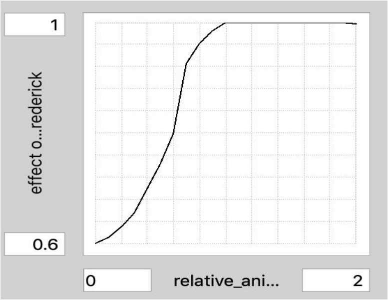

Figure 35 effect of relative animal scale to indicated corn planting acreage

In the table function, we have assumed when the animal scale is less than 1, it would restrict the farmers' indicated corn planting, or they would decrease utilization rate. However, when animal scale increases over reference scale, there would be no extra effect to farmers' indicated corn planting. This is similar to the principle of utilization. When farmers capture factor that can leads lower profits return or other risks, they could reduce production scale by destroying plants in land or stop harvest. But when there is factor that leads to higher profits return or other interests, they could not expand their production scale as the limit of production capacity[37].

We assume the largest restriction effect is 0.4. From information of USDA (2023c),

"...Feed use, a derived demand, is closely related to the number of animals (cattle, hogs, and poultry) that are fed corn and typically accounts for about 40 percent of total domestic corn use."

Hence, we assume 40% of corn planting is effected by animal grazing.

Figure 36 shows a comparison test on the effect from animal scale. We can see the animal scale of main animals has decreased from 104 thousand AU to 59.4 thousand AU from 2000 to 2020. With the effect from animal scale, the indicated planting increase rate is lower than that without the effect from animal scale. In Appendix B we include more uncertainty test on the effect from animal scale. The simulations indicate this external effect exists and can have visible influence for final planting acreage while the different of nonlinear shapes do not have much effect to final result. It increases commodity production structure's validity.

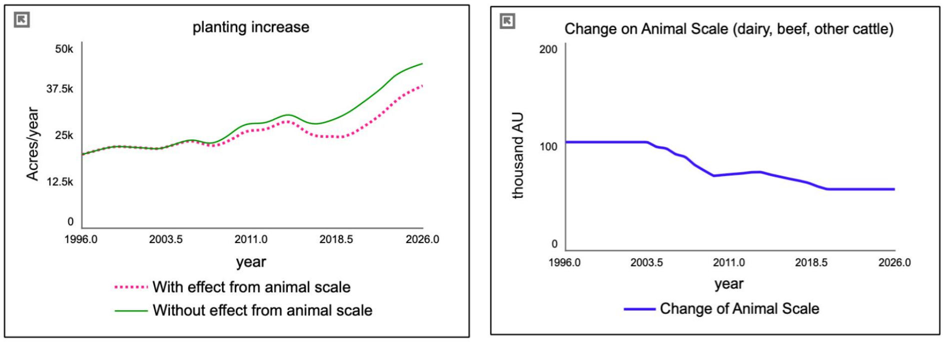

Figure 36 indicated planting acreage with/without animal scale; Change of animal scale (dairy, beef,

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[37] The principle comes from Meadows (1971).

other cattle). The data is available from 2000 to 2020 (CAST Data source,2023)

3.2.3 Robust Test for Commodity Structure by Soybean

In the commodity production structure for corn planting, we have used external market data from USDA to formulate the production of corn. For the whole structure ,we do not show the two balancing loops for whole commodity production cycles. We have captured most of parameters in rational values or ranges and successfully reproduced reference mode of grains planting (95% of grains is assumed to be corn grain). We hope to test if the structure is robust and generalized for other planting products. We got this indication from Meadows (1971), who has tested generalized structure with hog system and chicken system.

Soybean is seen as the second largest crops in U.S and important animal feeding plants like crops (Schlenker & Roberts, 2009). In the area of Frederick, Soybean and Corn are planted in the same season with same growth period from April to September (0.5 year). Hence, we use the price and cost data of soybean from USDA and plug them into our commodity structure. As the highly approximate commodity features on corn and soybean, we have kept all parameters of delays and external influence. Figure 37 shows that the simulation result has reproduced the main shape of historical data and gives a general rising trend for the future years.

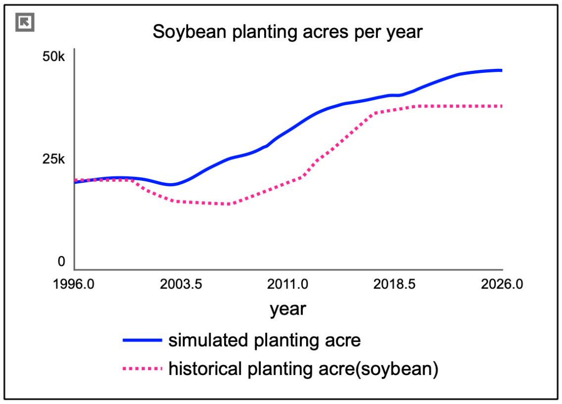


Figure 37 Robust Test for Commodity Structure on Soybean

The robust test indicates that our commodity structure is not only applicable to corn planting in Frederick, but can be generalized to other types of plants, with reliable market data input and necessary parameter adjustment.

4. Policy & Implementation

In Analysis 3.1, we got policy indications from structure and simulation analysis. N application control and soil quality preservation are recommended as average points in order to achieve our target of N load reduction. As some achievements have been discussed in Analysis, in this part, we will discuss more details for related best management practices (BMPs), including implementation feasibility and profit-cost evaluation. The main reliance is based on principle of leverage points of Meadows (1999), profit-cost policy analysis of David Wheat, related literature, simulation results as well as historical data .

4.1 Policy Discussion on N management

From Analysis 3.1.3, we get policy indications from the burden-shifting structure (Figure 33). Both N application control and soil quality improvement are considered as most important management practices.

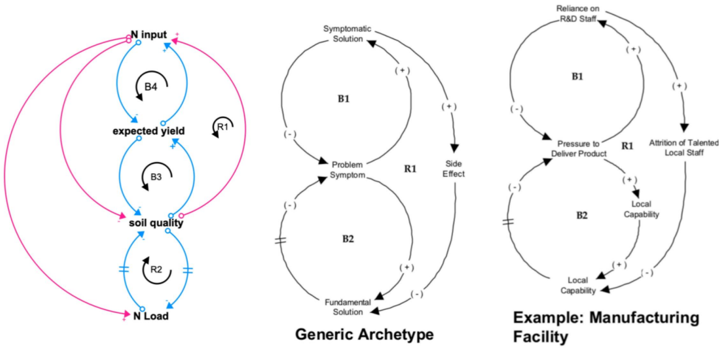


Figure 33 Structure of burden-shifting(left); Generic Archetype(middle); Manufacturing facility (Braun, 2002)

Figure 38 shows where present best management practices (BMPs) that have been conducted in the structure. Those agricultural BMPs that are mostly related to corn planting are nutrient management, cover crops, conservation tillage, manure transport and buffer areas. This part mainly discuss on these policies on their urgency, efficiency and feasibility.

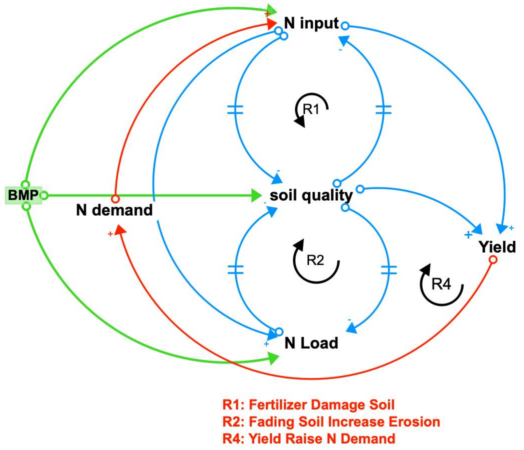
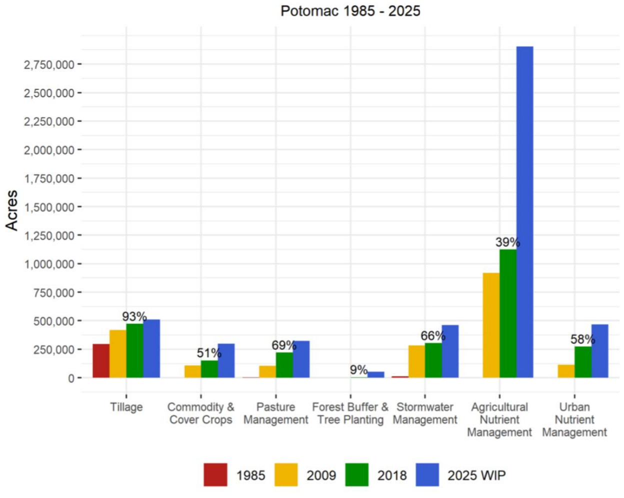


Figure 38 BMP on structure of Soil-Yield-N application

4.1.1 Nutrient Management

Figure 6 gives a review of BMPs achievement compared with WIP 2025 on N load reduction.



Values above the 2018 bars are the percent of the 2025 goal achieved.

Figure 6 BMP implementation in the Potomac watershed (Keisman et al., 2020)

Manure Management As discussed in Analysis 3.1.1, land with manure shows a higher surplus N input by simulation results. Figure 40 shows a comparison of gap between N input and N demand in land with manure and land without manure. The right picture is from historical data on CAST Data source (2023). They both verified our assumption on that planting with manure gives a higher surplus N and would causes more N load.

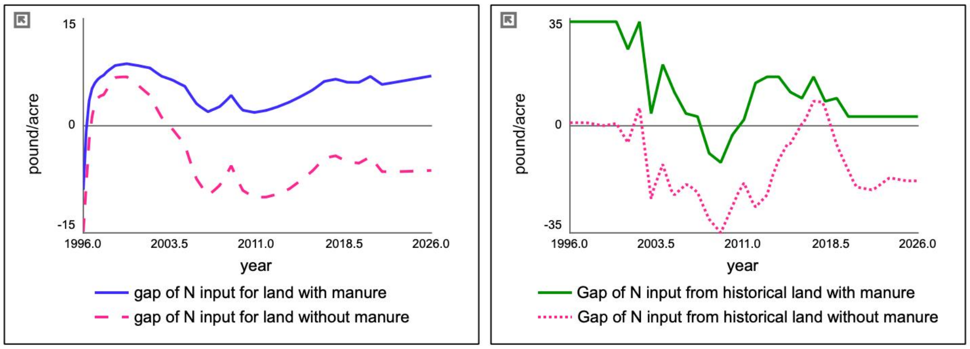


Figure 40 Gap of N input and N demand

We have analyzed farmers' assumption on surplus N application. They wrongly judge on uptake efficiency and get used to apply "insurance nitrogen" to achieve target yield. Though humus in manure land shows faster fading and more effect on N application, we consider that farmers' management on manure N is more important leverage point in N Management Policy.

Manure is can cause more serious consequence to soil quality except for the N load, when surplus fertilizer has priority to be absorbed as faster N lease and more manure is left in land. Hence, it is important to help farmers understand how to apply manure more scientifically.

Secondly, BMPs for manure management and transportation are also important as they total consists of management supply chain. The model has captured the effect of animal scale on manure use. As discussed in Analysis, proportion of lands with manure use stays very steady around 0.4-0.45. This indicates farmers who apply manure probably have steady manure sources or own animals. This mode does not make big problem when animal scales are steady or shrinking. However, when animal scales increases quickly, without a lower storage and transportation level, they have to apply more manure to land, as the limit or high cost. More manure leads to more surplus N application under less scientific methods. Hence, a scientific manure management in planting requires a total improvement for manure supply, including manure management and manure transport. Furthermore, without the conditions of the general upgrade of manure management, the implementation of manure application in planting is difficult and less realistic because farmers have no other choices to dispose manure.

Fertilizer Control Though we consider manure application as more problematic, fertilizer control is also important because it easily runs off as inorganic N. Except for scientific application amount, the structure indicates the effect from fertilizer price can be used to restrict extra N application by fertilizer. A higher fertilizer price or more strict fertilizer use standard for corps is expected to be assistant policy to decrease farmers' expectation on fertilizer use.

Implementation Discussion for Nitrogen Application Control

The control of N application reduces operational cost but farmers have to afford a risk or worry on yield loss. It is more difficult to change farmers' concept on using "Insurance nitrogen" than teach them a scientific N application. A change of concept stays at top difficult on the list of leverage points of system, according to the study of Meadows (1999). By contrast, BMPs on management of manure and manure transportation can be more costly and takes more long. But with the assistance of government (working-land program), it is better accepted by farmers and has feasibility.

4.1.2 Residue Return, Tillage and Buffer Area

Residue return[38] **and preservation tillage** are considered as the most common and efficient implementation for soil preservation. Figure 6 shows these two BMPs have achieved around 50% and 90% for target of WIP 2015. Figure 32 has supplied scenarios as comparison between present policy achievement and maximum implementation on residue

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[38] Residue return corresponds to cover proportion in BMPs.

return and preservation tillage in land with manure. It indicates there is still space for a better implementation achievement.

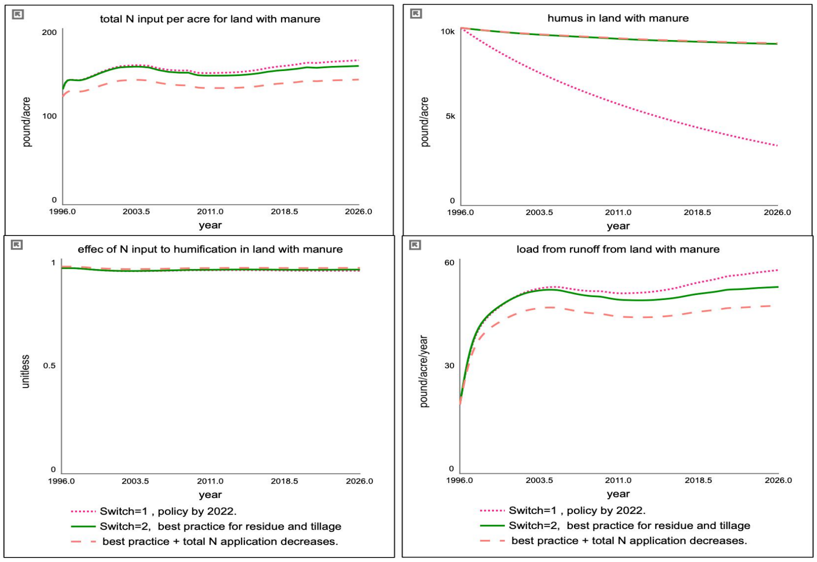

Figure 32 total N input effects humification (policy by 2022 is residue return = 0.045, preservation tillage = 91%; best practice: residue return =0.09 (maximum), preservation tillage = 100%). All scenarios contain 0.01 of N runoff and leaching moving to buffer area.

Besides, Figure 32 also shows the decrease of N application has more efficient effect on N load reduction than soil preservation policy. However, as we discussed earlier, soil preservation is not only used to pursue any independent target, but has more significant and long-term effect for whole agriculture.

Implementation BMPs on residue return and preservation tillage show higher feasibility. With a high achieved process and low cost, it is more like “parameter adjustment” to intervene the system (Meadows, 1999).

Buffer area includes wetland and forest, which absorb part of nitrogen after N leaching from land. In Figure 6, BMP target for buffer area including forest buffer and tree planting, is around 50,000 acres and by 2018 the achievement is only 0.9. Since we do not have detailed data on efficiency on N load reduction by buffer, we estimated its target as 0.1 of absorption for total N runoff from land and present implementation as 0.01 which corresponds to 9% of achievement in BMPs. Figure 41 shows with lower buffer implementation, the effect on N load is quite slight while a full implementation has more visible effect.

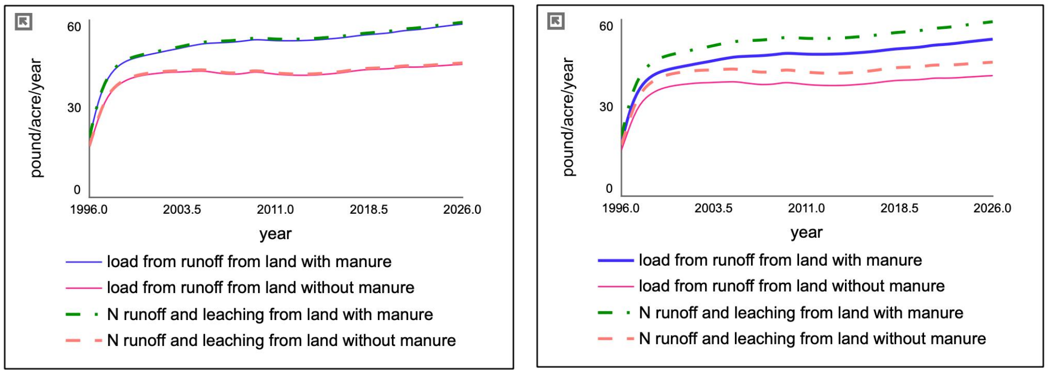

Figure 41 N load reduction by Buffer.assumed implementation process by 2022 (left): proportion of absorption N from runoff=0.01; Assumed implementation process target (right): proportion of absorption N from runoff=0.1. All scenarios are set under a residue return proportion as 0.45, preservation tillage cover proportion as 0.9.

Implementation The implementation of buffer area is quite different from nutrient management or soil quality preservation. A preservation of natural forest has better implementation feasibility and visible benefits. But for new-built buffer area, though it has long-term effect on N reduction once built, it takes high investment and long delay before effective[39]. Meanwhile, the establishment of buffer areas may contain huge implicit cost for land occupation and possible ecological impacts (Metaxoglou & Smith, 2022). These all make man-built buffer low feasible.

4.1.3 Government Preservation Policy

We included the effect from government land preservation policy into commodity production structure. By 2023, there have been 67,900 acres of lands protected under preservation policies from Frederick county and Maryland (Frederick County Government, 2023). Figure 42 shows with the preservation policy, corn planting acreage shows slight decreasing and

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[39] Long delay means it takes years before trees grow up to have strong root system for N absorption.

the trend is getting remarkable by year. As a result, total N load from corn land shows gradually visible reduction. This indicates the policy gives long-term and rising benefits, not restricted by load reduction, but also on soil and whole agricultural resource.

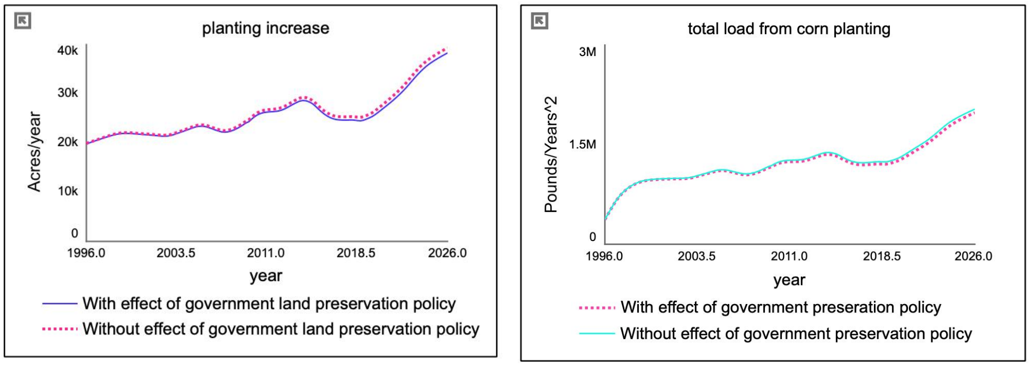

Figure 42 Planting acreage and N load under government preservation policy

Meanwhile, USDA has also conducted working-land program which pay landowners or producers to cover part or all of the costs of making changes in conservation practices and management decisions (Metaxoglou & Smith, 2022). We could assume this program is well combined with other BMPs and the improve their implementation feasibility

4.2 Implementation Comparison

Combination of Policy Scenario As we have discussed each policy, not we use land with manure as example to have a combined policy scenario. Figure 43 shows, from the first three scenarios, decrease N input can reduce N load by 35% - 41%. It leads to yield decreasing but with much lower proportion. In Scenario 4, maximum buffer policy only gives change N load reduction. In scenario 5 maximum residue return gives large improvement to humus and some effect on load reduction as better humus condition causes less soil erosion. In scenario 6, preservation tillage to 100% does not make obvious change as the process is 91% by 2022. The improvement of humus shows slight benefits on yield.

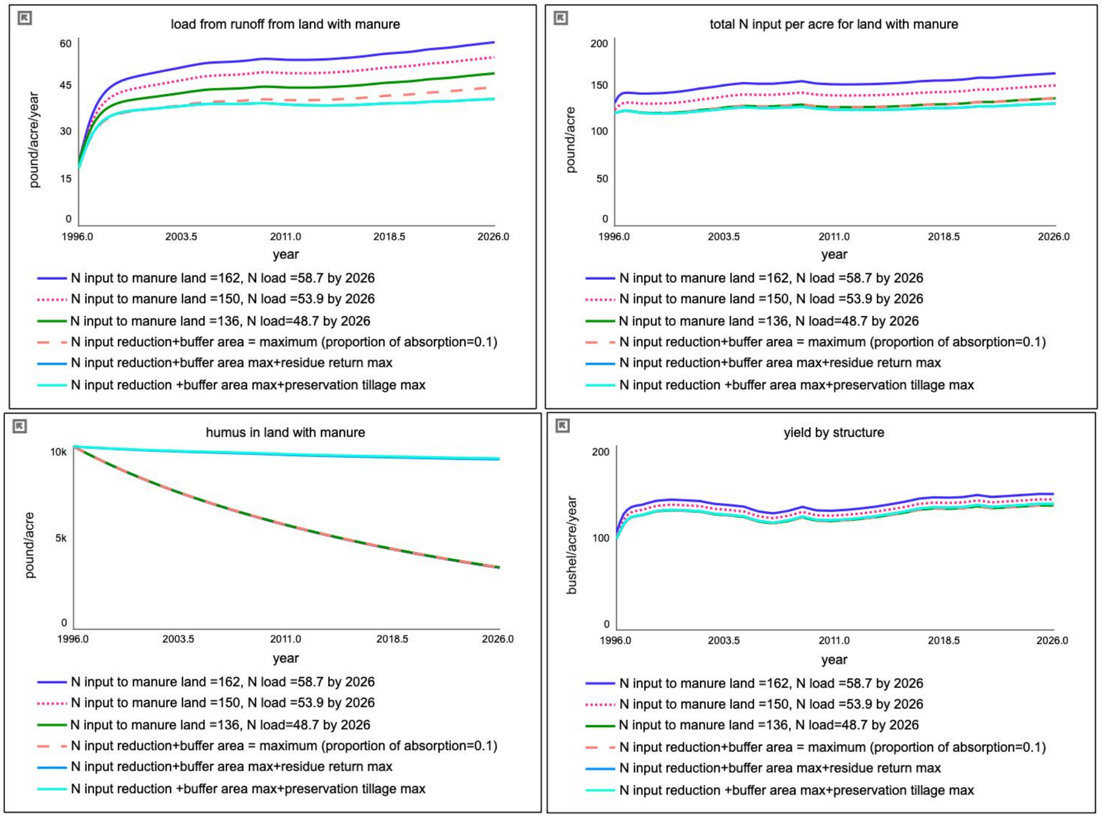

Figure 43 A Combined policy scenario in land with manure. The first three scenarios shows with three N input level with switch set by 2022 (residue return=0.45, preservation tillage =0.91, buffer=0.01), ; The 4th scenario = the 3rd scenario + maximum buffer area (0.1) implementation; The 5th scenario = the 4th scenario + maximum residue return rate(0.9); The 6th scenario = the 5th scenario + maximum preservation tillage(1.0).

The combined scenario indicates: Compared with N control after N load (buffer), it is more efficient to control N before N load (N application control), which is also referred by Metaxoglou & Smith, (2022). Besides analysis on each policy indicates it is also more expensive and difficult to conduct N control after N load.

Comparison of Implementation Feasibility We use a crosswise comparison for implementation feasibility for each policy, with leverage points and evaluation dimensions as efficiency, imperious level, cost and difficulty.

Table in next page

Policy / Dimentions			**Leverage point in system**	***Effeciency to N load reduction***	***Imperious level***	***Cost Demand***	***Implementation Difficulty***	**Sum Positve = (efficiency + Imperious level)**	**Sum Negative = (Cost + Difficulty)**	**Comprehensive Score = sum of all dimentions**
Nutrient Management (BMP)	**Manure application**	**Scientific application**	Control reinforcing loop	**4**	**5**	**5**	**3**	**9**	**8**	**17**
		Concept change on "Insurance Nitrogen"	Goals of the system; Control reinforcing loop	**4**	**4**	**5**	**1**	**8**	**6**	**14**
		Manure management and transportation	Structure of material stock and flows	**4**	**5**	**2**	**2**	**9**	**4**	**13**
	Fertilizer application	**Scientific application**	Control reinforcing loop	**4**	**4**	**5**	**4**	**8**	**9**	**17**
		Increase Fertilizer price	Rules of system, constraints, punishment	**2**	**2**	**3**	**2**	**4**	**5**	**9**
Soil Preservation (BMP)	**Residue return**	**Increase Residue return proportion to maximum**	Parameter adjustment	**3**	**5**	**5**	**4**	**8**	**9**	**17**
	Preservation Tillage	**Increase preservation tillage 100% cover**	Parameter adjustment	**3**	**5**	**5**	**5**	**8**	**10**	**18**
Buffer Area (BMP)	**Natural area**	**Forest and wetland Preservation**	Parameter adjustment	**3**	**5**	**4**	**5**	**8**	**9**	**17**
	New built	**Planting trees; build new wetland**	Structure of material stocks and flows	**3**	**2**	**2**	**2**	**5**	**4**	**9**
Land Preservation Policy			Parameter adjustment	**3**	**3**	**1**	**3**	**6**	**4**	**10**
Prevent pursuing high yield			Control reinforcing loop; Goals of system; Power structure, rules, culture	**5**	**2**	**1**	**1**	**7**	**2**	**9**
Remark:				1. No effective; 2. Low effective; 3. Effective; 4. Very effective; 5. Best effective.	1. Not emperious; 2. Low emperious; 3. Emperious; 4. High emperious; 5. Stremely emperious	1. Very high; 2. High; 3. Normal; 4. Low; 5. Very low or negative	1. Extremely difficult; 2. High difficult; 3. Difficult; 2. Low difficult; 5. Not difficult	It shows sum of positve factors for implementation feasibility.	It shows sum of negative factors for implementation feasibility.	Comprehensive Score indicates a general implementation feasibility.

Table 2 Policy Implementation Feasibility Comparison[40]. The dimensions and evaluations are based on literature, structure analysis and simulation results. The comprehension score is sum of scores of all dimensions. It does not distinguish different weights for four dimensions.

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[40] The principle comes by Meadows, 1999, Leverage points; David Wheat, course materials of GEO -SD 321 in University of Bergen; Metaxoglou & Smith, 2022; Meadows, 1973, Dynamics of commodity production cycles, chapter 7; CAST, Phase 6.

Table 2 gives an overview of implementation feasibility on all policies we discussed. Generally, Nutrient management and Soil preservation show the highest implementation feasibility. In Soil preservation policy, residue return and preservation tillage do not show high efficiency as nutrient management, but they gives the highest scores as a result of lower implementation difficulty. This corresponds to the high achievement result in BMPs. For Nutrient management, the scientific application for both manure and fertilizer are 16, however, manure shows more difficulty but higher imperious. Besides, manure management and transportation gives lower scores than others but its imperious level as 5 indicates the improvement is required instantly as it restricts scientific application of manure. Concept change on "Insurance nitrogen" gets high score but with an extremely high difficulty. The policy assumption on fertilizer price increase just gets a score of 9, which indicates a low implementation feasibility.

Buffer area shows high score of 17 for natural buffer policy and only 9 for new-built buffer policy. Hence, with no doubt to continue preservation for natural forests and wetland, it seems more questionable for the implementation feasibility of new-built buffer area for target of N load reduction. Though we are not sure the specific reasons on the low achievement process on Buffer area in BMPs (In Figure 6), we assume there is some relationships with the low implementation feasibility shown in the table.

In summary Table has corresponded to former analysis in this paper. It is recommended to strengthen the policy on nitrogen management, especially on manure related policies. Manure management and transportation should be improved at the same time. It is highly valuable to continue the implementation process for residue return (cover rate) and preservation tillage. For buffer areas, we see the high implementation feasibility on natural part, but we have more qualified opinion on how newly-built buffer area would contributes to N load reduction, as a lack of data, literature information and evaluation result from Table 2.

Land preservation policy is not included in the BMPs for N load reduction. As a long-term policy conducted by government, it shows higher difficulty and cost demand, but could largely benefit the future national agriculture.

The last item of “prevent pursuing high yield” is not exactly a policy but more an expectation for future. We assume: with the possibility to rebuild a new system for ecological agriculture, we could solve most of the problems. It has motivated the concept of ecological agriculture, revolution of diet as well as other endeavor by scientists.

5 Conclusion, Limits and Future

5.1 Conclusion

In this paper, we have chosen nitrogen load from corn planting in Frederick as study focus in order to understand dynamics of underlying structure for nutrient pollution from agricultural planting in Potomac watershed. We have explored two sections of structures: commodity production structure and nitrogen application structure, which separately focus on two core variables as planting acreage and nitrogen application. In Hypothesis, we have explained the structure validity and feasibility, described main feedback loops as well as assumptions. The model has successfully reproduced a series of reference mode and trend.

In Analysis, we tested sensitivity, uncertainty and robustness of structure. Combining analysis on structure and simulation results, we found important leverage points for policy. Nitrogen application control is indicated to be most efficient method for nitrogen load reduction while manure application shows more problematic scenarios. Soil preservation shows close relationship to N application and N load. Furthermore, the burden-shifting structure indicated, as a basic underlying structure, soil quality is most significant and has long-term effect for the whole system. Soil quality fading has been weakened and ignored as the mask of nutrient application and other losses. The test of soybean planting indicates the commodity production structure can be generalized to other agricultural products.

In Policy part, we further analyzed related best management practices (BMPs) and their implementation feasibility. We raised the necessary to further prompt soil preservation policy. For manure application, it is important to improve whole manure management system including manure management and transportation. Finally, we used crosswise comparison to evaluate implementation feasibility for all polices. The comprehensive score and rank of implementation feasibility of policies basically corresponds to our analysis in former parts.

5.2 Limits

Although the model simulation, test and analysis have achieved our main study target, there are some limits in this study.

1. Uncertainty of effects from weather conditions and climate change. As discussed in Hypothesis, weather conditions have a direct effect on agricultural planting. As the short simulation time and limit of resource, we could not capture effect on planting acreage by more precipitation or yield by high temperature. However, considering the global warming trend, the effect of climate change on agriculture and N load is assumed to be more severe in the future. Metaxoglou & Smith (2022) has discussed on it by citing from Sinha et al. (2017),

"...precipitation changes due to climate changes alone will increase by 19% the riverine total nitrogen loading within the CONUS by the end of the century for their business-as-usual scenario. The impacts are particularly large in the Northeast (28%), the upper Mississippi River Basin (24%), and the Great Lakes Basin (21%). According to the authors, precipitation changes alone will lead to a 18% increase in nitrogen loads in the MRB, which would require a 30% reduction in nitrogen inputs." (p6)

Hence, though climate effects is less included in our structure, we consider it has a long-term effects on the N pollution from agricultural planting and give a higher challenge for N reduction in the future.

2. Limit on simplified structure and uncertainty on parameter. Though we have

realized the importance of soil quality for the whole agricultural system from literature, the changing process of soil quality is very complex to capture. As a limit source and knowledge, We use stock of humus as a synthesis for soil properties of texture, structure, organic and mineral. We only used simplified structure to capture the relative interactions and test if soil fading effect N application and N load. There are also uncertainty on elasticity on yield structure while it does not bring make effect on our simulation target. But these uncertainty for the parameters and simplified structure, which prevent a further understanding of relationships between the key variables.

3. Limit of knowledge system and practical experience. As the limit of knowledge and practical experience we are not able to transform all related literature accurately into structure formulation. We try to capture important causal factors to corn planting and N application, there are some effects are not included in our structure. These lead to discrepancy between simulation and practice and cause boundedness to our policy analysis.

5.3 Future Study

It is expected to establish general understanding on the feeding crops development in the watershed, by generalizing the commodity structure to other corp plants types, especially animal feeding crops.

Secondly, a more precise structure on soil quality is expected, in order to distinguish how different soil properties interact with N management and N load as well as climate change.

Finally, it is valuable to have better understanding of implementation of BMPs. Though we have formulated the structure, found the leverage points and estimated implementation feasibility, only the practice get all the theory to its success.

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