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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Appendix A

1. Model Overview

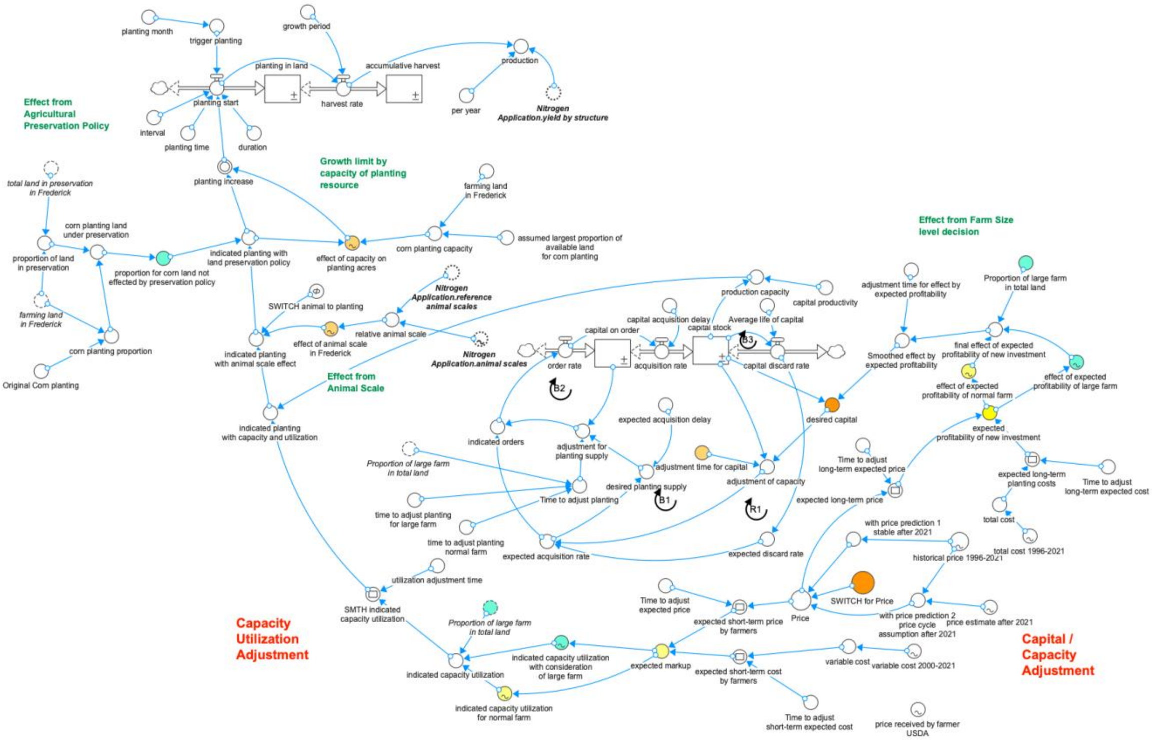
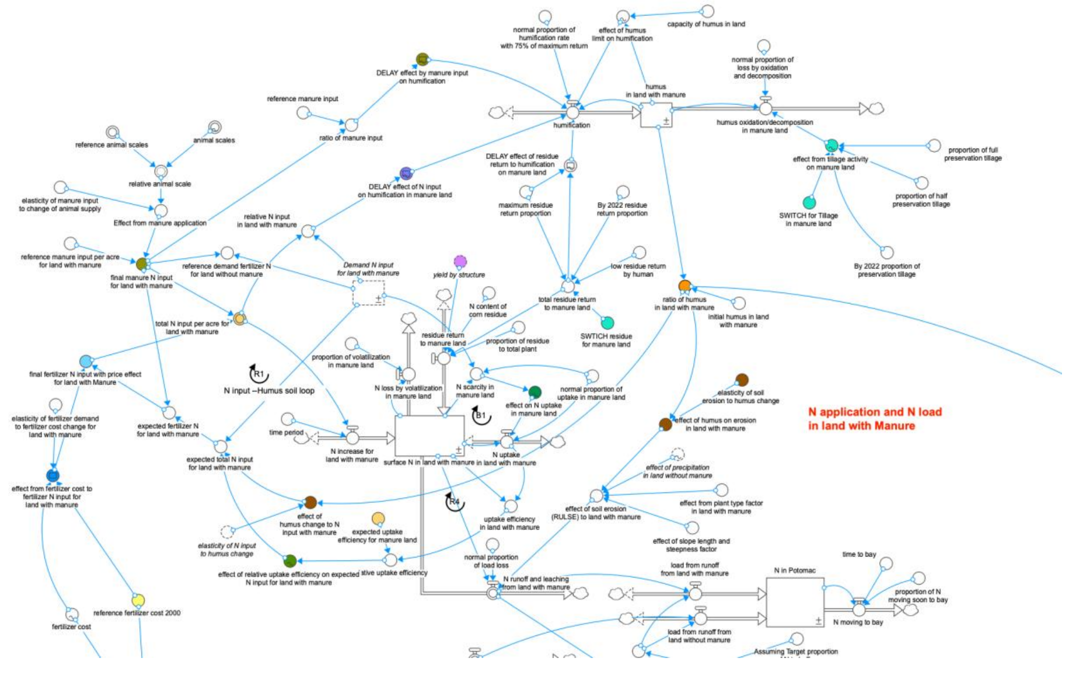


Figure 1 Modeling Overview - Commodity Production[1,2]



1 The commodity production does not show structure for soybean planting, as is is the same to structure for corn planting. We use soybean data to test the robustness and generalization for commodity production structure.

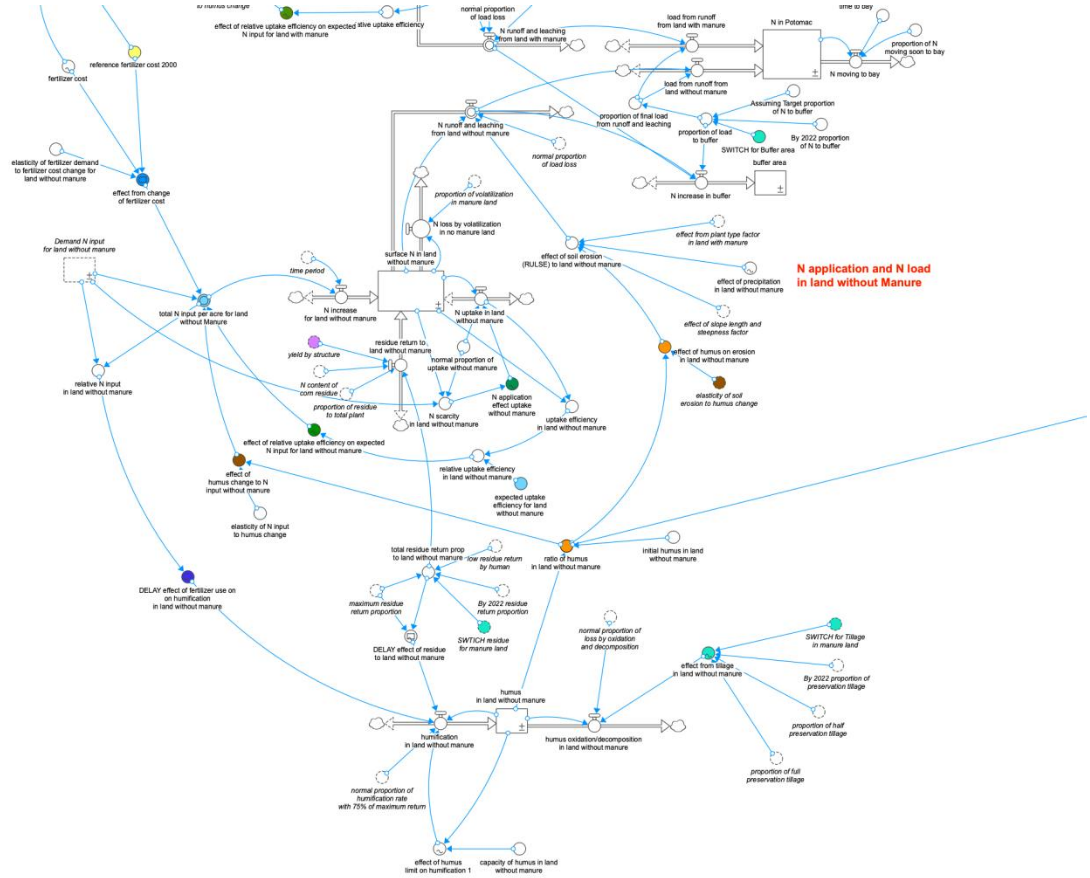


Figure 2 Modeling Overview 2/3: Nitrogen Application and Load in land with manure (upper) and land without manure (bottom)

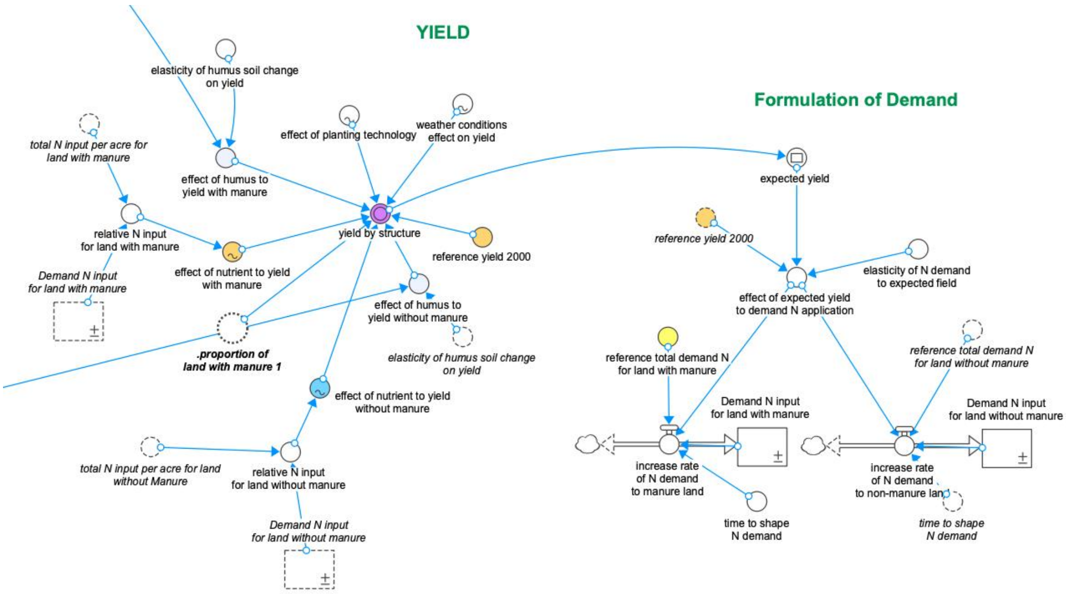


Figure 3 Model Overview 3/3: Structure of N application: Yield - Demand

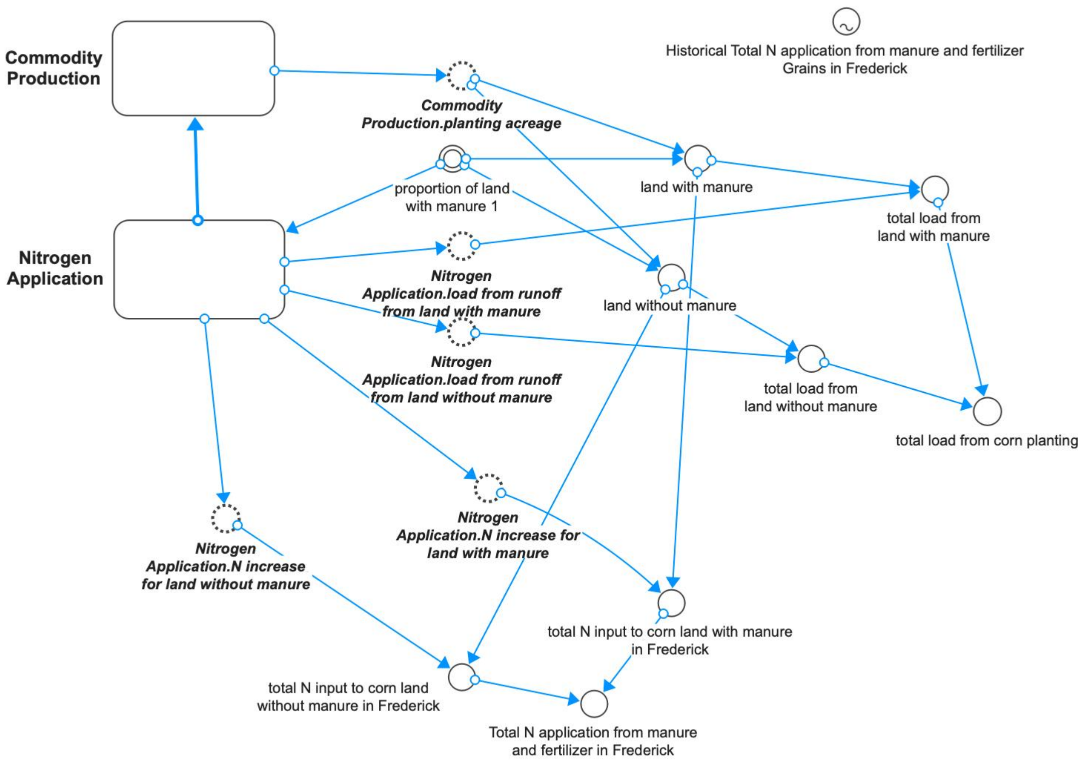


Figure 4 Total N application and N load calculation

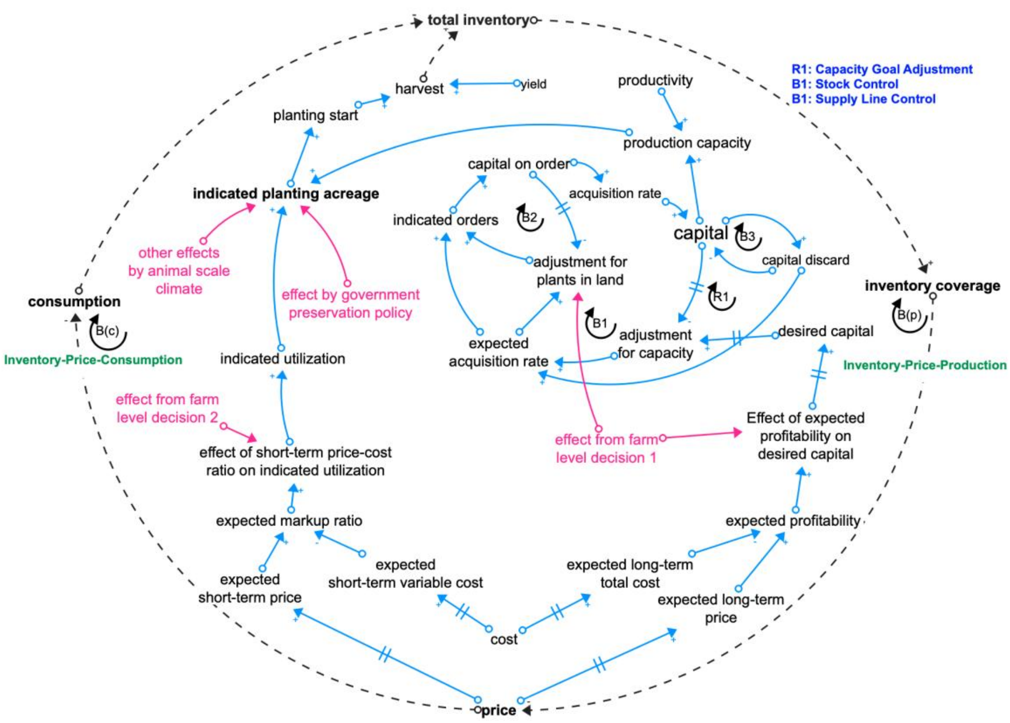


Figure 5 Commodity Production Structure (CLD)

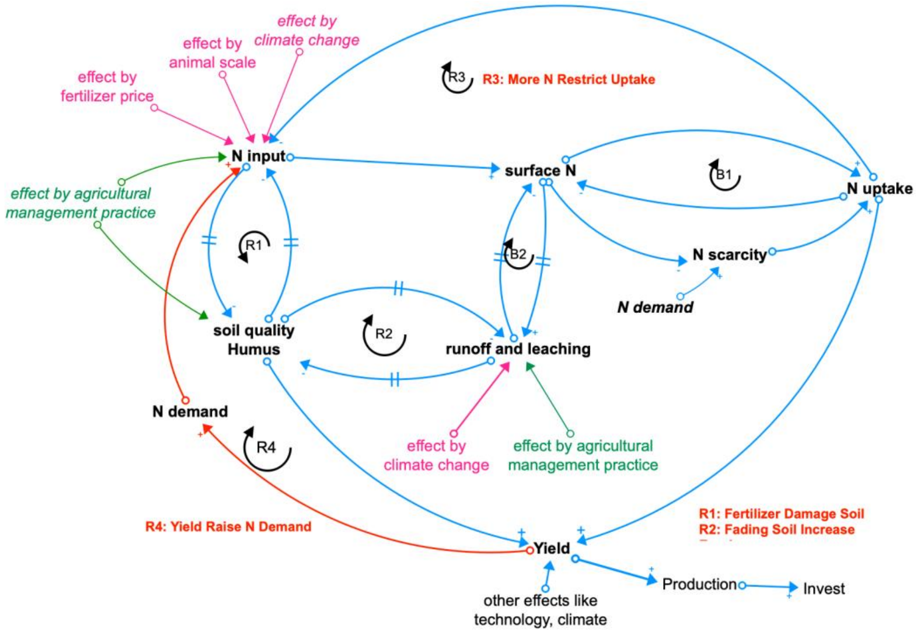


Figure 6 Nitrogen Application Structure (CLD)

1. Documentations

{ The model has 354 (354) variables (array expansion in parens).
In root model and 3 additional modules with 9 sectors.
Stocks: 16 (16) Flows: 30 (30) Converters: 308 (308)
Constants: 103 (103) Equations: 235 (235) Graphicals: 65 (65)
There are also 207 expanded macro variables. }

2.1 Top-Level Model:

Historical_Total_N_application_from_manure_and_fertilizer_Grains_in_Frederick = GRAPH(TIME)
Points: (2000.00, 3003246), (2001.00, 3069927), (2002.00, 3526624), (2003.00, 2869819), (2004.00, 3268401), (2005.00, 3118063), (2006.00, 3202761), (2007.00, 3218105), (2008.00, 3171116), (2009.00, 3232439), (2010.00, 3624256), (2011.00, 3987114), (2012.00, 3938870), (2013.00, 3736868), (2014.00, 3849667), (2015.00, 3835976), (2016.00, 4175950), (2017.00, 4606614), (2018.00, 4487359), (2019.00, 4326650), (2020.00, 4250565)

UNITS: pound/acre

DOCUMENT: The variable represents for the total N application from Grains land in Frederick.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

land_with_manure = Commodity_Production.planting_acreage*proportion_of_land_with_manure_1

UNITS: acre

DOCUMENT: The variable represents for the total land planting with manure. It it the product of total planting acreage and the proportion of land with manure.

land_without_manure = Commodity_Production.planting_acreage*(1-proportion_of_land_with_manure_1)

UNITS: acre

DOCUMENT: The variable represents for the total land planting without manure. It it the product of total planting acreage and the proportion of land without manure.

proportion_of_land_with_manure_1 = 0.45

UNITS: unitless

DOCUMENT: The variable represents for the proportion of planting land with manure. It is calculated from the historical planting data for grains from CAST.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

total_load_from_corn_planting = total_load_from_land_with_manure+total_load_from_land_without_manure

UNITS: Pounds/Years

DOCUMENT: The variable represents for the total N load for land with manure and without manure in the county. It is the sum of total load from both two types of lands.

total_load_from_land_with_manure = Nitrogen_Application.load_from_runoff_from_land_with_manure*land_with_manure

UNITS: Pounds/Years

DOCUMENT: The variable represents for the total N load for land with manure in the county. It is the product of total planting acreage and the N load per acre of land with manure.

total_load_from_land_without_manure = Nitrogen_Application.load_from_runoff_from_land_without_manure*land_without_manure

UNITS: Pounds/Years

DOCUMENT: The variable represents for the total N load for land without manure in the county. It is the product of total planting acreage and the N load per acre of land without manure.

Total_N_application_from_manure_and_fertilizer_in_Frederick = total_N_input_to_corn_land_without_manure_in_Frederick+total_N_input_to_corn_land_with_manure_in_Frederick

UNITS: Pounds/Years

DOCUMENT: The variable represents for the total N input for land with manure and without manure in the county. It is the sum of total N input from two types of land.

total_N_input_to_corn_land_with_manure_in_Frederick = Nitrogen_Application.N_increase_for_land_with_manure*land_with_manure

UNITS: Pounds/Years

DOCUMENT: The variable represents for the total N input for land with manure in the county. It is the product of total planting acreage and the N input per acre of land with manure.

total_N_input_to_corn_land_without_manure_in_Frederick = Nitrogen_Application.N_increase_for_land_without_manure*land_without_manure

UNITS: pound/year

DOCUMENT: The variable represents for the total N input for land without manure in the county. It is the product of total planting acreage and the N input per acre of land without manure.

2.2 Commodity_Production:

accumulative_harvest(t) = accumulative_harvest(t - dt) + (harvest_rate) * dt

INIT accumulative_harvest = 0

UNITS: Acres

DOCUMENT: The stock shows an accumulation of harvest/production every year. It could show the changing trend on production year by year in the time horizon.

capital_on_order(t) = capital_on_order(t - dt) + (order_rate - acquisition_rate) * dt

INIT capital_on_order = capital_discard_rate*capital_acquisition_delay

UNITS: dollar

DOCUMENT: The stock of capital on order represents for the product in process. It accumulates the new order and is depleted by acquisition rate. It can be seen as the plants in land which are still growing and waiting for harvest in this system.

capital_stock(t) = capital_stock(t - dt) + (acquisition_rate - capital_discard_rate) * dt

INIT capital_stock = ("reference_planting_acres_2000_(corn)"/SMTH_indicated_capacity_utilization)/capital_productivity*per_year

UNITS: dollar

DOCUMENT: The capital stock accumulates the capital increase from production selling and was depleted by the capital discard rate. The initial value is calculated based on the production and market price on year of 2000.

planting_in_land(t) = planting_in_land(t - dt) + (planting_start - harvest_rate) * dt

INIT planting_in_land = 0

UNITS: Acres

DOCUMENT: The stock accumulates the yearly planting rates and is depleted by the harvest rate every year.

The initial value is set as 0 in the beginning of simulation time.

acquisition_rate = DELAY3(order_rate, capital_acquisition_delay)

UNITS: dollar/Years

DOCUMENT: The flow of acquisition rate is the outflow of capital on order and inflow of capital stock. It represents for the product in process is transformed to capital and accumulate into capital stock. It is the ratio of capital on order and the capital acquisition delay. It reflects how fast the product completion in process and capital return speed.

capital_discard_rate = capital_stock/Average_life_of_capital

UNITS: dollar/Years

DOCUMENT: The capital discard rate represents the capital loss containing the normal depreciation of agricultural equipment, capital devaluation process and other capital depletion. It is given as division of capital stock and the average lifetime of capital in agriculture industry.

harvest_rate = DELAY(planting_start, growth_period)

UNITS: Acres/year

DOCUMENT: The harvest rate shows the production rate from planting every year. It is a delay function of planting start with a delay as growth period.

order_rate = MAX(0, indicated_orders)

UNITS: dollar/Years

DOCUMENT: The flow of order rate is the inflow that increase capital on order. It represents for the new investment is put into production process. The higher order rate, the faster the capital on order is accumulated. It is the non-negative of indicated orders. When the indicated order is below 0, we assume it as 0 in the structure. Because we use outflow to represents for the loss of stock but not negative inflow.

planting_start = STEP(planting_increase, planting_time,duration, interval)*trigger_planting

UNITS: Acres/year

DOCUMENT: The planting start rate is the inflow that fill in the stock of planting in land. It represents for how much the new planting is given in the planting season. The equation is a step up and down before and after planting duration, which simulates the planting pulse every spring.

adjustment_for_planting_supply = (desired_planting_supply-capital_on_order)/Time_to_adjust_planting

UNITS: dollar/Years

DOCUMENT: The variable of adjustment for planting land represents for the preparation for farmers when they decide to change planting types. It is the gap between capital on order and desired planting supply, divided by adjustment time for planting. It can be understood as the value calculation of work-in-process inventory.

Sterman, J. D. (2000a). Business dynamics : systems thinking and modeling for a complex world. (pp. XXVI, 982).Irwin McGraw-Hill.Chapter 20: Commodity Cycles. p791-p841.

adjustment_of_capacity = (desired_capital-capital_stock)/adjustment_time_for_capital

UNITS: dollar/Years

DOCUMENT: The adjustment of capacity stock represents for the process to adjust the gap between the capital stock and desired capital level with the adjustment delay. The result of adjustment of capital is realized in the change of capacity for planting, so it is named as adjustment of capacity though it starts by an adjustment of capital.

adjustment_time_for_capital = 8

UNITS: year

DOCUMENT: The time to adjust capital represents the necessary delay for the capital stock to reach the desired level. It is one of the most important delays in the commodity cycles.

It is set as around 8 year and in practice it can be even longer. We estimated the value based on the information of cattle cycles average about 10-12 years. As our study plants are used mainly for feeding animals especially cattles, we consider there is closely relationship between these two cycles. Considering the delays in other process of commodity cycle, we assume the adjustment time for capital is 8 years. By adjustment of this parameter, we could see how the capital stock and planting acreage would react to the change.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p 792-298.

Meadows, 1971, Dynamics of commodity production cycles, chapter 4-5.

adjustment_time_for_effect_by_expected_profitability = 3

UNITS: year

DOCUMENT: The variable represents for adjustment time for expected profitability has effect on desired capital. It is set as 3 years, as we assume the adjustment time for long-term expectation of profitability needs a few years to decide. Capital decision makers would not rely on just one or two years profitability to decide. And the whole renew of capital in the structure takes very long delay which can be over 10 years because we assume the cycle of corn grain is closely related to cattle cycles which is 10-12 years. So here we assume it not shorter than 3 years.

The principle comes form:

Sterman, 2000, Business Dynamics, Chapter 20.

Meadows, 1971, Dynamics of Commodity Production Cycles, Chapter 3 - 4.

adjustment_time_for_plants_in_land_by_large_farm = 5

UNITS: year

DOCUMENT: The parameters represents for the adjustment time for large farms to adjust planting types in land. It is assumed to be 5 years. We have considered the less sensitive of large farms to markets, long-term contracts with retailers and corresponding equipment and machines for some type of planting use, which are all seen as prevent large farms to adjust planting in land as quickly as normal-sized farms.

adjustment_time_for_plants_in_land_by_normal_farm = 1.5

UNITS: year

DOCUMENT: The delay time for producers/farmers to adjust planting type in land. Planting needs long time to adjust as long as seeds are broadcast to land. and planting needs preparation of months before broadcast. It is set as 2 years, which is estimated to include two types of plants that grow up in different season. Thus we estimate farmers spend 2 years to adjust the utilization rate.

adjustment_time_for_utilization = 2

UNITS: year

DOCUMENT: The delay time for producers/farmers to decide to accept and change the indicated capacity utilization by market price and cost effect. Planting needs long time to adjust as long as seeds are broadcast to land. and planting needs preparation of months before broadcast. It is set as 2 years, which is estimated to include two types of plants that grow up in different season. Thus we estimate farmers spend 2 years to adjust the utilization rate.

Sterman, J. D. . (2000e). Business dynamics: systems thinking and modeling for a complex world (pp. XXVI, 982). Irwin McGraw-Hill. Chapter 20: Capacity Utilization. p802-p805.

Agricultural_preservation = GRAPH(TIME)

Points: (2009.00, 0), (2009.48275862, 120.7), (2009.96551724, 241.4), (2010.44827586, 362.1), (2010.93103448, 482.8), (2011.4137931, 603.4), (2011.89655172, 724.1), (2012.37931034, 844.8), (2012.86206897, 965.5), (2013.34482759, 1086), (2013.82758621, 1207), (2014.31034483, 1328), (2014.79310345, 1448), (2015.27586207, 1569), (2015.75862069, 1690), (2016.24137931, 1810), (2016.72413793, 1931), (2017.20689655, 2052), (2017.68965517, 2172), (2018.17241379, 2293), (2018.65517241, 2414), (2019.13793103, 2534), (2019.62068966, 2655), (2020.10344828, 2776), (2020.5862069, 2897), (2021.06896552, 3017), (2021.55172414, 3138), (2022.03448276, 3259), (2022.51724138, 3379), (2023.00, 3500)

UNITS: acre

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

Frederick County Government. (2023b). Agricultural Preservation. https://www.frederickcountymd.gov/7980/Agricultural-Preservation

assumed_largest_proportion_of_available_land_for_corn_planting = 0.85

UNITS: unitless

DOCUMENT: The variable means the assumed largest proportion of available land for corn planting.

Average_life_of_capital = 20

UNITS: year

DOCUMENT: The lifetime of capital represents for the lifetime of capital invested in this field, which effects the speed of depletion for capital discard rate. The shorter lifetime the capital is, the faster the capital is discarded.

"average_planting_acres_2000-2020_(corn)" = 23646

UNITS: acres

DOCUMENT: The variable is an average planting acres from 2000 to 2020.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, 2023,https://cast.chesapeakebay.net/Home/SourceData

Calculated_historical_Corn_planting = Historical_Total_Planting_Acres_of_Grains_in_Frederick*Proportion_of_Corns_in_Grains

UNITS: acre

DOCUMENT: The variable represents for the calculated of corn planting with proportion of 95% in the total grains in Frederick, which is from the data from CAST.

capital_acquisition_delay = 0.75

UNITS: year

DOCUMENT: It means how long time the producers/farmers could obtain payback by capital investment into production. It should be no shorter than one complete production period, which is growth period of plant. Considering the whole growth and sale time, it is set as no shorter than 0.75 year.

capital_productivity = 1

UNITS: acre/dollar/year

DOCUMENT: capital productivity represents for the unit production achievement by capital.

It is set as 1, which means one unit of capital is equivalent one unit of production payment, including seed, tools and ferlizer, etc.

Conservation_reserve_enhancement_program = GRAPH(TIME)

Points: (2009.00, 0), (2009.48275862, 120.7), (2009.96551724, 241.4), (2010.44827586, 362.1), (2010.93103448, 482.8), (2011.4137931, 603.4), (2011.89655172, 724.1), (2012.37931034, 844.8), (2012.86206897, 965.5), (2013.34482759, 1086), (2013.82758621, 1207), (2014.31034483, 1328), (2014.79310345, 1448), (2015.27586207, 1569), (2015.75862069, 1690), (2016.24137931, 1810), (2016.72413793, 1931), (2017.20689655, 2052), (2017.68965517, 2172), (2018.17241379, 2293), (2018.65517241, 2414), (2019.13793103, 2534), (2019.62068966, 2655), (2020.10344828, 2776), (2020.5862069, 2897), (2021.06896552, 3017), (2021.55172414, 3138), (2022.03448276, 3259), (2022.51724138, 3379), (2023.00, 3500)

UNITS: Acres

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

Frederick County Government. (2023b). Agricultural Preservation. https://www.frederickcountymd.gov/7980/Agricultural-Preservation

corn_planting_capacity = assumed_largest_proportion_of_available_land_for_corn_planting*farming_land_in_Frederick

UNITS: acre

DOCUMENT: The variable represents for the corn planting capacity, which is the total farming land in the county times the assumption proportion that is suitable for corn planting.

corn_planting_land_under_preservation = proportion_of_land_in_preservation*corn_planting_proportion

UNITS: unitless

DOCUMENT: The variable represents for the proportion of corn land under preservation.

corn_planting_proportion = Original_Corn_planting/farming_land_in_Frederick

UNITS: unitless

DOCUMENT: The variable means the proportion of corn planting in all farm land. It is the ratio of the original corn acres and the total farming land in the county. As the corn planting is changing by years, here we toughly use the original acres to get a corn planting proportion.

Critical_farms = GRAPH(TIME)

Points: (1994.00, 0), (1995.00, 175.9), (1996.00, 351.7), (1997.00, 527.6), (1998.00, 703.4), (1999.00, 879.3), (2000.00, 1055), (2001.00, 1231), (2002.00, 1407), (2003.00, 1583), (2004.00, 1759), (2005.00, 1934), (2006.00, 2110), (2007.00, 2286), (2008.00, 2462), (2009.00, 2638), (2010.00, 2814), (2011.00, 2990), (2012.00, 3166), (2013.00, 3341), (2014.00, 3517), (2015.00, 3693), (2016.00, 3869), (2017.00, 4045), (2018.00, 4221), (2019.00, 4397), (2020.00, 4572), (2021.00, 4748), (2022.00, 4924), (2023.00, 5100)

UNITS: acre

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

Frederick County Government. (2023b). Agricultural Preservation. https://www.frederickcountymd.gov/7980/Agricultural-Preservation

desired_capital = capital_stock*Smoothed_effect_by_expected_profitability

UNITS: dollar

DOCUMENT: The desired capital means the expected capital level in the market. It is the product of present capital level-capital stock and the effect from long-term expected profitability. The effect contains the consideration of farm size level.

desired_planting_supply = expected_acquisition_delay*(expected_acquisition_rate)

UNITS: dollar

DOCUMENT: The desired planting land represents for the desired planting area for the target type of plants. The equation is given by a principle of Little's Law that producers must maintain the supply line that equals to the expected acquisition delay times the desired acquisition rate. Using here, it is farmers must maintain a planting resource(like lands) equal to the expected harvest rate times expected acquisition delay.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p 806.

duration = 0.0833333333333

UNITS: per year

DOCUMENT: The duration represents for the time to plant seeds in land. It is set 0.08 year. It is a tough estimation of one year's time for farmer to broadcast.

effect_of_animal_scale_in_Frederick = GRAPH(relative_animal_scale)

Points: (0.000, 0.6000), (0.100, 0.6106), (0.200, 0.6296), (0.300, 0.6550), (0.400, 0.6995), (0.500, 0.7439), (0.600, 0.7989), (0.700, 0.9259), (0.800, 0.9619), (0.900, 0.9852), (1.000, 1.0000), (1.100, 1.0000), (1.200, 1.0000), (1.300, 1.0000), (1.400, 1.0000), (1.500, 1.0000), (1.600, 1.0000), (1.700, 1.0000), (1.800, 1.0000), (1.900, 1.0000), (2.000, 0.9979)

UNITS: unitless

DOCUMENT: The table function shows how planting acreage decision will be effected by the change of animal scales. When animal scale ratio is over 1, there is no effect on the planting acreage. When the scale ratio is less than 1, decreasing from to 0, the effect will decrease increasingly from 1 to around 0.8, then decrease decreasingly to 0.6.

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

"...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.

The principle partly comes from

Meadows, 1971, Dynamics of Commodity Production Cycles, Chapter 6.

U.S. Department of Agriculture.(2023 c, May). Feed Grains Sector at a Glance. Chart U.S. corn production and price.

https://www.ers.usda.gov/topics/crops/corn-and-other-feed-grains/feed-grains-sector-at-a-glance/

effect_of_capacity_on_planting_acres = GRAPH(indicated_planting_with_land_preservation_policy/corn_planting_capacity)

Points: (0.000, 1.000), (0.050, 0.995), (0.100, 0.9874), (0.150, 0.9754), (0.200, 0.9566), (0.250, 0.9275), (0.300, 0.8835), (0.350, 0.8196), (0.400, 0.7324), (0.450, 0.6231), (0.500, 0.500), (0.550, 0.3769), (0.600, 0.2676), (0.650, 0.1804), (0.700, 0.1165), (0.750, 0.07251), (0.800, 0.04341), (0.850, 0.02463), (0.900, 0.01263), (0.950, 0.004963), (1.000, 0.000)

UNITS: unitless

DOCUMENT: The table functions shows a tough estimation of effect of corn planting capacity on planting acreage decision. When the planting acres is decreasing to 0, the effect will increase to 1 which means there is less limit from capacity. When the planting acres is approaching to 1, the effect will decrease decreasingly to 0, which means planting acres will increase very slow.

effect_of_expected_profitability_of_large_farm = GRAPH(expected_profitability_of_new_investment)

Points: (-1.000, 0.000), (-0.800, 0.571), (-0.600, 0.847), (-0.400, 1.000), (-0.200, 1.185), (0.000, 1.323), (0.200, 1.439), (0.400, 1.534), (0.600, 1.661), (0.800, 1.735), (1.000, 1.799)

UNITS: unitless

DOCUMENT: The variable shows how the desired capital would be effected by the expected profitability for large farms. From our assumption. Capital for large farms is less sensitive to the change of profitability. When the profitability is 0, the effect is still 1.32. When the profitability increase from 0 to 1, the effect increase decreasingly to 1.8 When the profitability is decreasing from 0 to -1, profit is negative, the effect decrease slowly. When the profitability is -0.4, the effect is 1, which means no change on desired capacity. When profitability is decreasing from -0.4 to -1, the effect decrease increasingly to 0. This describes that large farms have a less sensitive reaction to the change of profitability, as results of their large scale, long-term contract, high production efficiency and larger profit space than normal-sized farms and average level.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p807-810.

James M. MacDonald, Robert A. Hoppe, and Doris Newton, March,2018, USDA, Three Decades of Consolidation in U.S. Agriculture

effect_of_expected_profitability_of_normal_farm = GRAPH(expected_profitability_of_new_investment)

Points: (-1.000, 0.000), (-0.900, 0.0315), (-0.800, 0.063), (-0.700, 0.127), (-0.600, 0.212), (-0.500, 0.300), (-0.400, 0.451), (-0.300, 0.5725), (-0.200, 0.694), (-0.100, 0.847), (0.000, 1.000), (0.100, 1.217), (0.200, 1.365), (0.300, 1.503), (0.400, 1.587), (0.500, 1.640), (0.600, 1.704), (0.700, 1.746), (0.800, 1.767), (0.900, 1.788), (1.000, 1.810)

UNITS: unitless

DOCUMENT: The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p802-805.

The variable shows how the desired capital would be effected by the expected profitability by new investment. When the profitability is 0, there would be no new invest entering and the investors would like to keep present capital stock level. When the profitability decrease from 0 to -1, the profit is negative, the effect would decrease decreasingly to 0, which means invest willing will decrease to 0. When the profitability is higher than 0, increasing from 0 to 1, the profits space is positive and get larger, the effect will increase decreasingly to its highest level, which is finally around 1.8 with a result of market saturation. Generally, when the expected profitability is increasing from -1 to 1, the effect on desired capital on small farms experienced an increasing increasingly then shift to increasing decreasingly to its equilibrium, which shows an S-shaped growth.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p807-810.

expected_acquisition_delay = 1

UNITS: year

DOCUMENT: The expected acquisition delay is assumed as the sum of growth period duration and another few months' adjustment time. This indicates the period that farmers need to estimate, adjust and acquire capacity. Thus it is assumed to consist the growth period of plant and another half of year to sell and adjust other necessary resource to achieve new planing capacity. If modeled as simplification, the expected acquisition delay can be used as equal growth period duration. But in practice it can be much longer. So here we assume it as 1 year, a little longer than capital acquisition delay.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p 805-807.

expected_acquisition_rate = adjustment_of_capacity+expected_discard_rate

UNITS: dollar/Years

DOCUMENT: The variable represents for a total expected acquisition rate by producers or decision makers. It includes the replacement of expected loss from discard rate and the adjustment part of capital stock to its desired capital stock.

expected_discard_rate = capital_discard_rate

UNITS: dollar/Years

DOCUMENT: The variable of expected discard rate is the variable that is used for the capital discard rate. It is seen as part of expected acquisition rate. It is set as equal to capital discard rate.

"expected_long-term_planting_costs" = SMTH3(total_cost, "Time_to_adjust_long-term_expected_cost") {DELAY CONVERTER}

UNITS: dollar/bushel

DOCUMENT: The variables shows expected prices by investors. It is a smoothing of former cost with delay time to adjust.

Sterman, J. D. (2000d). Business dynamics: systems thinking and modeling for a complex world (pp. XXVI, 982). Irwin McGraw-Hill. Chapter 16: Modeling Expectation Formation. p631-p634

"expected_long-term_price" = SMTH3(Price, "Time_to_adjust_long-term_expected_price") {DELAY CONVERTER}

UNITS: dollar/bushel

DOCUMENT: The variables represents for an expected prices by investors. It is a smoothing of present market price with delay time to adjust.

Sterman, J. D. (2000d). Business dynamics: systems thinking and modeling for a complex world (pp. XXVI, 982). Irwin McGraw-Hill. Chapter 16: Modeling Expectation Formation. p631-p634

expected_markup = "expected_short-term_price_by_farmers"/"expected_short-term_cost_by_farmers"

UNITS: unitless

DOCUMENT: The variable of expected markup represents for ratio of expected price to the expected planting cost by farmers.

Sterman, J.D. (2000f) Business Dynamics. Chapter 20: Dependence of indicated capacity utilization on the expected markup. p803.

expected_profitability_of_new_investment = ("expected_long-term_price"-"expected_long-term_planting_costs")/"expected_long-term_price"

UNITS: unitless

DOCUMENT: The ratio represents for the expected profitability for new investment. It is the division of gap between the expected price and expected cost of new capacity and the expected

price. So it shows the profitability achievement level of the new investment.
"expected_short-term_cost_by_farmers" = SMTH1(variable_cost, "Time_to_adjust_short-term_expected_cost") {DELAY CONVERTER}

UNITS: dollar/bushel

DOCUMENT: The variable means a smooth on the practical cost with a short-term period.

Sterman, J. D. (2000d). Business dynamics: systems thinking and modeling for a complex world (pp. XXVI, 982). Irwin McGraw-Hill. Chapter 16: Modeling Expectation Formation. p631-p634

"expected_short-term_price_by_farmers" = SMTH1(Price, Time_to_adjust_expected_price) {DELAY CONVERTER}

UNITS: dollar/bushel

DOCUMENT: The variable means a smooth on the practical price with a short-term period.

Sterman, J. D. (2000d). Business dynamics: systems thinking and modeling for a complex world (pp. XXVI, 982). Irwin McGraw-Hill. Chapter 16: Modeling Expectation Formation. p631-p634

farming_land_in_Frederick = 181500

UNITS: acres

DOCUMENT: It means total farming land in Frederick county. The data comes from Frederick county government website in 2023.

final_effect_of_expected_profitability_of_new_investment = effect_of_expected_profitability_of_large_farm*Proportion_of_large_farm_in_total_land+effect_of_expected_profitability_of_normal_farm*(1-Proportion_of_large_farm_in_total_land)

UNITS: unitless

DOCUMENT: The variable represents for the final effect of expected profitability of new investment from a consideration of both farms of normal-sized and large farms, with their corresponding proportion.

growth_period = 0.5

UNITS: year

DOCUMENT: The growth period duration means the time between the plant starts growing till its harvest. Corn is from April to September.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data,2023, https://cast.chesapeakebay.net/Home/SourceData

"historical_price_1996-2021" = GRAPH(TIME)

Points: (1996.00, 3.04), (1997.00, 2.72), (1998.00, 2.12), (1999.00, 2.00), (2000.00, 1.87), (2001.00, 1.92), (2002.00, 2.57), (2003.00, 2.30), (2004.00, 2.18), (2005.00, 1.84), (2006.00, 2.63), (2007.00, 3.36), (2008.00, 4.52), (2009.00, 3.59), (2010.00, 4.70), (2011.00, 6.26), (2012.00, 7.10), (2013.00, 4.28), (2014.00, 3.53), (2015.00, 3.78), (2016.00, 3.53), (2017.00, 3.43), (2018.00, 3.61), (2019.00, 4.08), (2020.00, 3.79), (2021.00, 5.15) {GF EXTRAPOLATED}

UNITS: dollar/bushel

DOCUMENT: The data comes from external data from USDA--

Corn production costs and returns per planted acre, excluding Government payments, Eastern Uplands, Price.

Data source:

U.S. Department of Agriculture,2023, https://www.ers.usda.gov/

Historical_Total_Planting_Acres_of_Grains_in_Frederick = GRAPH(TIME)

Points: (2000.00, 19983), (2001.00, 21444), (2002.00, 22956), (2003.00, 23336), (2004.00, 23697), (2005.00, 24061), (2006.00, 24438), (2007.00, 24884), (2008.00, 25993), (2009.00, 27128), (2010.00, 28295), (2011.00, 29487), (2012.00, 30714), (2013.00, 30322), (2014.00, 29734), (2015.00, 29750), (2016.00, 29768), (2017.00, 29789), (2018.00, 29513), (2019.00, 29212), (2020.00, 28948)

UNITS: acre

DOCUMENT: The variable represents for the total planting acres of Grains in Frederick.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data,2023, https://cast.chesapeakebay.net/Home/SourceData

indicated_capacity_utilization = indicated_capacity_utilization_for_normal_farm*(1-Proportion_of_large_farm_in_total_land)+indicated_capacity_utilization_with_consideration_of_large_farm*Proportion_of_large_farm_in_total_land

UNITS: unitless

DOCUMENT: The variable represents for indicated capacity utilization that get the effects from two kinds of farms with their corresponding proportion. So its equation is the effect time corresponding proportion.

indicated_capacity_utilization_for_normal_farm = GRAPH(expected_markup)

Points: (0.400, 0.000), (0.530, 0.016), (0.660, 0.048), (0.790, 0.111), (0.920, 0.228), (1.050, 0.556), (1.180, 0.630), (1.310, 0.677), (1.440, 0.730), (1.570, 0.767), (1.700, 0.794), (1.830, 0.820), (1.960, 0.852), (2.090, 0.884), (2.220, 0.905), (2.350, 0.926), (2.480, 0.947), (2.610, 0.968), (2.740, 0.989), (2.870, 1.000), (3.000, 1.000)

UNITS: unitless

DOCUMENT: The table function describes how short-term expected markup effect the indicated utilization for small sized farm. When markup is around 1, the effect to indicated utilization is around 0.5. When the markup increase to 3, the effect would increase decreasingly to 1. When the markup decrease from 1 to 0.4, the effect would decrease quickly then decrease decreasingly to 0. This means when the markup is below 1, the production willing of small farms will decrease very fast to a very low level. When the markup is 0.79, the effect has decreased to 0.11. Finally it reaches 0 when markup is lower than 0.4.

This indicates for normal or small farms they react quickly with a low markup ratio as their smaller scale and low production efficiency than large farms.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p 802-805.

indicated_capacity_utilization_with_consideration_of_large_farm = GRAPH(expected_markup)

Points: (0.400, 0.000), (0.530, 0.164), (0.660, 0.339), (0.790, 0.466), (0.920, 0.540), (1.050, 0.598), (1.180, 0.656), (1.310, 0.693), (1.440, 0.730), (1.570, 0.767), (1.700, 0.794), (1.830, 0.820), (1.960, 0.852), (2.090, 0.884), (2.220, 0.905), (2.350, 0.926), (2.480, 0.947), (2.610, 0.968), (2.740, 0.989), (2.870, 1.000), (3.000, 1.000)

UNITS: unitless

DOCUMENT: The table function describes how short-term expected markup effect the indicated utilization for small sized farm. When markup is around 1, the effect to indicated utilization is around 0.5. When the markup increase to 3, the effect would increase decreasingly to 1. When the markup decrease from 1 to 0.4, the effect would decrease quickly then decrease decreasingly to 0. This means when the markup is below 1, the effect would decrease as linear speed, which is much slower than small farms. When the markup is 0.5, there is still 0.16 of effect. When markup is below 0.4, the effect would be 0. This is because large farms have a higher production efficiency which enable them to decrease slowly when the markup is below 1.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p802-805.

indicated_orders = expected_acquisition_rate+adjustment_for_planting_supply

UNITS: dollar/Years

DOCUMENT: The variable represents for the indicated order for capital. It is the sum of expected acquisition rate and adjustment for planting supply.

indicated_planting_with_animal_scale_effect = IF SWITCH_animal_scale_to_planting=1 THEN indicated_planting_with_capacity_and_utilization*effect_of_animal_scale_in_Frederick ELSE indicated_planting_with_capacity_and_utilization

UNITS: acre/year

DOCUMENT: The variable represents for the the indicated planting acreage with effect of animal scale. It is the product of indicated planting with capacity and utilization

indicated_planting_with_capacity_and_utilization = production_capacity*SMTH_indicated_capacity_utilization

UNITS: Acres/Years

DOCUMENT: The variable of indicated planting represents for the indicated planting area by farmers. It is given by indicated planting with capital amount and capital utilization times effect from animal scale change.

indicated_planting_with_land_preservation_policy = IF SWITCH_land_preservation=1 THEN indicated_planting_with_animal_scale_effect*proportion_for_corn_land_not_effected_by_preservation_policy ELSE indicated_planting_with_animal_scale_effect

UNITS: acre/year

DOCUMENT: The variable represents for the indicated planting with land preservation policy, so it is the product of indicated planting with animal scale effect times the proportion of corn land without preservation policy

installment_purchase_program = GRAPH(TIME)

Points: (2002.00, 0), (2002.72413793, 713.8), (2003.44827586, 1428), (2004.17241379, 2141), (2004.89655172, 2855), (2005.62068966, 3569), (2006.34482759, 4283), (2007.06896552, 4997), (2007.79310345, 5710), (2008.51724138, 6424), (2009.24137931, 7138), (2009.96551724, 7852), (2010.68965517, 8566), (2011.4137931, 9279), (2012.13793103, 9993), (2012.86206897, 10710), (2013.5862069, 11420), (2014.31034483, 12130), (2015.03448276, 12850), (2015.75862069, 13560), (2016.48275862, 14280), (2017.20689655, 14990), (2017.93103448, 15700), (2018.65517241, 16420), (2019.37931034, 17130), (2020.10344828, 17840), (2020.82758621, 18560), (2021.55172414, 19270), (2022.27586207, 19990), (2023.00, 20700)

UNITS: acre

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

Frederick County Government. (2023b). Agricultural Preservation. https://www.frederickcountymd.gov/7980/Agricultural-Preservation

interval = 1

UNITS: year

DOCUMENT: The variable means how many time the planting happens per year. It is set as 1 time.

Maryland_Agricultural_Land_Preservation_Foundation_MALPF = GRAPH(TIME)

Points: (1980.00, 0), (1981.48275862, 803.4), (1982.96551724, 1607), (1984.44827586, 2410), (1985.93103448, 3214), (1987.4137931, 4017), (1988.89655172, 4821), (1990.37931034, 5624), (1991.86206897, 6428), (1993.34482759, 7231), (1994.82758621, 8034), (1996.31034483, 8838), (1997.79310345, 9641), (1999.27586207, 10440), (2000.75862069, 11250), (2002.24137931, 12050), (2003.72413793, 12860), (2005.20689655, 13660), (2006.68965517, 14460), (2008.17241379, 15270), (2009.65517241, 16070), (2011.13793103, 16870), (2012.62068966, 17680), (2014.10344828, 18480), (2015.5862069, 19280), (2017.06896552, 20090), (2018.55172414, 20890), (2020.03448276, 21690), (2021.51724138, 22500), (2023.00, 23300)

UNITS: acre

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

Frederick County Government. (2023b). Agricultural Preservation. https://www.frederickcountymd.gov/7980/Agricultural-Preservation

Original_Corn_planting = 17400

UNITS: acres

DOCUMENT: The variable means the original corn planting in 1996.

Frederick County Government. (2023b). Agricultural Preservation. https://www.frederickcountymd.gov/7980/Agricultural-Preservation

per_year = 1

UNITS: per year

planting_acreage = planting_increase*year

UNITS: acre

DOCUMENT: The variable represents for the total planting acreage in one year.

planting_increase = indicated_planting_with_land_preservation_policy*effect_of_capacity_on_planting_acres

UNITS: Acres/year

DOCUMENT: The variables represents for the final planting increase per year. It is the product of indicated planting with land preservation policy and the effect of capacity on planting.

planting_month = 0.25

UNITS: year

DOCUMENT: The variable represents for which month of year that planting starts. As the simulation time is by year, 0.25 means planting starts after 0.25 of time of the year.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data,

https://cast.chesapeakebay.net/Home/SourceData
planting_time = TIME

UNITS: year

DOCUMENT: The variable represents for the time for planting, it equals the time.

Price = IF SWITCH_for_Price =1 THEN with_price_prediction_1_stable_after_2021 ELSE with_price_prediction_2_price_cycle_assumption_after_2021

UNITS: dollar/bushel

DOCUMENT: The price comes from the historical price, Eastern Upland Corn Price, from USDA and the estimation after year of 2021.

Data source:

U.S. Department of Agriculture,2023, https://www.ers.usda.gov/

price_estimate_after_2021 = GRAPH(TIME)
Points: (2021.000, 5.15), (2021.900, 5.71), (2022.800, 6.40), (2023.700, 6.83), (2024.600, 7.04), (2025.500, 6.72), (2026.400, 6.03), (2027.300, 5.34), (2028.200, 5.19), (2029.100, 5.13), (2030.000, 5.13)

UNITS: dollar/bushel

DOCUMENT: It shows the price after 2021 is estimated by the trend of price cycles with a period of 10 years.

price_received_by_farmer_USDA = GRAPH(TIME)
Points: (2000.00, 1.85), (2001.42857143, 1.97), (2002.85714286, 2.32), (2004.28571429, 2.42), (2005.71428571, 2.06), (2007.14285714, 2.00), (2008.57142857, 3.04), (2010.00, 4.20), (2011.42857143, 4.06), (2012.85714286, 3.55), (2014.28571429, 5.18), (2015.71428571, 6.22), (2017.14285714, 6.89), (2018.57142857, 4.46), (2020.00, 3.70), (2021.42857143, 3.61), (2022.85714286, 3.36), (2024.28571429, 3.36), (2025.71428571, 3.61), (2027.14285714, 3.56), (2028.57142857, 4.53), (2030.00, 5.95)

UNITS: dollar/bushel

DOCUMENT: The variable represents for the historical data from USDA which shows corn price received by farmer in U.S. We use it to adjust the short-term price expectation. Though this variable is used for national corn price, it supplies changing trend for corn price in Eastern Upland.

production = harvest_rate*Nitrogen_Application.yield_by_structure/per_year

UNITS: bushel/Years

DOCUMENT: The variable shows yearly production, which is the product of harvest and yield.

production_capacity = capital_stock*capital_productivity

UNITS: Acres/Years

DOCUMENT: production capital shows the production achievement ability of the capital by the capital avaliable at present. It is the division of capital stock and the capital productivity.

proportion_for_corn_land_not_effected_by_preservation_policy = 1-corn_planting_land_under_preservation

UNITS: unitless

DOCUMENT: The proportion shows the part of corn land that is not effected by preservation policy.

Proportion_of_Corns_in_Grains = 0.95

UNITS: unitless

DOCUMENT: The variables shows a normal proportion of corn in grains in the U.S. data source from USDA.

U.S. Department of Agriculture,2023, “Feed Grains Sector at a Glance”

https://www.ers.usda.gov/topics/crops/corn-and-other-feed-grains/feed-grains-sector-at-a-glance/
proportion_of_land_in_preservation = total_land_in_preservation_in_Frederick/farming_land_in_Frederick

UNITS: unitless

DOCUMENT: The variable is the proportion of how much farming land has been preserved by policies. It is the ratio of total land in preservation and the farming land.

Proportion_of_large_farm_in_total_land = 0.7

UNITS: unitless

DOCUMENT: The parameter of proportion of large farm is total land is evaluated from 50% ~70%, by the resource as following. This range would be tested in sensitivity test.

The principle comes from :

James M. MacDonald, Robert A. Hoppe, and Doris Newton, March,2018, USDA, Three Decades of Consolidation in U.S. Agriculture

"Consolidation was persistent: midpoint farm sizes increased in every inter-census period in 24 States that together accounted for nearly 77 percent of all U.S. cropland—Corn Belt, Delta, and Northern Plains States with dense concentrations of production" p32

This indicates that farm sizes have a general upgrade in the whole U.S. Here we assume as 0.7 for simulation. By adjusting this proportion we can see how this change on farm level could effect the commodity production for this type of plants.

"reference_planting_acres_2000_(corn)" = 20000

UNITS: acre

DOCUMENT: The variable is an historical planting acres in 2000.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, 2023, https://cast.chesapeakebay.net/Home/SourceData

relative_animal_scale = Nitrogen_Application.animal_scales/Nitrogen_Application.reference_animal_scales

UNITS: unitless

DOCUMENT: The variable shows a ratio of Animal scales to reference animal scales.

Rural_Legacy = GRAPH(TIME)

Points: (1997.00, 0), (1997.89655172, 231), (1998.79310345, 462.1), (1999.68965517, 693.1), (2000.5862069, 924.1), (2001.48275862, 1155), (2002.37931034, 1386), (2003.27586207, 1617), (2004.17241379, 1848), (2005.06896552, 2079), (2005.96551724, 2310), (2006.86206897, 2541), (2007.75862069, 2772), (2008.65517241, 3003), (2009.55172414, 3234), (2010.44827586, 3466), (2011.34482759, 3697), (2012.24137931, 3928), (2013.13793103, 4159), (2014.03448276, 4390), (2014.93103448, 4621), (2015.82758621, 4852), (2016.72413793, 5083), (2017.62068966, 5314), (2018.51724138, 5545), (2019.4137931, 5776), (2020.31034483, 6007), (2021.20689655, 6238), (2022.10344828, 6469), (2023.00, 6700)

UNITS: Acres

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

Frederick County Government. (2023b). Agricultural Preservation. https://www.frederickcountymd.gov/7980/Agricultural-Preservation

Smoothed_effect_by_expected_profitability = SMTH3(final_effect_of_expected_profitability_of_new_investment, adjustment_time_for_effect_by_expected_profitability)

UNITS: unitless

DOCUMENT: The variable shows a Smoothed effect by expected profitability on desired capital with an adjustment delay, as the capital decision makers or producers need time to accept for the change of profitability.

SMTH_indicated_capacity_utilization = SMTH3(indicated_capacity_utilization, adjustment_time_for_utilization) {DELAY CONVERTER}

UNITS: unitless

DOCUMENT: It reflects the the acceptance course for farmers to get and decide on indicted capital utilization under an adjustment time. So the equation is a smooth of indicated capacity utilization with utilization adjustment time.

SWITCH_animal_scale_to_planting = 1

UNITS: unitless

DOCUMENT: Switch=1, there is effect of animal scale;

Switch =0, there is no effect of animal scale

SWITCH_for_Price = 1

UNITS: unitless

DOCUMENT: The switch gives two policy for price after 2021:

1 The price is given as the average of last year of historical price.

2 The price is given as an estimated shape based by assumption of price cycles in the past 20 years.

SWITCH_land_preservation = 1

UNITS: unitless

DOCUMENT: Switch=1, there is effect of land preservation policy;

Switch =0, there is no effect of land preservation policy.

Time_to_adjust_expected_price = 1.6

UNITS: year

DOCUMENT: The variable represents for the time to get a short-term expected price by farmers, which is assumed to be no longer than 3 years.

It is set by a comparison with the price received by farmer from USDA-National Agricultural Status Service.

We assume it as 1.6 years.

https://www.ers.usda.gov/topics/crops/corn-and-other-feed-grains/feed-grains-sector-at-a-glance/

It is also indicated by Meadows, 1971, Dynamics of commodity production 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 from Bean, L. H. (1929). The Farmer’s response to Price. Journal of Farm Economics, Vol. 11. 1929, AgEcon Search. https://ageconsear.umn.edu

So assume a value around 1 - 2 years can be reasonable range and we pick up for 1.6 by the indication from comparison of historical data of USDA.

"Time_to_adjust_long-term_expected_cost" = 6

UNITS: year

DOCUMENT: It shows the time for capital decider to get a long-term expected cost, which is assumed to be longer than short-term time to be accepted by farmer or producer.

Capital adjustment refers to all the related resource management and upgrade, which is much complex than the decision for utilization rate. So it is assumed to be longer than the price accepting time by farmer or producer. It is set no shorter than 5 years. We use 6 years here, which is half of a circle of cattle cycles as the plant is mainly used for feeding cattle.

The value is an estimation, which refers to parameters/ delays discussion of Sterman in Business Dynamics, Chapter 20.

"Time_to_adjust_long-term_expected_price" = 6

UNITS: year

DOCUMENT: The variable represents for the delay time for capital deciders to get a long-term expected price because they need integrate the information and estimate an trend from the past few years of price and cost. Capital adjustment refers to all the related resource management and upgrade, which is much complex than the decision for utilization rate. So it is assumed to be longer than the price accepting time by farmer or producer. It is set no shorter than 5 years. We use 6 years here, which is half of a circle of cattle cycles as the plant is mainly used for feeding cattle.

The value is an estimation, which refers to parameters/ delays discussion of Sterman in Business Dynamics, Chapter 20.

Time_to_adjust_planting = adjustment_time_for_plants_in_land_by_large_farm*Proportion_of_large_farm_in_total_land+adjustment_time_for_plants_in_land_by_normal_farm*(1-Proportion_of_large_farm_in_total_land)

UNITS: year

DOCUMENT: The variables represents for the general adjustment time that farmers need to adjust the planting land or change planting types. It is the average of adjustment time from two type of farm sizes with their corresponding proportion.

"Time_to_adjust_short-term_expected_cost" = 2

UNITS: year

DOCUMENT: The variable represents for the time to get a short-term expected cost by farmers, which is assumed to be no longer than 3 years. We assume the farmers would estimate variable cost or operational cost of the recent two years.

The value is an estimation, which refers to parameters/ delays discussion of Sterman in Business Dynamics, Chapter 20.

It is also indicated by Meadows, 1971, Dynamics of commodity production 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".

So we assume a 2 years' delay is a reasonable value.

Sterman, J. D. (2000d). Business dynamics: systems thinking and modeling for a complex world (pp. XXVI, 982). Irwin McGraw-Hill. Chapter 16: Modeling Expectation Formation. p631-p634

total_cost = IF TIME<21 OR TIME=21 THEN "total_cost_1996-2021" ELSE (HISTORY("total_cost_1996-2021", TIME-1)+HISTORY("total_cost_1996-2021", TIME-2)+HISTORY("total_cost_1996-2021", TIME-3))/3 { 8.03}

UNITS: dollar/bushel

DOCUMENT: The variable means the total cost for corn planting. The data before 2021 comes from historical data of USDA, and the data after 2021 comes from average cost of the last three years.

"total_cost_1996-2021" = GRAPH(TIME)

Points: (2000.00, 2.92), (2000.84, 3.46), (2001.68, 3.08), (2002.52, 3.64), (2003.36, 2.91), (2004.20, 3.31), (2005.04, 4.43), (2005.88, 3.32), (2006.72, 3.07), (2007.56, 3.25), (2008.40, 2.85), (2009.24, 3.49), (2010.08, 4.09), (2010.92, 3.41), (2011.76, 3.52), (2012.60, 4.16), (2013.44, 6.32), (2014.28, 3.63), (2015.12, 3.76), (2015.96, 3.53), (2016.80, 3.64), (2017.64, 3.15), (2018.48, 3.44), (2019.32, 3.53), (2020.16, 3.25), (2021.00, 3.37)

UNITS: dollar/bushel

DOCUMENT: The data comes from external data from USDA--

Corn production costs and returns per planted acre, excluding Government payments, Eastern Uplands, Total cost.

total_land_in_preservation_in_Frederick = Agricultural_preservation+Critical_farms+Critical_farms+installment_purchase_program+Maryland_Agricultural_Land_Preservation_Foundation_MALPF+Rural_Legacy+Conservation_reserve_enhancement_program

UNITS: Acres

DOCUMENT: The variable represents for the total land under preservation policies in Frederick. It is the sum of all the polices conducted in the past years.

Frederick County Government. (2023b). Agricultural Preservation. https://www.frederickcountymd.gov/7980/Agricultural-Preservation

trigger_planting = IF TIME MOD 1=planting_month THEN 1 ELSE 0

UNITS: unitless

DOCUMENT: The variable means the only in the specific month that planting would starts. The equitation limits the specific month that planting can be given.

variable_cost = IF TIME<2021 OR TIME=2021 THEN "variable_cost_2000-2021" ELSE HISTORY("variable_cost_2000-2021", 2021)

UNITS: dollar/bushel

DOCUMENT: This variable represents for the variable cost of corn planting. It equals historical data from USDA before 2022 and from estimation after 2022.

"variable_cost_2000-2021" = GRAPH(TIME)

Points: (2000.00, 1.40), (2000.84, 1.60), (2001.68, 1.39), (2002.52, 1.62), (2003.36, 1.29), (2004.20, 1.57), (2005.04, 2.01), (2005.88, 1.59), (2006.72, 1.47), (2007.56, 1.69), (2008.40, 1.54), (2009.24, 1.93), (2010.08, 2.47), (2010.92, 2.00), (2011.76, 1.93), (2012.60, 2.40), (2013.44, 3.61), (2014.28, 2.05), (2015.12, 2.09), (2015.96, 1.87), (2016.80, 2.08), (2017.64, 1.74), (2018.48, 1.88), (2019.32, 1.94), (2020.16, 1.72), (2021.00, 1.81)

UNITS: dollar/bushel

DOCUMENT: The data comes from external data from USDA--

Corn production costs and returns per planted acre, excluding Government payments, Eastern Uplands, Operational cost.

Data source:

U.S. Department of Agriculture,2023, https://www.ers.usda.gov/

with_price_prediction_1_stable_after_2021 = IF TIME<2022 THEN "historical_price_1996-2021" ELSE HISTORY("historical_price_1996-2021", 2021)

UNITS: dollar/bushel

DOCUMENT: The variable describes that before 2021 the simulation refers to historical data and after 2021 the price is assumed to be steady as the level of 2021.

with_price_prediction_2_price_cycle_assumption_after_2021 = IF TIME< 2022 THEN"historical_price_1996-2021" ELSE price_estimate_after_2021

UNITS: dollar/bushel

DOCUMENT: The variable describes that before 2021 the simulation refers to historical data and after 2021 the price is estimated by the trend of price cycles with a period of 10 years. The shape is captured from the historical price data trend.

year = 1

UNITS: year

DOCUMENT: The variable is used to diminish the unit property of planting increase as inflow, in order to calculate the total N application. As planting increase is valued as acres/year in commodity structure and o N application / N Load are valued as pound/acre/year as flows, when we calculate total N application or N load there would be pound/year2. This is unit error in Stella but it does not effect our simulation result. So we use the variable to achieve a proper unit.

2.3 Nitrogen_Application:

buffer_area(t) = buffer_area(t - dt) + (N_increase_in_buffer) * dt

INIT buffer_area = 0

UNITS: pound/acre

DOCUMENT: The stock of buffer area represents for the N accumulation in the buffer area that can absorb the N load by human-made buffer area under BMP policy or natural buffer area like forest, wetland.

Demand_N_input_for_land_with_manure(t) = Demand_N_input_for_land_with_manure(t - dt) + (increase_rate_of_N_demand_to_manure_land) * dt

INIT Demand_N_input_for_land_with_manure = reference_total_demand_N_for_land_with_manure

UNITS: pound/acre

DOCUMENT: The stock of perceived demand N input for land without manure means how farmers perceive the information of N demanded from the effect of yield expectation with the fixed delayed time. The original value is assumed as 140, which equals the reference demand N of Year 2000.

Demand_N_input_for_land_without_manure(t) = Demand_N_input_for_land_without_manure(t - dt) + ("increase_rate_of_N_demand_to_non-manure_land") * dt

INIT Demand_N_input_for_land_without_manure = reference_total_demand_N_for_land_without_manure

UNITS: pound/acre

DOCUMENT: The stock of perceived demand N input for land without manure means how farmers perceive the information of N demanded from the effect of yield expectation with the fixed delayed time. The original value is assumed as 130, which equals the reference demand N of 2000.

humus_in_land_with_manure(t) = humus_in_land_with_manure(t - dt) + (humification - "humus_oxidation/decomposition_in_manure_land") * dt

INIT humus_in_land_with_manure = initial_humus_in_land_with_manure

UNITS: pound/acre

DOCUMENT: The humus stock is used to capture the other parts of soil quality expect for the nutrient level by Surface N. It includes the texture, structure and organic conditions of soil quality. In practice, there is complex change on these properties of soil. As we do have enough experience or theory to capture these changes, we toughly use one inflow of humification rate and an outflow of oxidation, decomposition rate to model the change of humus condition.

The stock variable humus soil represents for the stock that accumulates the humification rate and is depleted by oxidation and decomposition. The initial humus soil level is set as 10000 pounds. The stock is used to compare the difference of soil quality change under manure use and only fertilizer use.

humus_in_land_without_manure(t) = humus_in_land_without_manure(t - dt) + (humification_in_land_without_manure -

"humus_oxidation/decomposition_in_land_without_manure") * dt

INIT humus_in_land_without_manure = initial_humus_in_land_without_manure

UNITS: pound/acre

DOCUMENT: The humus stock is used to capture the other parts of soil quality expect for the nutrient level by Surface N. It includes the texture, structure and organic conditions of soil quality. In practice, there is complex change on these properties of soil. As we do have enough experience or theory to capture these changes, we toughly use one inflow of humification rate and an outflow of oxidation, decomposition rate to model the change of humus condition.

The stock variable humus soil represents for the stock that accumulates the humification rate and is depleted by oxidation and decomposition. The initial humus soil level is set as 10000 pounds. The stock is used to compare the difference of soil quality change under manure use and only fertilizer use.

N_in_Potomac(t) = N_in_Potomac(t - dt) + (load_from_runoff_from_land_with_manure + load_from_runoff_from_land_without_manure - N_moving_to_bay) * dt

INIT N_in_Potomac = 10

UNITS: pound/acre

DOCUMENT: The N in Potomac is the stock that accumulates the N load from plant land and is depleted by the water moving to the bay. We set original level as 10 pounds/acre. It does not contain practical meaning but helps to simulates the model. We could see the value from 2000 as normal simulation result and the period we concern.

Notice the two inflow means there is N from 1 acre of land with manure and land without manure to Potomac river every simulation time.

surface_N_in_land_with_manure(t) = surface_N_in_land_with_manure(t - dt) + (N_increase_for_land_with_manure + residue_return_to_manure_land - N_uptake_in_land_with_manure - N_runoff_and_leaching_from_land_with_manure - N_loss_by_volatilization_in_manure_land) * dt

INIT surface_N_in_land_with_manure = 70

UNITS: pound/acre

DOCUMENT: The stock of surface N in land with manure represents for the surface N level in manure land, which accumulates the N increase from N application from manure both and fertilizer, and N from residue return. The stock is depleted by the outflow of uptake by plants in land, volatilization and N runoff and leaching. In the model we ignore the other types of N loss from surface N.

We assume the original value of the stock is 70 pounds per acre in land, when the model starts simulation in 1996. It will effects a little on the N uptake as it effects scarcity but it will not effect the main simulation result after the year of 2000.

surface_N_in_land_without_manure(t) = surface_N_in_land_without_manure(t - dt) + (N_increase_for_land_without_manure + residue_return_to_land_without_manure - N_uptake_in_land_without_manure - N_runoff_and_leaching_from_land_without_manure - N_loss_by_volatilization_in_no_manure_land) * dt

INIT surface_N_in_land_without_manure = 60

UNITS: pound/acre

DOCUMENT: The stock of surface N in land without manure represents for the surface N level in no manure land, which accumulates the N increase from N application from only fertilizer, and N from residue return. The stock is depleted by the outflow of uptake by plants in land, volatilization and N runoff and leaching.In the model we ignore the other types of N loss from surface N.

We assume the original value of the stock is 60 pounds per acre in land, when the model starts simulation in 1996. It is a little lower than the value in land with manure as inorganic N cannot stay in the surface soil for long time or stay in the soil.

It will effects in a few years on the N uptake as it effects scarcity but it will not effect the main simulation result after 2000 that we concern.

humification = normal_proportion_of_humification_rate_with_75%_of_maximum_return*DELAY_effect_of_residue_return_to_humification_in_manure_land*humus_in_land_with_manure*DELAY_effect_of_N_input_on_humification_in_manure_land*DELAY_effect_by_manure_input_on_humification*effect_of_humus_limit_on_humification

UNITS: pound/acre/year

DOCUMENT: The flow of humification is the inflow that shows how humification process that accumulates the humus stock. In natural environment, it comes from natural dead plants and animals. In farming land, it comes from residue return to humus. So it is the product of humus stock, its proportion under normal residue return, effect from residue to land and effect from humus limit by humus capacity.

We assume when there is normal residue return rate, the inflow of humification just equals the outflow of oxidation by no tillage or all preservation tillage. When there is more oxidation, people should increase the inflow of humification rate to keep the humus steady. Or the stock of humus will decrease decreasingly or fade with a farming activity.

humification_in_land_without_manure = humus_in_land_without_manure*normal_proportion_of_humification_rate_with_75%_of_maximum_return*DELAY_effect_of_fertilizer_use_on_on_humification_in_land_without_manure*effect_of_humus_limit_on_humification_in_land_without_manure*DELAY_effect_of_residue_to_land_without_manure

UNITS: pound/acre/year

DOCUMENT: The flow of humification is the inflow that shows how humification process that accumulates the humus stock. In natural environment, it comes from natural dead plants and animals. In farming land, it comes from residue return to humus. So it is the product of humus stock, its proportion under normal residue return, effect from residue to land and effect from humus limit by humus capacity.

We assume when there is normal residue return rate, the inflow of humification just equals the outflow of oxidation by no tillage or all preservation tillage. When there is more oxidation, people should increase the inflow of humification rate to keep the humus steady. Or the stock of humus will decrease decreasingly or fade with a farming activity.

"humus_oxidation/decomposition_in_land_without_manure" =

humus_in_land_without_manure*normal_proportion_of_loss_by_oxidation_and_decomposition*effect_from_tillage_in_land_without_manure {UNIFLOW}

UNITS: pound/acre/year

DOCUMENT: The variable of humus oxidation represents for the oxidation and decomposition process deplete humus in land with the effect of tillage and natural erosion. It is the product of normal proportion of loss by oxidation and effect from tillage in land. When the effect is higher than normal, the humus oxidation speed will be fasten and more quickly depletes the stock of humus, then soil quality is falling fast. With a lower effect of tillage, the outflow can be as low as the normal proportion of loss per year, and the loss can be even lower than the inflow increase from residue return, which finally cause the steady or even increase of humus stock in land.

"humus_oxidation/decomposition_in_manure_land" = humus_in_land_with_manure*normal_proportion_of_loss_by_oxidation_and_decomposition*effect_from_tillage_activity_on_manure_land {UNIFLOW}

UNITS: pound/acre/year

DOCUMENT: The variable of humus oxidation represents for the oxidation and decomposition process deplete humus in land with the effect of tillage and natural erosion. It is the product of normal proportion of loss by oxidation and effect from tillage in land. When the effect is higher than normal, the humus oxidation speed will be fasten and more quickly depletes the stock of humus, then soil quality is falling fast. With a lower effect of tillage, the outflow can be as low as the normal proportion of loss per year, and the loss can be even lower than the inflow increase from residue return, which finally cause the steady or even increase of humus stock in land.

increase_rate_of_N_demand_to_manure_land = (reference_total_demand_N_for_land_with_manure*effect_of_expected_yield_to_demand_N_application-Demand_N_input_for_land_with_manure)/time_to_shape_N_demand

UNITS: pound/acre/year

DOCUMENT: The variable of increase rate of N demand of manure land is the inflow that fill in the demand N input for land with manure. It is the minus of expected demand and demand N in stock, divided by the time to adjust demand.

"increase_rate_of_N_demand_to_non-manure_land" = (reference_total_demand_N_for_land_without_manure*effect_of_expected_yield_to_demand_N_application-Demand_N_input_for_land_without_manure)/time_to_shape_N_demand

UNITS: pound/acre/year

DOCUMENT: The variable of increase rate of N demand of non-manure land is the inflow that fill in the demand N input for land without manure. It is the minus of expected demand and demand N in stock, divided by the time to adjust demand.

load_from_runoff_from_land_with_manure = N_runoff_and_leaching_from_land_with_manure*proportion_of_final_load_from_runoff_and_leaching

UNITS: pound/acre/year

DOCUMENT: The inflow of load from runoff with manure represents for the N is running off from manure land and loading to waters. It is the final load we concern to edge of stream. It is the product of N leaching and runoff and the production of final load from runoff and leaching. With a higher N leaching and runoff or proportion, the inflow will increase. With a lower runoff and leaching or lower proportion loading to waters, the inflow will decrease.

It indicates we could decrease the inflow from decreasing N running off form land with manure or increase the buffer proportion which decrease the final loading proportion.

load_from_runoff_from_land_without_manure = proportion_of_final_load_from_runoff_and_leaching*N_runoff_and_leaching_from_land_without_manure

UNITS: pound/acre/year

DOCUMENT: The inflow of load from runoff with manure represents for the N is running off from land without manure and loading to waters. It is the final load we concern to edge of stream. It is the product of N leaching and runoff and the production of final load from runoff and leaching. With a higher N leaching and runoff or proportion, the inflow will increase. With a lower runoff and leaching or lower proportion loading to waters, the inflow will decrease.

It indicates we could decrease the inflow from decreasing N running off form land without manure or increase the buffer proportion which decrease the final loading proportion.

N_increase_for_land_with_manure = total_N_input_per_acre_for_land_with_manure/time_period

UNITS: pound/acre/year

DOCUMENT: The variable of N increase for land with manure means the inflow that fill N to the surface N in land with manure and fertilizer. It reflects how fast the surface N is filled. It is the product of the total N input per acre for land with manure divided by time period as one year.

N_increase_for_land_without_manure = total_N_input_per_acre_for_land_without_Manure/time_period

UNITS: pound/acre/year

DOCUMENT: The variable of N increase for land without manure means the inflow that fill N to the surface N in land with manure . It reflects how fast the surface N is filled. It is the product of the total N input per acre for land without manure divided by time period as one year.

N_increase_in_buffer = N_runoff_and_leaching_from_land_with_manure*proportion_of_load_to_buffer+N_runoff_and_leaching_from_land_without_manure*proportion_of_load_to_buffer

UNITS: pound/acre/year

DOCUMENT: The N increase in buffer is the inflow that takes the N from runoff and leaching to the buffer area and accumulates the buffer area. It is the sum of flow of N runoff and leaching from two types of land and proportion of load to buffer.

N_loss_by_volatilization_in_manure_land = surface_N_in_land_with_manure*proportion_of_volatilization_in_manure_land {UNIFLOW}

UNITS: pound/acre/year

DOCUMENT: The outflow represents for how much N in surface soil is depleted by volatilization in manure land. It reflects how fast the volatilization decreases the stock of surface N. It is the product of surface N in land and proportion of volatilization in manure land.

N_loss_by_volatilization_in_no_manure_land = surface_N_in_land_without_manure*proportion_of_volatilization_in_manure_land {UNIFLOW}

UNITS: pound/acre/year

DOCUMENT: The outflow represents for how much N in surface soil is depleted by volatilization in land without manure. It reflects how fast the volatilization decreases the stock of surface N. It is the product of surface N in land and proportion of volatilization in land without manure.

N_moving_to_bay = MAX(0, N_in_Potomac*proportion_of_N_moving_soon_to_bay/time_to_bay) {UNIFLOW}

UNITS: pound/acre/year

DOCUMENT: The flow of nutrient moving to bay represents the outflow that deplete the nitrogen in river and move to bay. As we only consider the N that moves with water , so it is the ratio of proportional of N in Potomac river and the time moving from river to bay.

N_runoff_and_leaching_from_land_with_manure = surface_N_in_land_with_manure*normal_proportion_of_load_loss*"effect_of_soil_erosion_(RULSE)_to_land_with_manure" {UNIFLOW}

UNITS: pound/acre/year

DOCUMENT: The variable of N runoff and leaching represents for the outflow that depletes the N in land with manure. It reflects how fast the N is lost by runoff and leaching. It is the product of stock of surface N and the production of normal proportion of load loss.

N_runoff_and_leaching_from_land_without_manure = surface_N_in_land_without_manure*normal_proportion_of_load_loss*"effect_of_soil_erosion_(RULSE)_to_land_without_manure" {UNIFLOW}

UNITS: pound/acre/year

DOCUMENT: The variable of N runoff and leaching represents for the outflow that depletes the N in land without manure. It reflects how fast the N is lost by runoff and leaching. It is the product of stock of surface N and the production of normal proportion of load loss.

N_uptake_in_land_with_manure = surface_N_in_land_with_manure*normal_proportion_of_uptake_in_manure_land*effect_on_N_uptake_in_manure_land

UNITS: pound/acre/year

DOCUMENT: The outflow of Uptake by plants is the outflow that deplete surface N by plants absorption. It reflects how much N is used for the farmers' target for plant growth.

With a fixed normal proportion, the higher N in land or higher effect from scarcity can increase the outflow. The lower N in land or lower effect from scarcity can decrease the inflow of the uptake by plants.

N_uptake_in_land_without_manure = surface_N_in_land_without_manure*N_application_effect_uptake_without_manure*normal_proportion_of_uptake_without_manure

UNITS: pound/acre/year

DOCUMENT: The outflow of Uptake by plants is the outflow that deplete surface N by plants absorption. It reflects how much N is used for the farmers' target for plant growth.

With a fixed normal proportion, the higher N in land or higher effect from scarcity can increase the outflow. The lower N in land or lower effect from scarcity can decrease the inflow of the uptake by plants.

residue_return_to_land_without_manure = total_residue_return_prop_to_land_without_manure*yield_by_structure*N_content_of_corn_residue*proportion_of_residue_to_total_plant

UNITS: pound/acre/year

DOCUMENT: The flow of residue return represents for an inflow from residue return that accumulates the nutrient to soil surface. It shows the process of residue of plant is returned to land and support nutrient to soil surface. It is the product of nutrient uptake by plant and the proportion of nutrient return as well as proportion of residue in total land. We use a tough estimation and assume the N content for dry residue is the same to the N content in corn yield part.

residue_return_to_manure_land = yield_by_structure*N_content_of_corn_residue*total_residue_return_to_manure_land*proportion_of_residue_to_total_plant

UNITS: pound/acre/year

DOCUMENT: The flow of residue return represents for an inflow from residue return that accumulates the nutrient to soil surface. It shows the process of residue of plant is returned to land and support nutrient to soil surface. It is the product of nutrient uptake by plant and the proportion of nutrient return as well as proportion of residue in total land. We use a tough estimation and assume the N content for dry residue is the same to the N content in corn yield part.

Residue return only takes small part of N supplement for surface N. It is used more for soil humus preservation and prevent soil erosion from adding cover proportion.

animal_scales = GRAPH(TIME)

Points: (2000.00, 104.7), (2000.86206897, 104.7), (2001.72413793, 104.7), (2002.5862069, 104.7), (2003.44827586, 104.7), (2004.31034483, 99.9), (2005.17241379, 98.7), (2006.03448276, 92.9), (2006.89655172, 90.6), (2007.75862069, 82.7), (2008.62068966, 77.3), (2009.48275862, 72.1), (2010.34482759, 73.0), (2011.20689655, 73.8), (2012.06896552, 74.5), (2012.93103448, 75.6), (2013.79310345, 75.8), (2014.65517241, 73.3), (2015.51724138, 71.3), (2016.37931034, 69.3), (2017.24137931, 67.5), (2018.10344828, 65.4), (2018.96551724, 61.9), (2019.82758621, 59.2), (2020.68965517, 59.2), (2021.55172414, 59.2), (2022.4137931, 59.2), (2023.27586207, 59.2), (2024.13793103, 59.2), (2025.00, 59.2)

UNITS: thousand AU

DOCUMENT: The variable contains historical change on animal scales. We calculated three kinds of main cattle in the county: dairy, beef and other cattle.

Chesapeake Assessment and Scenario Tool (CAST). (2023). Phase 6 Source Data. Chesapeake bay Program. https://cast.chesapeakebay.net/Home/SourceData

Assuming_Target_proportion_of_N_to_buffer = 0.1

UNITS: unitless

DOCUMENT: The variable estimates an proportion for the buffer policy Target. As we cannot find exact buffer beneficial for corn grain planting area in Fredick, we toughly refer to the WIP 2025 achievement report and Potomac river report, which indicates that Buffer policy target is much lower than other policy and the present achievement is just 0,9. So we assume the target is around 0.1, the present achievement is 0.01.

Source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

Chesapeake Progress, 2025 Watershed Implementation Plans (WIPs), https://www.chesapeakeprogress.com/clean-water/watershed-implementation-plans

Keisman, J., Murphy, R. R., Devereux, O.H., Harcum, J., Karrh, R., Lane, M.,

Perry, E., Webber, J., Wei, Z., Zhang, Q., Petenbrink, M. 2020. Potomac Tributary Report: A summary of trends in tidal water quality and associated factors. Chesapeake Bay Program, Annapolis MD.

By_2022_proportion_of_N_to_buffer = 0.01

UNITS: unitless

DOCUMENT: The variable estimates an proportion for the buffer policy achieved by 2022. As we cannot find exact buffer beneficial for corn grain planting area in Fredick, we toughly refer to the WIP 2025 achievement report and Potomac river report, which indicates that Buffer policy target is much lower than other policy and the present achievement is just 0,9. So we assume the target is around 0.1, the present achievement is 0.01.

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

Chesapeake Progress, 2025 Watershed Implementation Plans (WIPs), https://www.chesapeakeprogress.com/clean-water/watershed-implementation-plans

By_2022_proportion_of_preservation_tillage = 0.91

UNITS: unitless

DOCUMENT: The variable presents for a preservation tillage level by 2022 in land.

Based on the data from CAST, by 2022, the average Plowing practice has covered 0.91 for Corn grain in Frederick, same on manure land and non-manure land. Plowing practice is most important tillage practice for soil preservation. So we assmue the present proportion has reached 0.91.

This also suits the WIP 2015 target achievement data, which shows preservation tillage has completed 93%.

Source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

Chesapeake Progress, 2025 Watershed Implementation Plans (WIPs), https://www.chesapeakeprogress.com/clean-water/watershed-implementation-plans

Keisman, J., Murphy, R. R., Devereux, O.H., Harcum, J., Karrh, R., Lane, M.,

Perry, E., Webber, J., Wei, Z., Zhang, Q., Petenbrink, M. 2020. Potomac Tributary Report: A summary of trends in tidal water quality and associated factors. Chesapeake Bay Program, Annapolis MD.

Potomac Tributary Report: A summary of trends in tidal water quality and associated factors, 1985-2018, December 18, 2020 Prepared for the Chesapeake Bay Program (CBP) Partnership by the

CBP Integrated Trends Analysis Team (ITAT)

By_2022_residue_return_proportion = 0.045

UNITS: unitless

DOCUMENT: The variable represents for the proportion of residue return by 2022, based on data from CAST.

Frederick-corn for grain, both manure and non-manure land show a cover faction of 0.08-0.09 from month of 10 to 2 the next year, which is winter period. As the residue is also used for cover. We use the lowest cover requirement for cropland as 30% (resource as follow). The target for cover is assumed to be over 30%, like 0.0-0.5.

From the WIP 2025 achievement report, the crops cover has completed for 51%. So we assume the residue return requirement has reached its 51%. We assume it corresponds to the largest residue return as 0.09. So we estimate the residue return rate at present is 0.51*0.09= 0.045, in winter half-year for corn grain in Frederick.

The 0.09 of residue return in residue is calculated as below.

From the reference below, we see with 125 bushels per acre, the highest residue return of corn is 0.4 *1200 pound dry round bald. The total residue of corn can be as high as 4.4 round bald. So the highest residue return proportion is 0.4/4.4. So highest proportion of residue return of corn is (0.4/4.4)*0.4 = 0.09. Here we don't calculate how much weight the residue return to humus but how much effect it gives to normal humufication rate, we only calculate the proportion of residue return to residue amount.

Principle comes from study findings of university of Minesota Extension.

https://extension.umn.edu/corn-harvest/crop-residue-management#how-it-relates-to-soil-productivity-1211761

This also suits the WIP 2015 target achievement data, which shows preservation tillage has completed 93%.

Source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

Chesapeake Progress, 2025 Watershed Implementation Plans (WIPs), https://www.chesapeakeprogress.com/clean-water/watershed-implementation-plans

Keisman, J., Murphy, R. R., Devereux, O.H., Harcum, J., Karrh, R., Lane, M., Perry, E., Webber, J., Wei, Z., Zhang, Q., Petenbrink, M. 2020. Potomac Tributary Report: A summary of trends in tidal water quality and associated factors. Chesapeake Bay Program, Annapolis MD.

Potomac Tributary Report: A summary of trends in tidal water quality and associated factors, 1985-2018, December 18, 2020 Prepared for the Chesapeake Bay Program (CBP) Partnership by the CBP Integrated Trends Analysis Team (ITAT)

calculated_demand_fertilizer_N_for_land_without_manure = Demand_N_input_for_land_with_manure-final_manure_N_input_for_land_with_manure

UNITS: pound/acre

DOCUMENT: The variable represents for a normal demand fertilizer N input level, which is minus of normal total demand N in manure land and the manure input. It is used to compare with the final fertilizer N input for land with manure, but not used as formulation of the total N input for land with manure.

capacity_of_humus_in_land = 20000

UNITS: pound/acre

DOCUMENT: The variable of capacity of humus represents for the largest mass of humus quantity that can accumulate and stay in the surface of land. It is decided by a multiple of factors, like soil property, climate and other environmental factors, which can not be changed by human behaviors. We consider it as the largest value that humus stock can reach and it would give an increasing limit to the humus in land.

As manure application could benefit humification, we assume that land with manure have a slightly higher capacity of humus compared than land without manure.

capacity_of_humus_in_land_without_manure = 18000

UNITS: pound/acre

DOCUMENT: The variable of capacity of humus represents for the largest mass of humus quantity that can accumulate and stay in the surface of land. It is decided by a multiple of factors, like soil property, climate and other environmental factors, which can not be changed by human behaviors. We consider it as the largest value that humus stock can reach and it would give an increasing limit to the humus in land.

As manure application could benefit humification, we assume that land with manure have a slightly higher capacity of humus compared than land without manure.

DELAY_effect_by_manure_input_on_humification = GRAPH(DELAY3(ratio_of_manure_input, 1))

Points: (0.000, 1.0000), (0.200, 1.0030), (0.400, 1.0110), (0.600, 1.0290), (0.800, 1.0670), (1.000, 1.1250), (1.200, 1.1830), (1.400, 1.2210), (1.600, 1.2390), (1.800, 1.2470), (2.000, 1.2500) {DELAY CONVERTER, GF EXTRAPOLATED}

UNITS: unitless

DOCUMENT: The variable represents for the effect of manure input prompts on humification. As we do not know the exact effect of manure in corn land in this area, we give a tough evaluation on the range.

A higher manure input proportion would give a higher effect of humification with a maximum effect value. If the manure input is twice of the reference input, the effect is assumed to increase decreasingly to its highest as 1.25. When there is half proportion as manure input, the effect is assumed as 1.125, which means the refernce manure input gives 1.125 of effect on the humification. When there is less manure input than reference level, the effect would fall down to 1 as humification also continue without manure. Even when the ratio is 0 which meaning no manure input, the humification will not be effected by this factor.

DELAY_effect_of_fertilizer_use_on_on_humification_in_land_without_manure = GRAPH(DELAY3(relative_N_input_in_land_without_manure, 3))
Points: (0.000, 1), (0.200, 0.9987), (0.400, 0.9957), (0.600, 0.9883), (0.800, 0.9732), (1.000, 0.95), (1.200, 0.9268), (1.400, 0.9117), (1.600, 0.9043), (1.800, 0.9013), (2.000, 0.9) {DELAY CONVERTER, GF EXTRAPOLATED}

UNITS: unitless

DOCUMENT: The table function describes how humification rate will be effected by the fertilizer N input with a 3 years delay.

As there is fertilizer input, there is normal harm to soil property. When N input is equal to demand level, the effect will be 0.95. When the N input is increasing to twice of demand, the humification rate will be decreasing to its 0.9. When N input is decreasing to 0, the effect will increase to 1, which means no N input would effect humus soil.

DELAY_effect_of_N_input_on_humification_in_manure_land = GRAPH(DELAY3(relative_N_input_in_land_with_manure, 3))
Points: (0.000, 1), (0.200, 0.9987), (0.400, 0.9957), (0.600, 0.9883), (0.800, 0.9732), (1.000, 0.95), (1.200, 0.9268), (1.400, 0.9117), (1.600, 0.9043), (1.800, 0.9013), (2.000, 0.9) {DELAY CONVERTER}

UNITS: unitless

DOCUMENT: The table function describes how humification rate will be effected by the N input from both manure and fertilizer with a 3 years delay. We toughly assmue there is difference of N from manure and fertilizer when surplus N harms the soil property.

As there is surplus N input, there is normal harm to soil property. When N input is equal to demand level, the effect will be 0.95. When the N input is increasing to twice of demand, the humification rate will be decreasing to its 0.9. When N input is decreasing to 0, the effect will increase to 1, which means no N input would effect humus soil.

DELAY_effect_of_residue_return_to_humification_in_manure_land = GRAPH(DELAY3(total_residue_return_to_manure_land/(maximum_residue_return_proportion*0.75), 1))
Points: (0.000, 0.000), (0.200, 0.02526), (0.400, 0.08682), (0.600, 0.2331), (0.800, 0.5352), (1.000, 1.000), (1.200, 1.465), (1.400, 1.767), (1.600, 1.913), (1.800, 1.975), (2.000, 2.000) {DELAY CONVERTER, GF EXTRAPOLATED}

UNITS: unitless

DOCUMENT: The variable shows a delayed effect for one year by the residue return to farming land. As the normal proportion of humification rate is corresponding to half maximum return. So we use residue return divided by 0.75 of maximum return.

When the residue return proportion is increasing to its twice times, the effect increases decreasingly to its highest as 2. When the return proportion is decreasing to 0, the effect to humification rate will be decreasing decreasingly to 0, which means there is no effect from residue to humification.

DELAY_effect_of_residue_to_land_without_manure = GRAPH(DELAY3(total_residue_return_prop_to_land_without_manure/(maximum_residue_return_proportion*0.75), 1))

Points: (0.000, 0.000), (0.200, 0.02526), (0.400, 0.08682), (0.600, 0.2331), (0.800, 0.5352), (1.000, 1.000), (1.200, 1.465), (1.400, 1.767), (1.600, 1.913), (1.800, 1.975), (2.000, 2.000) {DELAY CONVERTER, GF EXTRAPOLATED}

UNITS: unitless

DOCUMENT: The variable shows a delayed effect for one year by the residue return to farming land. As the normal proportion of humification rate is corresponding to half maximum return. So we use residue return divided by 0.75 of maximum return.

When the residue return proportion is increasing to its twice times, the effect increases decreasingly to its highest as 2. When the return proportion is decreasing to 0, the effect to humification rate will be decreasing decreasingly to 0, which means there is no effect from residue to humification.

effect_from_change_of_fertilizer_cost = SMTH3((fertilizer_cost/reference_fertilizer_cost_2000)^elasticity_of_fertilizer_demand_to_fertilizer_cost_change_for_land_without_manure, 0.5) {DELAY CONVERTER}

UNITS: unitless

DOCUMENT: The variables shows the cost change of fertilizer has effect on fertilizer N used in land without manure with 0.5 year's delay.

It is the elasticity as power to the ratio of fertilizer cost to reference fertilizer cost.

effect_from_fertilizer_cost_to_fertilizer_N_input_for_land_with_manure = SMTH3((fertilizer_cost/reference_fertilizer_cost_2000)^elasticity_of_fertilizer_demand_to_fertilizer_cost_change_for_land_with_manure, 0.5) {DELAY CONVERTER}

UNITS: unitless

DOCUMENT: The variables shows the cost change of fertilizer has effect on fertilizer N used in manure land with 0.5 year's delay.

It is the elasticity as power to the ratio of fertilizer cost to reference fertilizer cost.

Effect_from_manure_application = relative_animal_scale^elasticity_of_manure_input_to_change_of_animal_supply

UNITS: unitless

DOCUMENT: The variable represents for that how animal scale changes in the county can effect the manure application in corn. We use elasticity as power to relative animal scale change to capture the effect.

effect_from_plant_type_factor_in_land_with_manure = 1

UNITS: unitless

DOCUMENT: The variable represents for the effect by plant type on soil erosion. Different plants show a different soil fixation ability by the varied root system ability. At present, we only consider about corn and ignore the type change of corn, so we set it as 1.

effect_from_tillage_activity_on_manure_land = GRAPH(IF SWITCH_for_Tillage=0 THEN proportion_of_half_preservation_tillage ELSE IF SWITCH_for_Tillage=1 THEN By_2022_proportion_of_preservation_tillage ELSE proportion_of_full_preservation_tillage)

Points: (0.000, 2.000), (0.100, 1.987), (0.200, 1.957), (0.300, 1.883), (0.400, 1.732), (0.500, 1.500), (0.600, 1.268), (0.700, 1.117), (0.800, 1.043), (0.900, 1.013), (1.000, 1.000)

UNITS: unitless

DOCUMENT: The table function shows the decreasing effect that tillage activity has on humus oxidation and decomposition. The original humus oxidation is 0.05 when there is no any tillage or all tillage is preservation tillage type. As long as there is traditional tillage , it starts to increase.

When there is 0.5 of preservation tillage, 0.5 for traditional tillage, the effect on oxidation rate is assumed as 1.5 times of original rate. When the preservation is increasing to 1, there is less traditional tillage, the effect would be decreasing as much as 1. But when the preservation is less than 0.5 which means over half tillage is traditional tillage, the humus oxidation speed will be increasing to 2.

The range is estimated by an assumption of tillage effects humus oxidation but it will not totally determine it.

The principle comes to literature Saysel, A. K. (2004). System dynamics model for integrated environmental assessment of large scale surface irrigation.

effect_from_tillage_in_land_without_manure = GRAPH(IF SWITCH_for_Tillage=0 THEN proportion_of_half_preservation_tillage ELSE IF SWITCH_for_Tillage=1 THEN By_2022_proportion_of_preservation_tillage ELSE proportion_of_full_preservation_tillage)

Points: (0.000, 1.500), (0.100, 1.487), (0.200, 1.457), (0.300, 1.383), (0.400, 1.232), (0.500, 1.000), (0.600, 0.7676), (0.700, 0.6165), (0.800, 0.5434), (0.900, 0.5126), (1.000, 0.500)

UNITS: unitless

DOCUMENT: The table function shows the decreasing effect that tillage activity has on humus oxidation and decomposition. The original and natural humus oxidation like by wind and rain erosion is 0.05, when there is no any tillage or all tillage is preservation tillage type. As long as there is traditional tillage , it starts to increase.

When there is 0.5 of preservation tillage, 0.5 for traditional tillage, the effect on oxidation rate is assumed as 1.5 times of original rate. When the preservation is increasing to 1, there is less traditional tillage, the effect would be decreasing as much as 1. But when the preservation is less than 0.5 which means over half tillage is traditional tillage, the humus oxidation speed will be increasing to 2.

The range is estimated by an assumption of tillage effects humus oxidation but it will not totally determine it.

The principle comes to literature Saysel, A. K. (2004). System dynamics model for integrated environmental assessment of large scale surface irrigation.

effect_of_expected_yield_to_demand_N_application = (expected_yield/reference_yield_2000)^elasticity_of_N_demand_to_expected_field

UNITS: unitless

DOCUMENT: It shows how the demand N application will be effected by the change of expected yield change. As we would include price factor, soil factor and planting factor later in the formulation, here we only need to consider about the effect of expected yield to N demand. We find the formulation of Charles. We use a simple function of elasticity of expected yield to demand N application. The elasticity is adjusted by historical demand of N application from CAST.

Charles et al., 2019, Nutrient Management Suggestions for Corn,

https://www.researchgate.net/publication/353615625_Nutrient_Management_Suggestions_for_Corn

effect_of_humus_change_to_N_input_with_manure = ratio_of_humus_in_land_with_manure^elasticity_of_N_input_to_humus_change

UNITS: unitless

DOCUMENT: The variable represents for how the soil quality/humus condition could effect the indicated nutrient input by farmers.

It is the elasticity as power of a relative/ratio of humus level.

The effect shows the process that farmer would increase nutrient to make up for the soil quality fading.

The principle comes from:

Saysel, A. K. (2004). System dynamics model for integrated environmental assessment of large scale surface irrigation.

effect_of_humus_change_to_N_input_without_manure = ratio_of_humus_in_land_without_manure^elasticity_of_N_input_to_humus_change

UNITS: unitless

DOCUMENT: The variable represents for how the soil quality/humus condition could effect the indicated nutrient input by farmers.

It is the elasticity as power of a relative/ratio of humus level.

The effect shows the process that farmer would increase nutrient to make up for the soil quality fading.

The principle comes from:

Saysel, A. K. (2004). System dynamics model for integrated environmental assessment of large scale surface irrigation.

effect_of_humus_limit_on_humification = GRAPH(humus_in_land_with_manure/capacity_of_humus_in_land)

Points: (0.000, 1.000), (0.050, 0.995), (0.100, 0.9874), (0.150, 0.9754), (0.200, 0.9566), (0.250, 0.9275), (0.300, 0.8835), (0.350, 0.8196), (0.400, 0.7324), (0.450, 0.6231), (0.500, 0.500), (0.550, 0.3769), (0.600, 0.2676), (0.650, 0.1804), (0.700, 0.1165), (0.750, 0.07251), (0.800, 0.04341), (0.850, 0.02463), (0.900, 0.01263), (0.950, 0.004963), (1.000, 0.000)

UNITS: unitless

DOCUMENT: The table function describes a simple nonlinear relationship that capacity of humus on growth of humification rate.

When the humus in land is far from the capacity level, the restriction effect is very low. With the humus in land increasing to half of capacity of humus, the restriction effect would increase increasingly to 0.5. In this period humus can still increase quickly as its total amount is much less than capacity while the restriction effect is increasing too. When humus in land increases from half to the capacity level, the restriction effect would increase decreasingly to 0. The effect changing rate is near 0 and the effect value is also 0, which means humus cannot increase any more.

effect_of_humus_limit_on_humification_in_land_without_manure =

GRAPH(humus_in_land_without_manure/capacity_of_humus_in_land_without_manure)
Points: (0.000, 1.000), (0.050, 0.995), (0.100, 0.9874), (0.150, 0.9754), (0.200, 0.9566), (0.250, 0.9275), (0.300, 0.8835), (0.350, 0.8196), (0.400, 0.7324), (0.450, 0.6231), (0.500, 0.500), (0.550, 0.3769), (0.600, 0.2676), (0.650, 0.1804), (0.700, 0.1165), (0.750, 0.07251), (0.800, 0.04341), (0.850, 0.02463), (0.900, 0.01263), (0.950, 0.004963), (1.000, 0.000)

UNITS: unitless

DOCUMENT: The table function describes a simple nonlinear relationship that capacity of humus on growth of humification rate.

When the humus in land is far from the capacity level, the restriction effect is very low. With the humus in land increasing to half of capacity of humus, the restriction effect would increase increasingly to 0.5. In this period humus can still increase quickly as its total amount is much less than capacity while the restriction effect is increasing too. When humus in land increases from half to the capacity level, the restriction effect would increase decreasingly to 0. The effect changing rate is near 0 and the effect value is also 0, which means humus cannot increase any more.

effect_of_humus_on_erosion_in_land_with_manure = ratio_of_humus_in_land_with_manure^elasticity_of_soil_erosion_to_humus_change

UNITS: unitless

DOCUMENT: The variables represents for the effect by soil quality/humus condition on surface on soil erosion. A higher level of humus condition would decrease soil erosion. When the humus increase to 3 times as normal level, the limit effect on soil erosion would increase and soil erosion would be decrease to 0.4. When the humus condition falls, the restraining effect would be weaken. Without humus soil, the soil erosion would increase to 1 as there is no humus to prevent the soil erosion.

effect_of_humus_on_erosion_in_land_without_manure = ratio_of_humus_in_land_without_manure^elasticity_of_soil_erosion_to_humus_change

UNITS: unitless

DOCUMENT: The variables represents for the effect by soil quality/humus condition on surface on soil erosion. A higher level of humus condition would decrease soil erosion. When the humus increase to 3 times as normal level, the limit effect on soil erosion would increase and soil erosion would be decrease to 0.4. When the humus condition falls, the restraining effect would be weaken. Without humus soil, the soil erosion would increase to 1 as there is no humus to prevent the soil erosion.

effect_of_humus_to_yield_with_manure = ratio_of_humus_in_land_with_manure^elasticity_of_humus_soil_change_on_yield

UNITS: unitless

DOCUMENT: The variables represents for the effect by humus condition on yield. A higher level of humus condition would increase yield while a low quality of humus would decrease yield. We have used a elasticity of 0.2 as power to the relative change of humus. The value is a tough evaluation as we could not find how much effect that property of humus for soil contributes to yield. As we assume humus stands for part of of property of soil quality and the soil quality change is very slow. We use it to describe that the restriction effect from humus fading will drive farmers to use more N from fertilizer.

effect_of_humus_to_yield_without_manure = ratio_of_humus_in_land_without_manure^elasticity_of_humus_soil_change_on_yield

UNITS: unitless

DOCUMENT: The variables represents for the effect by humus condition on yield. A higher level of humus condition would increase yield while a low quality of humus would decrease yield. We have used a elasticity of 0.2 as power to the relative change of humus. The value is a tough evaluation as we could not find how much effect that property of humus for soil contributes to yield. As we assume humus stands for part of of property of soil quality and the soil quality change is very slow. We use it to describe that the restriction effect from humus fading will drive farmers to use more N from fertilizer.

As we adjust the elasticity from 0.15 to 0.3, the effect in example year of 2023 would change from 0.86 to 0.93, which stays in a sensitive range. The value can be adjusted to see the result to yield.

effect_of_nutrient_to_yield_with_manure = GRAPH(relative_N_input_for_land_with_manure)

Points: (0.000, 0.400), (0.200, 0.4177), (0.400, 0.4608), (0.600, 0.5631), (0.800, 0.7746), (1.000, 1.100), (1.200, 1.425), (1.400, 1.637), (1.600, 1.739), (1.800, 1.782), (2.000, 1.800) {GF EXTRAPOLATED}

UNITS: unitless

DOCUMENT: The variables represents for the effect by nutrient input on yield . A higher level of nutrient input would increase yield, however, with the . When ratio increase to a double as normal level, the effect would increase to its highest level as 1.8, which shows a limit by plant growth limit. When ratio falls to 0, the effect would decrease decreasingly to 0.2. We assume when the ratio is 1, the effect is 1, which means no extra change to the reference year. It indicates that fertilizer or manure nutrient input would replace role of humus soil in the yield achievement but it will not 100% decide the yield of plant.

The effect is estimated according to literature:

1. Benefits of Nitrogen for Corn Production

https://www.jungseedgenetics.com/en-us/agronomy-library/benefits-of-nitrogen-for-corn-production.html

2. Nitrogen Uptake by Corn

http://nmsp.cals.cornell.edu/publications/factsheets/factsheet98.pdf

effect_of_nutrient_to_yield_without_manure = GRAPH(relative_N_input_for_land_without_manure)

Points: (0.000, 0.200), (0.200, 0.2202), (0.400, 0.2695), (0.600, 0.3864), (0.800, 0.6282), (1.000, 1.000), (1.200, 1.372), (1.400, 1.614), (1.600, 1.731), (1.800, 1.780), (2.000, 1.800)

UNITS: unitless

DOCUMENT: The variables represents for the effect by nutrient input on yield . A higher level of nutrient input would increase yield, however, with the . When ratio increase to a double as normal level, the effect would increase to its highest level as 1.8, which shows a limit by plant growth limit. When ratio falls to 0, the effect would decrease decreasingly to 0.2. We assume when the ratio is 1, the effect is 1, which means no extra change to the reference year. It indicates that fertilizer or manure nutrient input would replace role of humus soil in the yield achievement but it will not 100% decide the yield of plant.

The effect is estimated according to literature:

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https://www.jungseedgenetics.com/en-us/agronomy-library/benefits-of-nitrogen-for-corn-production.html

2. Nitrogen Uptake by Corn

http://nmsp.cals.cornell.edu/publications/factsheets/factsheet98.pdf

effect_of_planting_technology = GRAPH(TIME)

Points: (1996.00, 1.0000), (1997.16, 1.0120), (1998.32, 1.0240), (1999.48, 1.0360), (2000.64, 1.0480), (2001.80, 1.0600), (2002.96, 1.0720), (2004.12, 1.0840), (2005.28, 1.0960), (2006.44, 1.1080), (2007.60, 1.1200), (2008.76, 1.1320), (2009.92, 1.1440), (2011.08, 1.1560), (2012.24, 1.1680), (2013.40, 1.1800), (2014.56, 1.1920), (2015.72, 1.2040), (2016.88, 1.2160), (2018.04, 1.2280), (2019.20, 1.2400), (2020.36, 1.2520), (2021.52, 1.2640), (2022.68, 1.2760), (2023.84, 1.2880), (2025.00, 1.3000)

UNITS: unitless

DOCUMENT: The variable represents for how planting technology effects the change on yield, containing more advanced biology technology on seeds, more productive planting methods and other technology factors in planting practice. As we didn't find accurate reference for it, we assume it has increased linearly by 30% in the past 20-30 years.

The 30% is estimated by the report of "global productivity" of world bank, which indicates productivity growth by innovation activity has increased 20-30%. We assume this corresponds to advanced biology technology on plants seeds. And we assume a more scientific modern planting technology in practice also benefit the increase on yield. So we assume it totally as 30%.

source:

World Bank, Global Productivity: Trends, Drivers, and Policies, https://pubdocs.worldbank.org/en/687781593465323067/Global-Productivity-Chapter-2.pdf

effect_of_precipitation_in_land_without_manure = GRAPH(TIME)

Points: (1996.00, 1), (1997.00, 1), (1998.00, 1.001), (1999.00, 1.001), (2000.00, 1.001), (2001.00, 1.002), (2002.00, 1.002), (2003.00, 1.002), (2004.00, 1.003), (2005.00, 1.003), (2006.00, 1.003), (2007.00, 1.004), (2008.00, 1.004), (2009.00, 1.004), (2010.00, 1.005), (2011.00, 1.005), (2012.00, 1.006), (2013.00, 1.006), (2014.00, 1.006), (2015.00, 1.007), (2016.00, 1.007), (2017.00, 1.007), (2018.00, 1.008), (2019.00, 1.008), (2020.00, 1.008), (2021.00, 1.009), (2022.00, 1.009), (2023.00, 1.009), (2024.00, 1.01), (2025.00, 1.01)

UNITS: unitless

DOCUMENT: The variable shows how much precipitation can effect the soil erosion in land without manure. As our time horizon is too short to show the climate change, by the global climate trend, we assume this area also faces a slowly wetter and warmer climate change but it will continue for long-term and has a larger effect in the future. We give the table effect of precipitation a very slight change from 1 to 1.01 from 1996 to 2025.

Metaxoglou, K., & Smith, A. (2022). Nutrient Pollution and US Agriculture: Causal Effects, Integrated Assessment, and Implications of Climate Change (No. w30124). National Bureau of

Economic Research. https://www.nber.org/system/files/working_papers/w30124/w30124.pdf
effect_of_relative_uptake_efficiency_on_expected_N_input_for_land_with_manure = GRAPH(relative_uptake_efficiency)
Points: (0.000, 1.1500), (0.200, 1.1460), (0.400, 1.1370), (0.600, 1.1150), (0.800, 1.0700), (1.000, 1.0000), (1.200, 0.9303), (1.400, 0.8850), (1.600, 0.8630), (1.800, 0.8538), (2.000, 0.8500)

UNITS: unitless

DOCUMENT: This table function shows how farmers' expectation on N input will be effected by the change of uptake efficiency.

When the ratio is increasing to 2, the effect will decrease decreasingly to 0.85. Farmers can save N input when the uptake efficiency of plants is better. When the ratio is decreasing to 0, the effect will increase decreasingly to 1.15. Farmers will increase N input to maintain N uptake by the plants.

effect_of_relative_uptake_efficiency_on_expected_N_input_for_land_without_manure = GRAPH(relative_uptake_efficiency_in_land_without_manure)
Points: (0.000, 1.1500), (0.200, 1.1460), (0.400, 1.1370), (0.600, 1.1150), (0.800, 1.0700), (1.000, 1.0000), (1.200, 0.9303), (1.400, 0.8850), (1.600, 0.8630), (1.800, 0.8538), (2.000, 0.8500) {GF EXTRAPOLATED}

UNITS: unitless

DOCUMENT: This table function shows how farmers' expectation on N input will be effected by the change of uptake efficiency.

When the ratio is increasing to 2, the effect will decrease decreasingly to 0.85. Farmers can save N input when the uptake efficiency of plants is better. When the ratio is decreasing to 0, the effect will increase decreasingly to 1.15. Farmers will increase N input to maintain N uptake by the plants.

effect_of_slope_length_and_steepness_factor = 1

UNITS: unitless

DOCUMENT: The variable represents for the effect by slope factor on soil erosion. The changes and differences on slope length and steepness have a effect on soil erosion by the gravity. At present, we assume there is no big change on the slope factor and ignore this effect. So it is set as 1.

"effect_of_soil_erosion_(RULSE)_to_land_with_manure" = effect_of_precipitation_in_land_without_manure*effect_of_humus_on_erosion_in_land_with_manure*effect_from_plant_type_factor_in_land_with_manure*effect_of_slope_length_and_steepness_factor

UNITS: unitless

DOCUMENT: The variable represents for the effects on runoff and leaching flow. It is calculated by equation for soil erosion. As we estimate a relative change from different effects, so it is the multiple product of effect from different factors. The principle is given from RULSE, which contains rain, soil, plant, slope and management. The effect of management is not included here as it has been contained in the BMPs like soil quality control, buffer and others.

Chesapeake Assessment and Scenario Tool (CAST). (2018b). Phase 6 Dynamic Watershed Model and CAST-17 documentation. Chesapeake bay Program. Chapter 2 Average Loads: RULSE. p19. https://cast.chesapeakebay.net/Documentation/ModelDocumentation

"effect_of_soil_erosion_(RULSE)_to_land_without_manure" =

effect_of_precipitation_in_land_without_manure*effect_of_humus_on_erosion_in_land_without_manure*effect_from_plant_type_factor_in_land_with_manure*effect_of_slope_length_and_steepness_factor

UNITS: unitless

DOCUMENT: The variable represents for the effects on runoff and leaching flow. It is calculated by equation for soil erosion. As we estimate a relative change from different effects, so it is the multiple product of effect from different factors. The principle is given from RULSE, which contains rain, soil, plant, slope and management. The effect of management is not included here as it has been contained in the BMPs like soil quality control, buffer and others.

effect_on_N_uptake_in_manure_land = GRAPH(N_scarcity_in_manure_land)

Points: (0.000, 0.800), (0.200, 0.8126), (0.400, 0.8434), (0.600, 0.9165), (0.800, 1.068), (1.000, 1.300), (1.200, 1.532), (1.400, 1.683), (1.600, 1.757), (1.800, 1.787), (2.000, 1.800) {GF EXTRAPOLATED}

UNITS: unitless

DOCUMENT: The table function describes how N uptake will be effected by scarcity level. As corn is seen as Nutrient intensive crops and their root system have a very strong absorption ability. We assume:

When the scarcity level is 0.8, the uptake effect can reach its normal level 1. When scarcity effect would increase to 2, the uptake ability will increase decreasingly to 1.8 which contains the principle of growth limit of plants. When the effect from scarcity is decreasing to nearly 0, which means there is abundant N available, the uptake ability will be decreased to 0.8, which means plants absorption ability is restricted but they still absorb N for growth. Here we do not set the scarcity effect to 0 as it means plants uptake no N from soil and they will die. Obviously this does not meet the practice.

The table function describes how N uptake will be effected by scarcity level.

This describes that corn plant is N intensive and sensitive crops. When there is a lack of N, root absorption ability will be strengthen. When there is higher N available than demand, their absorption is limited but will not get hurt on plants or yield.

The principle comes from :

Saysel, A. K. (2004); Foth, H. D. (1990);

Bach, N. L. and K. Saeed (1992) ;

Metaxoglou & Smith, 2022

elasticity_of_fertilizer_demand_to_fertilizer_cost_change_for_land_with_manure = -0.1

UNITS: unitless

DOCUMENT: The elasticity represents for how sensitive the fertilizer N application expectation is reacting to the change of fertilizer cost in market. It is referred to the finding of Metaxoglow and Smith, which calculates it as -0.06 of the elasticity of fertilizer demand to price fertilizer price. They have linked price elasticity of the demand for fertilizer to the price elasticity demand for corn, by using proportion of fertilizer cost to total cost in corn planting.

However, as we are concerning about the surplus part of N input for corn planting. The cost proportion of N input in the total price of corn is higher than the average evaluation of the literature.

As we have separate corn land into manure use and no manure use, In land without manure, the elasticity absolute value is-0.12. We assume that in the land with manure is a little lower as -0.1 as it demands less fertilizer N than land without manure.

Metaxoglou, K., & Smith, A. (2022). Nutrient Pollution and US Agriculture: Causal Effects, Integrated Assessment, and Implications of Climate Change (No. w30124). National Bureau of Economic Research. https://www.nber.org/system/files/working_papers/w30124/w30124.pdf

elasticity_of_fertilizer_demand_to_fertilizer_cost_change_for_land_without_manure = -0.12

UNITS: unitless

DOCUMENT: The elasticity represents for how sensitive the fertilizer N application expectation is reacting to the change of fertilizer cost in market. It is referred to the finding of Metaxoglow and Smith, which calculates it as -0.06 of the elasticity of fertilizer demand to price fertilizer price. They have linked price elasticity of the demand for fertilizer to the price elasticity demand for corn, by using proportion of fertilizer cost to total cost in corn planting.

However, as we are concerning about the surplus part of N input for corn planting. The cost proportion of N input in the total price of corn is higher than the average evaluation of the literature.

As we have separate corn land into manure use and no manure use, In land without manure, the elasticity absolute value is-0.12. We assume that in the land with manure is a little lower as -0.1 as it demands less fertilizer N than land without manure.

elasticity_of_humus_soil_change_on_yield = 0.1

UNITS: unitless

DOCUMENT: The variable means how much sensitive the yield would react to the change by humus soil change. It is set 0.1, which is a tough estimation, which gives positive sensitive to the yield. As we assume humus stands for part of of property of soil quality and the soil quality change is very slow. It directly decide the effect of humus to the yield.

And we assume the elasticity of N input by farmers to humus change is -0.05. We use the gap between absolute values of them to show that :

The importance of soil quality to yield is not recognized well by farmers. And farmers usually act less active to the fading of soil/humus property fading, as they could increase some nutrient to make up for the yield. But humus fading cannot be improved but even harmed by fertilizer. Humus fading also causes more serious soil erosion and load.

elasticity_of_manure_input_to_change_of_animal_supply = 0.581

UNITS: unitless

DOCUMENT: The elasticity shows how manure input decision is effected from the relative animal scale change in the county. It is adjusted as 0.581 by comparison of the historical data from CAST.

Besides, the manure land proportion is steady 0.4-0.45. We assume there are 40% of farms that have steady manure N source. This also effects elasticity assumption stays in 0-1, around 0.5.

Data source : CAST
https://cast.chesapeakebay.net/

elasticity_of_N_demand_to_expected_field = 0.6
UNITS: unitless
DOCUMENT: It shows how sensitive that the demand N application will respond to the change of expected yield change.

As we would include price factor, soil factor and planting factor later in the formulation, here we only need to consider about the effect of expected yield to N demand. We find the formulation of Charles et al., We use a simple function of elasticity of expected yield to demand N application.

As we we estimated that dry residue content N is similar to yield content N and yield takes up for 0.6. We calculated it as 0.6, with the equation:
elasticity of B to A = (change of B/original B)/(change of A/original A)
B for N demand
A for yield

The value is also tested with historical date from CAST, which fits the basic line.

Charles et al., 2019, Nutrient Management Suggestions for Corn,

https://www.researchgate.net/publication/353615625_Nutrient_Management_Suggestions_for_Corn

We also have indication from: Nitrogen demand for yield of corn crop Other related resources:
We estimate N content for corn grain as 1 pound per bushel. The total N demand should also contain the N demand for the residue part. This is estimated from the literature:

1. Jason DeBruina and Steve Butzenb. Summary, Nitrogen Uptake in Corn. https://www.pioneer.com/CMRoot/Pioneer/US/Non_Searchable/programs_services/earn-the-right/Corn-Nitrogen-Uptake.pdfCorn Nitrogen Management - LSU AgCenter

2."A 200-bushel corn crop requires about 200 to 250 pounds nitrogen per acre i.e., roughly 1 to 1.25 pounds nitrogen per bushel corn harvested."
https://www.lsuagcenter.com/articles/page1616180617871

elasticity_of_N_input_to_humus_change = -0.05
UNITS: unitless
DOCUMENT: The variables shows how farmers' decision on N input is sensitive to the humus soil change. It is set as -0.05. This is a tough estimate as we are not sure how exact range they could

have. However, we have tested -0.1 stays in a sensitive range.

And we assume the elasticity of yield change to humus change is -0.1. We use the gap between absolute values of them to show that :

The importance of soil quality to yield is not recognized well by farmers. And farmers usually act less active to the fading of soil/humus property fading, as they could increase some nutrient to make up for the yield. But humus fading cannot be improved but even harmed by fertilizer. Humus fading also causes more serious soil erosion and load.

elasticity_of_soil_erosion_to_humus_change = -0.1

UNITS: unitless

DOCUMENT: The elasticity of soil erosion to humus change represents for how the humus change will effect the soil erosion condition. With a fading humus condition, the soil physicochemical properties are both worsen and more easily be erosion by wind and ground water.

As the global warmer up and wetter, the soil erosion will get worse.So we assume it as negative by time.The process is very slow but can be larger with longer simulation time. The elasticity is set as -0.1. In the Analysis, we further test its elasticity.

Metaxoglou, K., & Smith, A. (2022). Nutrient Pollution and US Agriculture: Causal Effects, Integrated Assessment, and Implications of Climate Change (No. w30124). National Bureau of Economic Research.

expected_fertilizer_N_for_land_with_manure = expected_total_N_input_for_land_with_manure-final_manure_N_input_for_land_with_manure

UNITS: pound/acre

DOCUMENT: The variable represents for the expected fertilizer N application in land with manure. It is the expected total N input minus the N from manure.

expected_total_N_input_for_land_with_manure = Demand_N_input_for_land_with_manure*effect_of_humus_change_to_N_input_with_manure*effect_of_relative_uptake_efficiency_on_expected_N_input_for_land_with_manure

UNITS: pound/acre

DOCUMENT: The variable represents for the total N input for land with manure. It is product of demand total N input in land with manure and the effect from humus change and effect of uptake efficiency.

expected_uptake_efficiency_for_land_without_manure = 0.5

UNITS: unitless

DOCUMENT: The expected uptake efficiency represents for how much effective the farmers expect for plant absorption. We assume it is the same to the normal proportion of N uptake.

As fertilizer N is effective faster in shorter time than manure. We assume farmers would have a little higher expectation on uptake efficiency for land without manure as 0.55 than land with manure as 0.5.

expected_uptake_efficiency_for_manure_land = 0.45

UNITS: unitless

DOCUMENT: The expected uptake efficiency represents for how much effective the farmers expect for plant absorption. It is set as normal proportion of uptake by plants.

As fertilizer N is effective faster in shorter time than manure. We assume farmers would have a

little higher expectation on uptake efficiency for land without manure than land with manure.
expected_yield = SMTH3(yield_by_structure, 5) {DELAY CONVERTER}

UNITS: bushel/acre/year

DOCUMENT: The variable represents for the expected yield of farmers, which is based on the former yield. We use a SMOOTH function to simulate the process. The delay time is assumed to be 5 year.

The principle comes form the literature:

Charles et al., 2019, Nutrient Management Suggestions for Corn,

https://www.researchgate.net/publication/353615625_Nutrient_Management_Suggestions_for_Corn

fertilizer_cost = GRAPH(TIME)

Points: (1996.00, 61.01), (1997.00, 65.3192), (1998.00, 59.034), (1999.00, 60.188), (2000.00, 65.9744), (2001.00, 72.696), (2002.00, 88.45), (2003.00, 98.74), (2004.00, 111.8308), (2005.00, 150.5716), (2006.00, 173.232), (2007.00, 158.3748), (2008.00, 134.7116), (2009.00, 169.3784), (2010.00, 180.7968), (2011.00, 181.224), (2012.00, 177.4504), (2013.00, 170.6464), (2014.00, 159.2128), (2015.00, 147.8224), (2016.00, 133.424), (2017.00, 131.816), (2018.00, 139.4312), (2019.00, 141.4396), (2020.00, 134.14), (2021.00, 152.83)

UNITS: dollar/acre

DOCUMENT: The data comes from external data from USDA--

Corn production costs and returns per planted acre, excluding Government payments, Eastern Uplands, Fertilizer price.

U.S. Department of Agriculture, 2023. https://www.ers.usda.gov/

final_fertilizer_N_input_with_price_effect_for_land_with_Manure = expected_fertilizer_N_for_land_with_manure*effect_from_fertilizer_cost_to_fertilizer_N_input_for_land_with_manure

UNITS: pound/acre

DOCUMENT: The variable represents for a final decision on fertilizer N input by farmers for land with manure. It is the expected fertilizer N fro land with manure times the effect from fertilizer cost in market. It describes the demand from soil fading and uptake efficiency condition in planting both and a cost restriction effect from market.

final_manure_N_input_for_land_with_manure = reference_manure_input_per_acre_for_land_with_manure*Effect_from_manure_application

UNITS: pound/acre

DOCUMENT: The variable means how much final manure N input to corn land. It is the product of reference application N from manure and the effect from the change of animal scale.

gap_of_N_input_for_land_without_manure = total_N_input_per_acre_for_land_without_Manure-Demand_N_input_for_land_without_manure

UNITS: pound/acre

DOCUMENT: The variable represents for the gap of N input between demand and practical input in land without manure.

Gap_of_N_input_from_historical_land_with_manure = historical_N_input_for_land_with_manure-historical_demand_N_per_acre_for_manure_land

UNITS: pound/acre

DOCUMENT: The variable represents for the gap of N input between historical demand and input in land with manure.

historical_demand_N_per_acre_for_land_without_manrue = GRAPH(TIME)

Points: (1996.00, 130.0), (1997.45, 130.0), (1998.90, 131.0), (2000.35, 130.0), (2001.80, 129.0), (2003.25, 130.0), (2004.70, 137.0), (2006.15, 135.0), (2007.60, 138.0), (2009.05, 140.0), (2010.50, 139.0), (2011.95, 141.0), (2013.40, 128.0), (2014.85, 121.0), (2016.30, 129.0), (2017.75, 131.0), (2019.20, 144.0), (2020.65, 156.0), (2022.10, 157.0), (2023.55, 153.0), (2025.00, 154.0)

UNITS: pound/acre

DOCUMENT: The variable represents for the historical demanb N input for land without manure.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

historical_demand_N_per_acre_for_manure_land = GRAPH(TIME)

Points: (2000.00, 140.0), (2001.00, 141.0), (2002.00, 142.0), (2003.00, 140.0), (2004.00, 140.0), (2005.00, 140.0), (2006.00, 148.0), (2007.00, 147.0), (2008.00, 150.0), (2009.00, 151.0), (2010.00, 151.0), (2011.00, 153.0), (2012.00, 134.0), (2013.00, 126.0), (2014.00, 135.0), (2015.00, 136.0), (2016.00, 149.0), (2017.00, 163.0), (2018.00, 164.0), (2019.00, 158.0), (2020.00, 160.0)

UNITS: pound/acre

DOCUMENT: The variable represents for the historical demand N per acre for manure land.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

historical_fertilizer_input_for_land_without_manure = GRAPH(TIME)

Points: (2000.00, 131.0), (2001.00, 124.0), (2002.00, 135.0), (2003.00, 106.0), (2004.00, 121.0), (2005.00, 114.0), (2006.00, 116.0), (2007.00, 115.0), (2008.00, 108.0), (2009.00, 105.0), (2010.00, 113.0), (2011.00, 121.0), (2012.00, 114.0), (2013.00, 109.0), (2014.00, 114.0), (2015.00, 116.0), (2016.00, 128.0), (2017.00, 138.0), (2018.00, 139.0), (2019.00, 136.0), (2020.00, 136.0)

UNITS: pound/acre

DOCUMENT: The variable represents for the historical fertilizer N input for land without manure.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

historical_fertilizr_N_input_for_manure_land = GRAPH(TIME)

Points: (2000.00, 105.0), (2001.00, 98.0), (2002.00, 109.0), (2003.00, 79.0), (2004.00, 98.0), (2005.00, 92.0), (2006.00, 94.0), (2007.00, 94.0), (2008.00, 87.0), (2009.00, 84.0), (2010.00, 95.0), (2011.00, 105.0), (2012.00, 88.0), (2013.00, 81.0), (2014.00, 87.0), (2015.00, 93.0), (2016.00, 104.0), (2017.00, 108.0), (2018.00, 116.0), (2019.00, 110.0), (2020.00, 117.0)

UNITS: pound/acre

DOCUMENT: The variable represents for the historical demand N from fertilizer per acre for manure land.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

historical_gap_of_N_input_for_land_with_manure = total_N_input_per_acre_for_land_with_manure-Demand_N_input_for_land_with_manure

UNITS: pound/acre

DOCUMENT: The variable represents for the gap of N input between demand and practical input in land with manure.

historical_Gap_of_N_input_from_historical_land_without_manure = historical_fertilizer_input_for_land_without_manure-historical_demand_N_per_acre_for_land_without_manrue

UNITS: pound/acre

DOCUMENT: The variable represents for the gap of N input between historical demand and input in land without manure.

historical_manure_N_input_for_manure_land = GRAPH(TIME)

Points: (2000.00, 69.0), (2001.00, 68.0), (2002.00, 67.0), (2003.00, 65.0), (2004.00, 62.0), (2005.00, 59.0), (2006.00, 58.0), (2007.00, 56.0), (2008.00, 54.0), (2009.00, 55.0), (2010.00, 53.0), (2011.00, 50.0), (2012.00, 60.0), (2013.00, 61.0), (2014.00, 64.0), (2015.00, 54.0), (2016.00, 54.0), (2017.00, 71.0), (2018.00, 56.0), (2019.00, 57.0), (2020.00, 46.0)

UNITS: pound/acre

DOCUMENT: The variable represents for the historical demand N from manure per acre for manure land.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

historical_N_input_for_land_with_manure = historical_manure_N_input_for_manure_land+historical_fertilizr_N_input_for_manure_land

UNITS: pound/acre

DOCUMENT: The variable represents for the historical total demand N per acre for manure land.

"historical_yield_corn_2000-21" = GRAPH(TIME)

Points: (2000.00, 128.0), (2001.00, 95.0), (2002.00, 67.0), (2003.00, 98.0), (2004.00, 111.0), (2005.00, 112.0), (2006.00, 136.0), (2007.00, 121.0), (2008.00, 126.0), (2009.00, 156.0), (2010.00, 135.0), (2011.00, 129.0), (2012.00, 90.0), (2013.00, 161.0), (2014.00, 157.0), (2015.00, 163.0), (2016.00, 159.0), (2017.00, 180.0), (2018.00, 169.0), (2019.00, 170.0), (2020.00, 178.0), (2021.00, 188.0)

UNITS: bushel/acre

DOCUMENT: The variable represents for the historical yield for corn from 2000 to 2021.

Data source : CAST

https://cast.chesapeakebay.net/

initial_humus_in_land_with_manure = 10000

UNITS: pound/acre

DOCUMENT: The variable represents an initial humus soil level in the land. We toughly estimate there is 10000 pound humus soil that covers per acre of land, which is around 5 t.

initial_humus_in_land_without_manure = 10000

UNITS: pound/acre

DOCUMENT: The variable represents an initial humus soil level in the land. We toughly estimate there is 10000 pound humus soil that covers per acre of land, which is around 5 t.

low_residue_return_by_human = 0.01

UNITS: unitless

DOCUMENT: The variable represents for how much proportion of residue part in one unit of plant. It is calculated as below. No residue return means human does not put any residue back to soil, so there is only partly root structure part left in soil, which we assume it as very very low as 0.01.

maximum_residue_return_proportion = 0.09

UNITS: unitless

DOCUMENT: The variable represents for the maximum proportion of residue return to land. It is calculated as below.

It is calculated as below.

From the reference below, we see with 125 bushels per acre, the highest residue return of corn is 0.4 *1200 pound dry round bald. The total residue of corn can be as high as 4.4 round bald. So the highest proportion of residue return of corn is 0.4/4.4= 0.09. Here we don't calculate how much weight the residue return to humus but how much effect it gives to normal humufication rate, we only calculate the proportion of residue return to residue amount.

Principle comes from study findings of university of Minesota Extension.

https://extension.umn.edu/corn-harvest/crop-residue-management#how-it-relates-to-soil-producti vity-1211761

N_application_effect_uptake_without_manure = GRAPH(N_scarcity_in_land_without_manure)

Points: (0.000, 0.800), (0.200, 0.8126), (0.400, 0.8434), (0.600, 0.9165), (0.800, 1.068), (1.000, 1.300), (1.200, 1.532), (1.400, 1.683), (1.600, 1.757), (1.800, 1.787), (2.000, 1.800) {GF EXTRAPOLATED}

UNITS: per year

DOCUMENT: The table function describes how N uptake will be effected by scarcity level. As corn is seen as Nutrient intensive crops and their root system have a very strong absorption ability. We assume:

When the scarcity level is 0.8, the uptake effect can reach its normal level 1. When scarcity effect would increase to 2, the uptake ability will increase decreasingly to 1.8 which contains the principle of growth limit of plants. When the effect from scarcity is decreasing to nearly 0, which means there is abundant N available, the uptake ability will be decreased to 0.8, which means plants absorption ability is restricted but they still absorb N for growth. Here we do not set the scarcity effect to 0 as it means plants uptake no N from soil and they will die. Obviously this does not meet the practice.

The table function describes how N uptake will be effected by scarcity level.

This describes that corn plant is N intensive and sensitive crops. When there is a lack of N, root absorption ability will be strengthen. When there is higher N available than demand, their absorption is limited but will not get hurt on plants or yield.

The principle comes from :
Saysel, A. K. (2004); Foth, H. D. (1990);
Bach, N. L. and K. Saeed (1992) ;
Metaxoglou & Smith, 2022

N_content_of_corn_residue = 1
UNITS: pound/bushel
DOCUMENT: We toughly assume the N content of residue is the same to the N content from corn yield, which is 1 pound/bushel.

The estimation N content in corn grain from the literature:

1. Jason DeBruina and Steve Butzenb. Summary, Nitrogen Uptake in Corn. https://www.pioneer.com/CMRoot/Pioneer/US/Non_Searchable/programs_services/earn-the-right/Corn-Nitrogen-Uptake.pdfCorn Nitrogen Management - LSU AgCenter

2."A 200-bushel corn crop requires about 200 to 250 pounds nitrogen per acre i.e., roughly 1 to 1.25 pounds nitrogen per bushel corn harvested."
https://www.lsuagcenter.com/articles/page1616180617871

3. https://www.jungseedgenetics.com/en-us/agronomy-library/benefits-of-nitrogen-for-corn-production.html

N_scarcity_in_land_without_manure = Demand_N_input_for_land_without_manure*normal_proportion_of_uptake_without_manure/surface_N_in_land_without_manure
UNITS: unitless
DOCUMENT: The variable show how N in surface soil is in shortage for the plants demand. It is the ratio of Demand N for plants and the surface soil. Demand N for plants is the total demand N input times the normal proportion N uptake by plants.

When the demand level is very high or surface soil N is very low, the scarcity can be very high. With a lower demand or high surface N the scarcity can be lower. This all directly effects N uptake by plants.

N_scarcity_in_manure_land = Demand_N_input_for_land_with_manure*normal_proportion_of_uptake_in_manure_land/surface_N_in_land_with_manure
UNITS: per year
DOCUMENT: The variable show how N in surface soil is in shortage for the plants demand. It is

the ratio of Demand N for plants and the surface soil. Demand N for plants is the total demand N input times the normal proportion N uptake by plants.

When the demand level is very high or surface soil N is very low, the scarcity can be very high. With a lower demand or high surface N the scarcity can be lower. This all directly effects N uptake by plants.

normal_load_from_land_with_manure_from_CAST_data = 54.7

UNITS: pound/acre

DOCUMENT: The normal load in land without manure is used to compare the final simulation result for load to rivers.

It is 54.7.

source: CAST, phase 6, chapter 2, p17

normal_load_from_without_manure_from_CAST_data = 39.07

UNITS: pound/acre

DOCUMENT: The normal load in land without manure is used to compare the final simulation result for load to rivers.

It is 39.07.

source: CAST, phase 6, chapter 2, p17

normal_proportion_of_humification_rate_with_75%_of_maximum_return = 0.05

UNITS: Per Year

DOCUMENT: The variable represents for a normal proportion of hums increase under a normal residue return to soil, which is set as 0.05.

Compared with the normal proportion of loss by oxidation. We assume with a normal increase of humification rate and no tillage or all preservation tillage, the humus should be at equilibrium. We assume the equilibrium is similar to a humus balance in natural environment, while the maximum increase with residue return is similar to the natural plant return after they are dead.

normal_proportion_of_load_loss = 0.29

UNITS: per year

DOCUMENT: The variable represents for the normal proportion of N loss from loading. It is said an average of 0.29 of N has lost from land. We use it as a reference load proportion.

Besides, the reference N load from CAST data is around 54 Ib/acre/year for land with manure and 39 Ib/acre/year for land without manure. Based on the normal N application in land, these two values are quite close. So we assume that 0.29 is a reasonable proportion we can take to see how other factors' changes finally effect N load change.

resource:

Metaxoglou, K., & Smith, A. (2022). Nutrient Pollution and US Agriculture: Causal Effects, Integrated Assessment, and Implications of Climate Change (No. w30124). National Bureau of Economic Research.

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Chapter 2.

normal_proportion_of_loss_by_oxidation_and_decomposition = 0.05

UNITS: per year

DOCUMENT: The variable represents for an original proportion of hums loss by oxidation and decomposition, as a result of natural erosion by wind and rain, without any tillage operation or there is all covered by preservation tillage operation. It is set as 0.05 per year.

normal_proportion_of_uptake_in_manure_land = 0.45

UNITS: per year

DOCUMENT: The variable shows a normal proportion N uptake in land by corn. As fertilizer N is effective more quickly than manure N, we assume the proportion for N in manure land is 0.45, lower than land without manure.

The value is estimated from the literature:

Jason DeBruina and Steve Butzenb. Summary, Nitrogen Uptake in Corn. https://www.pioneer.com/CMRoot/Pioneer/US/Non_Searchable/programs_services/earn-the-right/Corn-Nitrogen-Uptake.pdfCorn Nitrogen Management - LSU AgCenter

normal_proportion_of_uptake_without_manure = 0.5

UNITS: unitless

DOCUMENT: The variable shows a normal proportion N uptake in land by corn. As fertilizer N is effective more quickly than manure N, we assume the proportion for N in non-manure land is 0.5, a little higher than that in land with manure.

The value is estimated from the literature:

Jason DeBruina and Steve Butzenb. Summary, Nitrogen Uptake in Corn. https://www.pioneer.com/CMRoot/Pioneer/US/Non_Searchable/programs_services/earn-the-right/Corn-Nitrogen-Uptake.pdf

proportion_of_final_load_from_runoff_and_leaching = 1-proportion_of_load_to_buffer

UNITS: unitless

DOCUMENT: The proportion represents for how much proportion of N is finally loading to waters. It is the 1- proportion of load to buffer, which means it would decrease with rising buffer proportion.

proportion_of_full_preservation_tillage = 0.8

UNITS: unitless

DOCUMENT: The variable presents for the whole corn grain planting has practices a preservation tillage level in land, without any traditional tillage.

proportion_of_half_preservation_tillage = 0.1

UNITS: unitless

DOCUMENT: The variable presents for a preservation tillage level in land. Half level means 50% of land use preservation tillage while the other 50% of land is using traditional tillage.

proportion_of_load_to_buffer = IF SWITCH_for_Buffer_area=1 THEN By_2022_proportion_of_N_to_buffer ELSE IF SWITCH_for_Buffer_area=2 THEN Assuming_Target_proportion_of_N_to_buffer ELSE 0

UNITS: unitless

DOCUMENT: The proportion represents for how much proportion of N is staying in buffer area before loading to waterways.

when switch = 0, there is no buffer area;

when switch = 1, the buffer level by 2022;

when switch = 2, the buffer level reaches the target proportion.
proportion_of_N_moving_soon_to_bay = 0.5
UNITS: unitless
DOCUMENT: The variable represents for the proportion of N that can move to the bay soon from water. The other part of N is assumed to stay in sediment or consumed by plants or animals in Potomac river and will not move to bay in short time.
proportion_of_residue_to_total_plant = 0.4
UNITS: unitless
DOCUMENT: The parameter represents for an estimate how much proportion of residue in total plant. Here we use a tough estimation of their weight in dry status as 0.4 of total plants.
proportion_of_volatilization_in_manure_land = 0.2
UNITS: per year
DOCUMENT: We assume around 20% of N would volatilize during planting both for land with manure and without manure. In practice, there is difference for those two N application but we ignore it in the modeling.

Resource: Harper, L. A., Sharpe>, R. R., Langdale, G. W., & Giddens, J. E. (1987). Nitrogen cycling in a wheat crop: soil, plant, and aerial nitrogen transport 1. Agronomy Journal, 79(6), 965-973.
ratio_of_humus_in_land_with_manure = humus_in_land_with_manure/initial_humus_in_land_with_manure
UNITS: unitless
DOCUMENT: The variable shows the ratio of humus soil stock to the initial humus soil level, which shows the change of humus soil level compared with its initial level.
ratio_of_humus_in_land_without_manure = humus_in_land_without_manure/initial_humus_in_land_without_manure
UNITS: unitless
DOCUMENT: The variable shows the ratio of humus soil stock to the initial humus level, which shows the change of humus soil level compared with original level.
ratio_of_manure_input = final_manure_N_input_for_land_with_manure/reference_manure_input
UNITS: unitless
DOCUMENT: The variable means the ratio of final manure N input and the reference manure input
reference_animal_scales = 104
UNITS: thousand AU
DOCUMENT: The variable estimates the normal animal scale, which comes from the average of starting years of historical change on animal scales. We calculated three kinds of main cattle in the county: dairy, beef and other cattle.

Chesapeake Assessment and Scenario Tool (CAST). (2023). Phase 6 Source Data. Chesapeake bay Program. https://cast.chesapeakebay.net/Home/SourceData
reference_fertilizer_cost_2000 = 61.01
UNITS: dollar/acre
DOCUMENT: The variable represents for a reference fertilizer cost in the year of 2000.
reference_manure_input = 69

UNITS: pound/acre

DOCUMENT: We use the manure input in 1996 as referrence manure input.

Data source: Chesapeake Assessment and Scenario Tool (CAST). (2023). Phase 6 Source Data. Chesapeake bay Program. https://cast.chesapeakebay.net/Home/SourceData

reference_manure_input_per_acre_for_land_with_manure = 69

UNITS: pound/acre

DOCUMENT: The reference manure input per acre for corn land with manure is used the year of manure input amount as 69 pound/acre from data of 2000.

Data source : CAST

https://cast.chesapeakebay.net/

reference_total_demand_N_for_land_with_manure = 140

UNITS: pound/acre

DOCUMENT: The variable represents for a reference total N demand for land with manure as 140 pound/acre. It equals the value of 2000 historical data of total demand N in manure land from CAST.

Data source : CAST

https://cast.chesapeakebay.net/

reference_total_demand_N_for_land_without_manure = 130

UNITS: pound/acre

DOCUMENT: The variable represents for a reference total N demand for land without manure as 130 pound/acre. It equals the value of 2000 historical data of total demand N in manure land from CAST.

Data source : CAST

https://cast.chesapeakebay.net/

reference_yield_2000 = 120

UNITS: bushel/acre/year

DOCUMENT: We use the yield of 2000 to be our reference yield, which is used to calculate the yield in the concerning time horizon.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

relative_animal_scale = animal_scales/reference_animal_scales

UNITS: unitless

DOCUMENT: The variable shows how animal scales are changing compared with reference animal scales.

relative_N_input_for_land_with_manure = total_N_input_per_acre_for_land_with_manure/Demand_N_input_for_land_with_manure

UNITS: unitless

DOCUMENT: The variable represents for a relative N input condition in land with manure. It is the ratio of N input to normal demand N.

relative_N_input_for_land_without_manure =

total_N_input_per_acre_for_land_without_Manure/Demand_N_input_for_land_without_manure

UNITS: unitless

DOCUMENT: The variable represents for a relative N input condition in land without manure. It is the ratio of N input to normal demand N.

relative_N_input_in_land_with_manure = total_N_input_per_acre_for_land_with_manure/Demand_N_input_for_land_with_manure

UNITS: unitless

DOCUMENT: The variable shows how much surplus or shortage that the total N input is compared with demand N input. It is the ratio of total N input per acre to Demand N input per acre for land.

relative_N_input_in_land_without_manure = total_N_input_per_acre_for_land_without_Manure/Demand_N_input_for_land_without_manure

UNITS: unitless

DOCUMENT: The variable shows how much surplus or shortage that the total N input is compared with demand N input. It is the ratio of total N input per acre to Demand N input per acre for land.

relative_uptake_efficiency = uptake_efficiency_in_land_with_manure/expected_uptake_efficiency_for_manure_land

UNITS: per year

relative_uptake_efficiency_in_land_without_manure = uptake_efficiency_in_land_without_manure/expected_uptake_efficiency_for_land_without_manure

UNITS: per year

DOCUMENT: The variable shows how much N in land is effective on plant and taken up by plants. So it is the ratio of uptake outflow and the surface N in soil.

SWITCH_for_Buffer_area = 1

UNITS: unitless

DOCUMENT: The switch is used to adjust how much proportion that buffer has been completed.

when switch = 0, there is no buffer area;

when switch = 1, the buffer level by 2022;

when switch = 2, the buffer level reaches the target proportion.

SWITCH_for_Tillage = 1

UNITS: unitless

DOCUMENT: The switch is used to adjust just the proportion of preservation tillage in land.

when switch =0, there is low preservation tillage as 0.5. when switch =1, there is land using preservation tillage by 2022 as 0.91, when switch = 2, there is full preservation tillage as 1.

SWTICH_residue = 1

UNITS: unitless

DOCUMENT: The switch for residue is used to adjust how much proportion of residue return to land.

When switch =0, total residue return =0.01, which means only root structure left in soil.

When switch =1, total residue return = 0.045, which is half of maximum residue return level.

When switch =2, total residue return = 0.09, which is maximum residue return level.

It is calculated as below.

From the reference below, we see with 125 bushels per acre, the highest residue return of corn is 0.4 *1200 pound dry round bald. The total residue of corn can be as high as 4.4 round bald. So the highest residue return proportion is 0.4/4.4. So highest proportion of residue return of corn is (0.4/4.4)*0.4 = 0.09. Here we don't calculate how much weight the residue return to humus but how much effect it gives to normal humufication rate, we only calculate the proportion of residue return to residue amount.

Principle comes from study findings of university of Minesota Extension.

https://extension.umn.edu/corn-harvest/crop-residue-management#how-it-relates-to-soil-productivity-1211761

Source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

Chesapeake Progress, 2025 Watershed Implementation Plans (WIPs), https://www.chesapeakeprogress.com/clean-water/watershed-implementation-plans

Keisman, J., Murphy, R. R., Devereux, O.H., Harcum, J., Karrh, R., Lane, M.,

Perry, E., Webber, J., Wei, Z., Zhang, Q., Petenbrink, M. 2020. Potomac Tributary Report: A summary of trends in tidal water quality and associated factors. Chesapeake Bay Program, Annapolis MD.

Potomac Tributary Report: A summary of trends in tidal water quality and associated factors, 1985-2018, December 18, 2020 Prepared for the Chesapeake Bay Program (CBP) Partnership by the CBP Integrated Trends Analysis Team (ITAT)

time_period = 1

UNITS: year

DOCUMENT: The variable represents for the total N input is used for one year.

time_to_bay = 0.16

UNITS: year

DOCUMENT: The parameter represents for the time for nutrients to reach bay from river. As we are not sure how long time the N would move from Potomac to the bay, part of N would move from water and part of N would stay in sediment. Considering the whole N cycles can contain

time_to_shape_N_demand = 2

UNITS: year

total_N_input_per_acre_for_land_with_manure = final_manure_N_input_for_land_with_manure+final_fertilizer_N_input_with_price_effect_for_land_with_Manure

UNITS: pound/acre

DOCUMENT: The total N input per acre for land with manure means the total N application decision by farmers, it is sum of manure N input and fertilizer N input.

total_N_input_per_acre_for_land_without_Manure = Demand_N_input_for_land_without_manure*effect_from_change_of_fertilizer_cost*effect_of_humus_change_to_N_input_without_manure*effect_of_relative_uptake_efficiency_on_expected_N_input_for_land_without_manure

UNITS: pound/acre

DOCUMENT: The total N input per acre for land without manure means the total N application decision by farmers, it is the normal demand N amount multiple the effects from humus soil fading, N uptake efficiency condition and fertilizer cost change from market.

It describes the course that farmers would increase N application when the hums effect or N uptake effect gives higher value than 1. However, fertilizer cost has a restriction effect on the use of fertilizer when could capture the restriction effect from cost.

Total_Nitrogen_Application_by_Grains_from_CAST_data = GRAPH(TIME)

Points: (2000.00, 3003246), (2001.00, 3069927), (2002.00, 3526624), (2003.00, 2869819), (2004.00, 3268401), (2005.00, 3118063), (2006.00, 3202761), (2007.00, 3218105), (2008.00, 3171116), (2009.00, 3232439), (2010.00, 3624256), (2011.00, 3987114), (2012.00, 3938870), (2013.00, 3736868), (2014.00, 3849667), (2015.00, 3835976), (2016.00, 4175950), (2017.00, 4606614), (2018.00, 4487359), (2019.00, 4326650), (2020.00, 4250565)

UNITS: pound

DOCUMENT: The variable represents for the historical total N application for grains from CAST.

Data source : CAST

https://cast.chesapeakebay.net/

total_residue_return_prop_to_land_without_manure = IF SWTICH_residue=0 THEN low_residue_return_by_human ELSE IF SWTICH_residue=1 THEN By_2022_residue_return_proportion ELSE maximum_residue_return_proportion

UNITS: unitless

DOCUMENT: The variable represents for how much proportion of residue part in one unit of plant. Respectively,

When switch =0, total residue return =0.01, which means only root structure left in soil.

When switch =1, total residue return = 0.045, which is half of maximum residue return level.

When switch =2, total residue return = 0.09, which is maximum residue return level.

It is calculated as below.

From the reference below, we see with 125 bushels per acre, the highest residue return of corn is 0.4 *1200 pound dry round bald. The total residue of corn can be as high as 4.4 round bald. So the highest residue return proportion is 0.4/4.4. We estimate a normal proportion of residue harvest proportion in plant as 40%. So highest proportion of residue return of corn is (0.4/4.4)*0.4 = 0.09.

Principle comes from study findings of university of Minesota Extension.

https://extension.umn.edu/corn-harvest/crop-residue-management#how-it-relates-to-soil-productivity-1211761

total_residue_return_to_manure_land = IF SWTICH_residue=0 THEN low_residue_return_by_human ELSE IF SWTICH_residue=1 THEN By_2022_residue_return_proportion ELSE maximum_residue_return_proportion

UNITS: unitless

DOCUMENT: The variable represents for how much proportion of residue part in one unit of plant. Respectively,

When switch =0, total residue return =0.01, which means only root structure left in soil.

When switch =1, total residue return = 0.045, which is half of maximum residue return level.

When switch =2, total residue return = 0.09, which is maximum residue return level.

It is calculated as below.

From the reference below, we see with 125 bushels per acre, the highest residue return of corn is 0.4 *1200 pound dry round bald. The total residue of corn can be as high as 4.4 round bald. So the highest residue return proportion is 0.4/4.4. So highest proportion of residue return of corn is (0.4/4.4)*0.4 = 0.09. Here we don't calculate how much weight the residue return to humus but how much effect it gives to normal humufication rate, we only calculate the proportion of residue return to residue amount.

Principle comes from study findings of university of Minesota Extension.

https://extension.umn.edu/corn-harvest/crop-residue-management#how-it-relates-to-soil-productivity-1211761

uptake_efficiency_in_land_with_manure = N_uptake_in_land_with_manure/surface_N_in_land_with_manure

UNITS: per year

DOCUMENT: The variable shows how much N in land is effective on plant and taken up by plants. So it is the ratio of uptake outflow and the surface N in soil.

uptake_efficiency_in_land_without_manure = N_uptake_in_land_without_manure/surface_N_in_land_without_manure

UNITS: per year

DOCUMENT: The variable shows how much N in land is effective on plant and taken up by plants. So it is the ratio of uptake outflow and the surface N in soil.

weather_conditions_effect_on_yield = GRAPH(TIME)

Points: (1996.00, 1), (1997.00, 0.9997), (1998.00, 0.9993), (1999.00, 0.999), (2000.00, 0.9986), (2001.00, 0.9983), (2002.00, 0.9979), (2003.00, 0.9976), (2004.00, 0.9972), (2005.00, 0.9969), (2006.00, 0.9966), (2007.00, 0.9962), (2008.00, 0.9959), (2009.00, 0.9955), (2010.00, 0.9952), (2011.00, 0.9948), (2012.00, 0.9945), (2013.00, 0.9941), (2014.00, 0.9938), (2015.00, 0.9934), (2016.00, 0.9931), (2017.00, 0.9928), (2018.00, 0.9924), (2019.00, 0.9921), (2020.00, 0.9917), (2021.00, 0.9914), (2022.00, 0.991), (2023.00, 0.9907), (2024.00, 0.9903), (2025.00, 0.99)

UNITS: unitless

DOCUMENT: The variable shows how weather conditions effects yield. At present we do not concern the effects from weather condition, we assume it almost steady to 1. However, with the global climate change, this effect will keep going larger and decrease yield.The study shows when temperature is over 29C corn yield can be hurt. We assume it as a little effect on yield.

The principle comes from :

Metaxoglou, K., & Smith, A. (2022). Nutrient Pollution and US Agriculture: Causal Effects, Integrated Assessment, and Implications of Climate Change (No. w30124). National Bureau of Economic Research.

Schlenker, W. and M. Roberts (2009). Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. Proceedings of the National Academy of Sciences, 106, 15594–15598.

yield_by_structure = ((effect_of_nutrient_to_yield_with_manure*effect_of_humus_to_yield_with_manure*.proportion_of_land_with_manure_1)+effect_of_nutrient_to_yield_without_manure*effect_of_humus_to_yield_without_manure*(1-.proportion_of_land_with_manure_1))*weather_conditions_effect_on_yield*effect_of_planting_technology*reference_yield_2000

UNITS: bushel/acre/year

DOCUMENT: The variable gives yearly yield by structure, which was based on reference yield, multiple with effect from factors that have influence on yield, like planting technology, rain, soil, fertilizer.

2.4 Structure_Robust_Test_on_Soybean:

accumulative_harvest(t) = accumulative_harvest(t - dt) + (harvest_rate) * dt

INIT accumulative_harvest = 0

UNITS: Acres

DOCUMENT: The stock shows an accumulation of harvest/production every year. It could show the changing trend on production year by year in the time horizon.

capital_on_order(t) = capital_on_order(t - dt) + (order_rate - acquisition_rate) * dt

INIT capital_on_order = capital_discard_rate*capital_acquisition_delay

UNITS: dollar

DOCUMENT: The stock of capital on order represents for the product in process. It accumulates the new order and is depleted by acquisition rate. It can be seen as the plants in land which are still growing and waiting for harvest in this system.

capital_stock(t) = capital_stock(t - dt) + (acquisition_rate - capital_discard_rate) * dt

INIT capital_stock = ("reference_planting_acres_2000_(soybean)"/SMTH_indicated_capacity_utilization)/capital_productivity*per_year

UNITS: dollar

DOCUMENT: The capital stock accumulates the capital increase from production selling and was depleted by the capital discard rate. The initial value is calculated based on the production and

market price on year of 2000.
planting_in_land(t) = planting_in_land(t - dt) + (planting_start - harvest_rate) * dt
INIT planting_in_land = 0
UNITS: Acres
DOCUMENT: The stock accumulates the yearly planting rates and is depleted by the harvest rate every year.

The initial value is set as 0 in the beginning of simulation time.
acquisition_rate = DELAY3(order_rate, capital_acquisition_delay)
UNITS: dollar/Years
DOCUMENT: The flow of acquisition rate is the outflow of capital on order and inflow of capital stock. It represents for the product in process is transformed to capital and accumulate into capital stock. It is the ratio of capital on order and the capital acquisition delay. It reflects how fast the product completion in process and capital return speed.
capital_discard_rate = capital_stock/Average_life_of_capital
UNITS: dollar/Years
DOCUMENT: The capital discard rate represents the capital loss containing the normal depreciation of agricultural equipment, capital devaluation process and other capital depletion. It is given as division of capital stock and the average lifetime of capital in agriculture industry.
harvest_rate = DELAY(planting_start, growth_period)
UNITS: Acres/year
DOCUMENT: The harvest rate shows the production rate from planting every year. It is a delay function of planting start with a delay as growth period.
order_rate = MAX(0, indicated_orders)
UNITS: dollar/Years
DOCUMENT: The flow of order rate is the inflow that increase capital on order. It represents for the new investment is put into production process. The higher order rate, the faster the capital on order is accumulated. It is the non-negative of indicated orders. When the indicated order is below 0, we assume it as 0 in the structure. Because we use outflow to represents for the loss of stock but not negative inflow.
planting_start = STEP(planting_increase, planting_time,duration, interval)*trigger_planting
UNITS: Acres/year
DOCUMENT: The planting start rate is the inflow that fill in the stock of planting in land. It represents for how much the new planting is given in the planting season. The equation is a step up and down before and after planting duration, which simulates the planting pulse every spring.
adjustment_for_planting_supply = (desired_planting_supply-capital_on_order)/Time_to_adjust_planting
UNITS: dollar/Years
DOCUMENT: The variable of adjustment for planting land represents for the preparation for farmers when they decide to change planting types. It is the gap between capital on order and desired planting supply, divided by adjustment time for planting. It can be understood as the value calculation of work-in-process inventory.
adjustment_of_capacity = (desired_capital-capital_stock)/adjustment_time_for_capital
UNITS: dollar/Years

DOCUMENT: The adjustment of capacity stock represents for the process to adjust the gap between the capital stock and desired capital level with the adjustment delay. The result of adjustment of capital is realized in the change of capacity for planting, so it is named as adjustment of capacity though it starts by an adjustment of capital.

adjustment_time_for_capital = 8

UNITS: year

DOCUMENT: The time to adjust capital represents the necessary delay for the capital stock to reach the desired level. It is one of the most important delays in the commodity cycles.

It is set as around 8 year and in practice it can be even longer. We estimated the value based on the information of cattle cycles average about 10-12 years. As our study plants are used mainly for feeding animals especially cattles, we consider there is closely relationship between these two cycles. Considering the delays in other process of commodity cycle, we assume the adjustment time for capital is 8 years. By adjustment of this parameter, we could see how the capital stock and planting acreage would react to the change.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p 792-298.

Meadows, 1971, Dynamics of commodity production cycles, chapter 4-5.

adjustment_time_for_effect_by_expected_profitability = 3

UNITS: year

DOCUMENT: The variable represents for adjustment time for expected profitability has effect on desired capital. It is set as 3 years, as we assume the adjustment time for long-term expectation of profitability needs a few years to decide. Capital decision makers would not rely on just one or two years profitability to decide. And the whole renew of capital in the structure takes very long delay which can be over 10 years because we assume the cycle of corn grain is closely related to cattle cycles which is 10-12 years. So here we assume it not shorter than 3 years.

The principle comes form:

Sterman, 2000, Business Dynamics, Chapter 20.

Meadows, 1971, Dynamics of Commodity Production Cycles, Chapter 3 - 4.

Agricultural_preservation = GRAPH(TIME)

Points: (2009.00, 0), (2009.48275862, 120.7), (2009.96551724, 241.4), (2010.44827586, 362.1), (2010.93103448, 482.8), (2011.4137931, 603.4), (2011.89655172, 724.1), (2012.37931034, 844.8), (2012.86206897, 965.5), (2013.34482759, 1086), (2013.82758621, 1207), (2014.31034483, 1328), (2014.79310345, 1448), (2015.27586207, 1569), (2015.75862069, 1690), (2016.24137931, 1810), (2016.72413793, 1931), (2017.20689655, 2052), (2017.68965517, 2172), (2018.17241379, 2293), (2018.65517241, 2414), (2019.13793103, 2534), (2019.62068966, 2655), (2020.10344828, 2776), (2020.5862069, 2897), (2021.06896552, 3017), (2021.55172414, 3138), (2022.03448276, 3259), (2022.51724138, 3379), (2023.00, 3500)

UNITS: acre

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

assumed_largest_proportion_of_available_land_for_corn_planting = 0.85

UNITS: unitless

DOCUMENT: The variable means the assumed largest proportion of available land for corn planting.

Average_life_of_capital = 20

UNITS: year

DOCUMENT: The lifetime of capital represents for the lifetime of capital invested in this field, which effects the speed of depletion for capital discard rate. The shorter lifetime the capital is, the faster the capital is discarded.

capital_acquisition_delay = 0.75

UNITS: year

DOCUMENT: It means how long time the producers/farmers could obtain payback by capital investment into production. It should be no shorter than one complete production period, which is growth period of plant. Considering the whole growth and sale time, it is set as no shorter than 0.75 year.

capital_productivity = 1

UNITS: acre/dollar/year

DOCUMENT: capital productivity represents for the unit production achievement by capital.

It is set as 1, which means one unit of capital is equivalent one unit of production payment, including seed, tools and ferlizer, etc.

Conservation_reserve_enhancement_program = GRAPH(TIME)

Points: (2009.00, 0), (2009.48275862, 120.7), (2009.96551724, 241.4), (2010.44827586, 362.1), (2010.93103448, 482.8), (2011.4137931, 603.4), (2011.89655172, 724.1), (2012.37931034, 844.8), (2012.86206897, 965.5), (2013.34482759, 1086), (2013.82758621, 1207), (2014.31034483, 1328), (2014.79310345, 1448), (2015.27586207, 1569), (2015.75862069, 1690), (2016.24137931, 1810), (2016.72413793, 1931), (2017.20689655, 2052), (2017.68965517, 2172), (2018.17241379, 2293), (2018.65517241, 2414), (2019.13793103, 2534), (2019.62068966, 2655), (2020.10344828, 2776), (2020.5862069, 2897), (2021.06896552, 3017), (2021.55172414, 3138), (2022.03448276, 3259), (2022.51724138, 3379), (2023.00, 3500)

UNITS: Acres

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

corn_planting_capacity = assumed_largest_proportion_of_available_land_for_corn_planting*farming_land_in_Frederick

UNITS: acre

DOCUMENT: The variable represents for the corn planting capacity, which is the total farming land in the county times the assumption proportion that is suitable for corn planting.

Critical_farms = GRAPH(TIME)

Points: (1994.00, 0), (1995.00, 175.9), (1996.00, 351.7), (1997.00, 527.6), (1998.00, 703.4), (1999.00, 879.3), (2000.00, 1055), (2001.00, 1231), (2002.00, 1407), (2003.00, 1583), (2004.00, 1759), (2005.00, 1934), (2006.00, 2110), (2007.00, 2286), (2008.00, 2462), (2009.00, 2638), (2010.00, 2814), (2011.00, 2990), (2012.00, 3166), (2013.00, 3341), (2014.00, 3517), (2015.00, 3693), (2016.00, 3869), (2017.00, 4045), (2018.00, 4221), (2019.00, 4397), (2020.00, 4572), (2021.00, 4748), (2022.00, 4924), (2023.00, 5100)

UNITS: acre

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

desired_capital = capital_stock*Smoothed_effect_by_expected_profitability

UNITS: dollar

DOCUMENT: The desired capital means the expected capital level in the market. It is the product of present capital level-capital stock and the effect from long-term expected profitability. The effect contains the consideration of farm size level.

desired_planting_supply = expected_acquisition_delay*(expected_acquisition_rate)

UNITS: dollar

DOCUMENT: The desired planting land represents for the desired planting area for the target type of plants. The equation is given by a principle of Little's Law that producers must maintain the supply line that equals to the expected acquisition delay times the desired acquisition rate. Using here, it is farmers must maintain a planting resource(like lands) equal to the expected harvest rate times expected acquisition delay.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p 806.

duration = 0.0833333333333

UNITS: per year

DOCUMENT: The duration represents for the time to plant seeds in land. It is set 0.08 year.

effect_of_animal_scale_in_Frederick = GRAPH(relative_animal_scale)

Points: (0.000, 0.6000), (0.100, 0.6106), (0.200, 0.6296), (0.300, 0.6550), (0.400, 0.6995), (0.500, 0.7439), (0.600, 0.7989), (0.700, 0.9259), (0.800, 0.9619), (0.900, 0.9852), (1.000, 1.0000), (1.100, 1.0000), (1.200, 1.0000), (1.300, 1.0000), (1.400, 1.0000), (1.500, 1.0000), (1.600, 1.0000), (1.700, 1.0000), (1.800, 1.0000), (1.900, 1.0000), (2.000, 0.9979)

UNITS: unitless

DOCUMENT: The table function shows how planting acreage decision will be effected by the change of animal scales. When animal scale ratio is over 1, there is no effect on the planting acreage. When the scale ratio is less than 1, decreasing from to 0, the effect will decrease increasingly from 1 to around 0.8, then decrease decreasingly to 0.6.

This indicates when there are less animals, they consider about decreasing corn production. But when there are more animals, they cannot increase the production capacity. The set of 0.6 is assumed from the proportion of farms that have animals. From the manure use proportion as a steady 0.4-0.45 from 1996 to 2000, we assume that farms with animals and manure supply take up 0.4 of total animals.

Although in the commodity production structure, we have used price to capture the market change including consumption effect on inventory deplete, we find the decreasing trend of planting acres might be closely related to the animal scale shrinking at the same time. Combined with the status of farms with animals to feed, we have this assumption.

The principle partly comes from

Meadows, 1971, Dynamics of Commodity Production Cycles, Chapter 6.

Data source:

U.S. Department of Agriculture,2023, https://www.ers.usda.gov/

effect_of_capacity_on_planting_acres = GRAPH(indicated_planting_with_land_preservation_policy/corn_planting_capacity)

Points: (0.000, 1.000), (0.050, 0.995), (0.100, 0.9874), (0.150, 0.9754), (0.200, 0.9566), (0.250, 0.9275), (0.300, 0.8835), (0.350, 0.8196), (0.400, 0.7324), (0.450, 0.6231), (0.500, 0.500), (0.550, 0.3769), (0.600, 0.2676), (0.650, 0.1804), (0.700, 0.1165), (0.750, 0.07251), (0.800, 0.04341), (0.850, 0.02463), (0.900, 0.01263), (0.950, 0.004963), (1.000, 0.000)

UNITS: unitless

DOCUMENT: The table functions shows a tough estimation of effect of corn planting capacity on planting acreage decision. When the planting acres is decreasing to 0, the effect will increase to 1 which means there is less limit from capacity. When the planting acres is approaching to 1, the effect will decrease decreasingly to 0, which means planting acres will increase very slow.

effect_of_expected_profitability_of_large_farm = GRAPH(expected_profitability_of_new_investment)

Points: (-1.000, 0.000), (-0.800, 0.571), (-0.600, 0.847), (-0.400, 1.000), (-0.200, 1.185), (0.000, 1.323), (0.200, 1.439), (0.400, 1.534), (0.600, 1.661), (0.800, 1.735), (1.000, 1.799)

UNITS: unitless

DOCUMENT: The variable shows how the desired capital would be effected by the expected profitability for large farms. From our assumption. Capital for large farms is less sensitive to the change of profitability. When the profitability is 0, the effect is still 1.32. When the profitability increase from 0 to 1, the effect increase decreasingly to 1.8 When the profitability is decreasing from 0 to -1, profit is negative, the effect decrease slowly. When the profitability is -0.4, the effect is 1, which means no change on desired capacity. When profitability is decreasing from -0.4 to -1, the effect decrease increasingly to 0. This describes that large farms have a less sensitive reaction to the change of profitability, as results of their large scale, long-term contract, high production efficiency and larger profit space than normal-sized farms and average level.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p807-810.

James M. MacDonald, Robert A. Hoppe, and Doris Newton, March,2018, USDA, Three Decades of Consolidation in U.S. Agriculture

effect_of_expected_profitability_of_normal_farm = GRAPH(expected_profitability_of_new_investment)

Points: (-1.000, 0.000), (-0.900, 0.0315), (-0.800, 0.063), (-0.700, 0.127), (-0.600, 0.212), (-0.500, 0.300), (-0.400, 0.451), (-0.300, 0.5725), (-0.200, 0.694), (-0.100, 0.847), (0.000, 1.000), (0.100, 1.217), (0.200, 1.365), (0.300, 1.503), (0.400, 1.587), (0.500, 1.640), (0.600, 1.704), (0.700, 1.746), (0.800, 1.767), (0.900, 1.788), (1.000, 1.810)

UNITS: unitless

DOCUMENT: The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p802-805.

The variable shows how the desired capital would be effected by the expected profitability by new investment. When the profitability is 0, there would be no new invest entering and the investors would like to keep present capital stock level. When the profitability decrease from 0 to -1, the profit is negative, the effect would decrease decreasingly to 0, which means invest willing will decrease to 0. When the profitability is higher than 0, increasing from 0 to 1, the profits space is positive and get larger, the effect will increase decreasingly to its highest level, which is finally around 1.8 with a result of market saturation. Generally, when the expected profitability is increasing from -1 to 1, the effect on desired capital on small farms experienced an increasing increasingly then shift to increasing decreasingly to its equilibrium, which shows an S-shaped growth.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p807-810.

expected_acquisition_delay = 1

UNITS: year

DOCUMENT: The expected acquisition delay is assumed as the sum of growth period duration and another few months' adjustment time. This indicates the period that farmers need to estimate, adjust and acquire capacity. Thus it is assumed to consist the growth period of plant and another half of year to sell and adjust other necessary resource to achieve new planing capacity. If modeled as simplification, the expected acquisition delay can be used as equal growth period duration. But in practice it can be much longer. So here we assume it as 1 year, a little longer than capital acquisition delay.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p 805-807.

expected_acquisition_rate = adjustment_of_capacity+expected_discard_rate

UNITS: dollar/Years

DOCUMENT: The variable represents for a total expected acquisition rate by producers or decision makers. It includes the replacement of expected loss from discard rate and the adjustment part of capital stock to its desired capital stock.

expected_discard_rate = capital_discard_rate

UNITS: dollar/Years

DOCUMENT: The variable of expected discard rate is the variable that is used for the capital discard rate. It is seen as part of expected acquisition rate. It is set as equal to capital discard rate.

"expected_long-term_planting_costs" = SMTH3(total_cost, "Time_to_adjust_long-term_expected_cost") {DELAY CONVERTER}

UNITS: dollar/bushel

DOCUMENT: The variables shows expected prices by investors. It is a smoothing of former cost with delay time to adjust.

"expected_long-term_price" = SMTH3(Price, "Time_to_adjust_long-term_expected_price") {DELAY CONVERTER}

UNITS: dollar/bushel

DOCUMENT: The variables represents for an expected prices by investors. It is a smoothing of present market price with delay time to adjust.

expected_markup =

"expected_short-term_price_by_farmers"/"expected_short-term_cost_by_farmers"

UNITS: unitless

DOCUMENT: The variable of expected markup represents for ratio of expected price to the expected planting cost by farmers.

expected_profitability_of_new_investment = ("expected_long-term_price"-"expected_long-term_planting_costs")/"expected_long-term_price"

UNITS: unitless

DOCUMENT: The ratio represents for the expected profitability for new investment. It is the division of gap between the expected price and expected cost of new capacity and the expected price. So it shows the profitability achievement level of the new investment.

"expected_short-term_cost_by_farmers" = SMTH1(variable_cost, "Time_to_adjust_short-term_expected_cost") {DELAY CONVERTER}

UNITS: dollar/bushel

DOCUMENT: The variable means a smooth on the practical cost with a short-term period.

"expected_short-term_price_by_farmers" = SMTH1(Price, Time_to_adjust_expected_price) {DELAY CONVERTER}

UNITS: dollar/bushel

DOCUMENT: The variable means a smooth on the practical price with a short-term period.

farming_land_in_Frederick = 181500

UNITS: acres

DOCUMENT: It means total farming land in Frederick county. The data comes from Frederick county government website in 2023.

final_effect_of_expected_profitability_of_new_investment = effect_of_expected_profitability_of_large_farm*Proportion_of_large_farm_in_total_land+effect_of_expected_profitability_of_normal_farm*(1-Proportion_of_large_farm_in_total_land)

UNITS: unitless

DOCUMENT: The variable represents for the final effect of expected profitability of new investment from a consideration of both farms of normal-sized and large farms, with their corresponding proportion.

growth_period = 0.5

UNITS: year

DOCUMENT: The growth period duration means the time between the plant starts growing till its harvest.

"historical_planting_acre(soybean)" = GRAPH(TIME)

Points: (2000.00, 20322), (2001.00, 18098), (2002.00, 16702), (2003.00, 15515), (2004.00, 15328), (2005.00, 15155), (2006.00, 15003), (2007.00, 14904), (2008.00, 16090), (2009.00, 17304), (2010.00, 18544), (2011.00, 19806), (2012.00, 21002), (2013.00, 24722), (2014.00, 27059), (2015.00, 29873), (2016.00, 32682), (2017.00, 35438), (2018.00, 36006), (2019.00, 36520), (2020.00, 37070), (2021.00, 37070)

UNITS: acre

DOCUMENT: The variable represents for the total planting acres of Soybean in Frederick.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

"historical_price_2000-2021(soybean)" = GRAPH(TIME)

Points: (2000.00, 4.45), (2001.00, 4.15), (2002.00, 5.20), (2003.00, 6.56), (2004.00, 5.60), (2005.00, 5.68), (2006.00, 5.54), (2007.00, 7.95), (2008.00, 10.48), (2009.00, 9.30), (2010.00, 9.56), (2011.00, 11.94), (2012.00, 14.21), (2013.00, 13.28), (2014.00, 10.88), (2015.00, 8.97), (2016.00, 9.46), (2017.00, 9.28), (2018.00, 8.61), (2019.00, 8.61), (2020.00, 9.67), (2021.00, 11.98) {GF EXTRAPOLATED}

UNITS: dollar/bushel

DOCUMENT: The data comes from external data from USDA--

Data source:

U.S. Department of Agriculture,2023, https://www.ers.usda.gov/

indicated_capacity_utilization = indicated_capacity_utilization_for_normal_farm*(1-Proportion_of_large_farm_in_total_land)+indicated_capacity_utilization_with_consideration_of_large_farm*Proportion_of_large_farm_in_total_land

UNITS: unitless

DOCUMENT: The variable represents for indicated capacity utilization that get the effects from two kinds of farms with their corresponding proportion. So its equation is the effect time corresponding proportion.

indicated_capacity_utilization_for_normal_farm = GRAPH(expected_markup)

Points: (0.400, 0.000), (0.530, 0.016), (0.660, 0.048), (0.790, 0.111), (0.920, 0.228), (1.050, 0.556), (1.180, 0.630), (1.310, 0.677), (1.440, 0.730), (1.570, 0.767), (1.700, 0.794), (1.830, 0.820), (1.960, 0.852), (2.090, 0.884), (2.220, 0.905), (2.350, 0.926), (2.480, 0.947), (2.610, 0.968), (2.740, 0.989), (2.870, 1.000), (3.000, 1.000)

UNITS: unitless

DOCUMENT: The table function describes how short-term expected markup effect the indicated utilization for small sized farm. When markup is around 1, the effect to indicated utilization is around 0.5. When the markup increase to 3, the effect would increase decreasingly to 1. When the markup decrease from 1 to 0.4, the effect would decrease quickly then decrease decreasingly to 0. This means when the markup is below 1, the production willing of small farms will decrease very fast to a very low level. When the markup is 0.79, the effect has decreased to 0.11. Finally it reaches 0 when markup is lower than 0.4.

This indicates for normal or small farms they react quickly with a low markup ratio as their smaller scale and low production efficiency than large farms.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p802-805.

indicated_capacity_utilization_with_consideration_of_large_farm = GRAPH(expected_markup)

Points: (0.400, 0.000), (0.530, 0.164), (0.660, 0.339), (0.790, 0.466), (0.920, 0.540), (1.050, 0.598), (1.180, 0.656), (1.310, 0.693), (1.440, 0.730), (1.570, 0.767), (1.700, 0.794), (1.830, 0.820), (1.960, 0.852), (2.090, 0.884), (2.220, 0.905), (2.350, 0.926), (2.480, 0.947), (2.610, 0.968), (2.740, 0.989), (2.870, 1.000), (3.000, 1.000)

UNITS: unitless

DOCUMENT: The table function describes how short-term expected markup effect the indicated utilization for small sized farm. When markup is around 1, the effect to indicated utilization is around 0.5. When the markup increase to 3, the effect would increase decreasingly to 1. When the markup decrease from 1 to 0.4, the effect would decrease quickly then decrease decreasingly to 0. This means when the markup is below 1, the effect would decrease as linear speed, which is much slower than small farms. When the markup is 0.5, there is still 0.16 of effect. When markup is below 0.4, the effect would be 0. This is because large farms have a higher production efficiency which enable them to decrease slowly when the markup is below 1.

The principle comes form Sterman, 2000, Business Dynamics, Chapter 20, p802-805.

indicated_orders = expected_acquisition_rate+adjustment_for_planting_supply

UNITS: dollar/Years

DOCUMENT: The variable represents for the indicated order for capital. It is the sum of expected acquisition rate and adjustment for planting supply.

indicated_planting_with_animal_scale_effect = IF SWITCH_animal_scale_to_planting=1 THEN indicated_planting_with_capacity_and_utilization*effect_of_animal_scale_in_Frederick ELSE indicated_planting_with_capacity_and_utilization

UNITS: acre/year

DOCUMENT: The variable represents for the the indicated planting acreage with effect of animal scale. It is the product of indicated planting with capacity and utilization

indicated_planting_with_capacity_and_utilization = production_capacity*SMTH_indicated_capacity_utilization

UNITS: Acres/Years

DOCUMENT: The variable of indicated planting represents for the indicated planting area by farmers. It is given by indicated planting with capital amount and capital utilization times effect from animal scale change.

indicated_planting_with_land_preservation_policy = IF SWITCH_land_preservation=1 THEN indicated_planting_with_animal_scale_effect*proportion_for_soybean_land_not_effected_by_preservation_policy ELSE indicated_planting_with_animal_scale_effect

UNITS: acre/year

DOCUMENT: The variable represents for the indicated planting with land preservation policy, so it is the product of indicated planting with animal scale effect times the proportion of corn land without preservation policy

installment_purchase_program = GRAPH(TIME)

Points: (2002.00, 0), (2002.72413793, 713.8), (2003.44827586, 1428), (2004.17241379, 2141), (2004.89655172, 2855), (2005.62068966, 3569), (2006.34482759, 4283), (2007.06896552, 4997), (2007.79310345, 5710), (2008.51724138, 6424), (2009.24137931, 7138), (2009.96551724, 7852), (2010.68965517, 8566), (2011.4137931, 9279), (2012.13793103, 9993), (2012.86206897, 10710), (2013.5862069, 11420), (2014.31034483, 12130), (2015.03448276, 12850), (2015.75862069, 13560), (2016.48275862, 14280), (2017.20689655, 14990), (2017.93103448, 15700), (2018.65517241, 16420), (2019.37931034, 17130), (2020.10344828, 17840), (2020.82758621, 18560), (2021.55172414, 19270), (2022.27586207, 19990), (2023.00, 20700)

UNITS: acre

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

interval = 1

UNITS: year

DOCUMENT: The variable means how many time the planting happens per year. It is set as 1 time.

Maryland_Agricultural_Land_Preservation_Foundation_MALPF = GRAPH(TIME)

Points: (1980.00, 0), (1981.48275862, 803.4), (1982.96551724, 1607), (1984.44827586, 2410), (1985.93103448, 3214), (1987.4137931, 4017), (1988.89655172, 4821), (1990.37931034, 5624), (1991.86206897, 6428), (1993.34482759, 7231), (1994.82758621, 8034), (1996.31034483, 8838), (1997.79310345, 9641), (1999.27586207, 10440), (2000.75862069, 11250), (2002.24137931, 12050), (2003.72413793, 12860), (2005.20689655, 13660), (2006.68965517, 14460), (2008.17241379, 15270), (2009.65517241, 16070), (2011.13793103, 16870), (2012.62068966, 17680), (2014.10344828, 18480), (2015.5862069, 19280), (2017.06896552, 20090), (2018.55172414, 20890), (2020.03448276, 21690), (2021.51724138, 22500), (2023.00, 23300)

UNITS: acre

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

Original_soybean_planting = 20322

UNITS: acres

DOCUMENT: The variable means the original soybean planting since we start the simulation.

per_year = 1

UNITS: per year

planting_increase = indicated_planting_with_land_preservation_policy*effect_of_capacity_on_planting_acres

UNITS: Acres/year

DOCUMENT: The variables represents for the final planting increase per year. It is the product of indicated planting with land preservation policy and the effect of capacity on planting.

planting_month = 0.25

UNITS: year

DOCUMENT: The variable represents for which month of year that planting starts. As the simulation time is by year, 0.25 means planting starts after 0.25 of time of the year.

planting_time = TIME

UNITS: year

DOCUMENT: The variable represents for the time for planting, it equals the time.

Price = IF SWITCH_for_Price =1 THEN with_price_prediction_1_stable_after_2021 ELSE with_price_prediction_2_price_cycle_assumption_after_2021

UNITS: dollar/bushel

DOCUMENT: The price comes from the historical price, Eastern Upland Corn Price, from USDA and the estimation after year of 2021.

Data source:

U.S. Department of Agriculture,2023, https://www.ers.usda.gov/
price_estimate_after_2021 = GRAPH(TIME)
Points: (2021.000, 11.98), (2021.800, 13.97), (2022.600, 12.91), (2023.400, 11.43), (2024.200, 9.63), (2025.000, 9.74)

UNITS: dollar/bushel

DOCUMENT: It shows the price after 2021 is estimated by the trend of price cycles with a period of 10 years.

production = harvest_rate*Nitrogen_Application.yield_by_structure/per_year

UNITS: bushel/Years

DOCUMENT: The variable shows yearly production, which is the product of harvest and yield.

production_capacity = capital_stock*capital_productivity

UNITS: Acres/Years

DOCUMENT: production capital shows the production achievement ability of the capital by the capital avaliable at present. It is the division of capital stock and the capital productivity.

proportion_for_soybean_land_not_effected_by_preservation_policy = 1-soybean_planting_land_under_preservation

UNITS: unitless

DOCUMENT: The proportion shows the part of soybean land that is not effected by preservation policy.

proportion_of_land_in_preservation = total_land_in_preservation_in_Frederick/farming_land_in_Frederick

UNITS: unitless

DOCUMENT: The variable is the proportion of how much farming land has been preserved by policies. It is the ratio of total land in preservation and the farming land.

Proportion_of_large_farm_in_total_land = 0.7

UNITS: unitless

DOCUMENT: The parameter of proportion of large farm is total land is evaluated from 50% ~70%, by the resource as following. This range would be tested in sensitivity test.

The principle comes from :

James M. MacDonald, Robert A. Hoppe, and Doris Newton, March,2018, USDA, Three Decades of Consolidation in U.S. Agriculture

"Consolidation was persistent: midpoint farm sizes increased in every inter-census period in 24 States that together accounted for nearly 77 percent of all U.S. cropland—Corn Belt, Delta, and Northern Plains States with dense concentrations of production" p32

This indicates that farm sizes have a general upgrade in the whole U.S. Here we assume as 0.7 for simulation. By adjusting this proportion we can see how this change on farm level could effect the commodity production for this type of plants.

"reference_planting_acres_2000_(soybean)" = 20322

UNITS: acre

DOCUMENT: The variable represents for the soybean planing acres in 2000. It is used as reference planting acres in the model.

Data source:

CAST, Chesapeake Assessment Scenario Tool, Phase 6, Source Data, https://cast.chesapeakebay.net/Home/SourceData

relative_animal_scale = Nitrogen_Application.animal_scales/Nitrogen_Application.reference_animal_scales

UNITS: unitless

DOCUMENT: The variable shows a ratio of Animal scales to reference animal scales.

Rural_Legacy = GRAPH(TIME)

Points: (1997.00, 0), (1997.89655172, 231), (1998.79310345, 462.1), (1999.68965517, 693.1), (2000.5862069, 924.1), (2001.48275862, 1155), (2002.37931034, 1386), (2003.27586207, 1617), (2004.17241379, 1848), (2005.06896552, 2079), (2005.96551724, 2310), (2006.86206897, 2541), (2007.75862069, 2772), (2008.65517241, 3003), (2009.55172414, 3234), (2010.44827586, 3466), (2011.34482759, 3697), (2012.24137931, 3928), (2013.13793103, 4159), (2014.03448276, 4390), (2014.93103448, 4621), (2015.82758621, 4852), (2016.72413793, 5083), (2017.62068966, 5314), (2018.51724138, 5545), (2019.4137931, 5776), (2020.31034483, 6007), (2021.20689655, 6238), (2022.10344828, 6469), (2023.00, 6700)

UNITS: Acres

DOCUMENT: The variable represents for one type of land preservation policy conducted in Frederick county. The data comes from Frederick county government website, which supplies policy starting time and achievement till 2023. We assume it increases by a linear increasing in the past years.

Smoothed_effect_by_expected_profitability = SMTH3(final_effect_of_expected_profitability_of_new_investment, adjustment_time_for_effect_by_expected_profitability)

UNITS: unitless

DOCUMENT: The variable shows a Smoothed effect by expected profitability on desired capital with an adjustment delay, as the capital decision makers or producers need time to accept for the change of profitability.

SMTH_indicated_capacity_utilization = SMTH3(indicated_capacity_utilization, utilization_adjustment_time) {DELAY CONVERTER}

UNITS: unitless

DOCUMENT: It reflects the the acceptance course for farmers to get and decide on indicted capital utilization under an adjustment time. So the equation is a smooth of indicated capacity utilization with utilization adjustment time.

soybean_planting_land_under_preservation = proportion_of_land_in_preservation*soybean_planting_proportion

UNITS: unitless

DOCUMENT: The variable represents for the proportion of corn land under preservation.

soybean_planting_proportion = Original_soybean_planting/farming_land_in_Frederick

UNITS: unitless

DOCUMENT: The variable means the proportion of soybean planting in all farm land. It is the ratio of the original corn acres and the total farming land in the county.

SWITCH_animal_scale_to_planting = 1

UNITS: unitless

DOCUMENT: Switch=1, there is effect of animal scale;

Switch =0, there is no effect of animal scale

SWITCH_for_Price = 1

UNITS: unitless

DOCUMENT: The switch gives two policy for price after 2021:

1 The price is given as the average of last year of historical price.

2 The price is given as an estimated shape based by assumption of price cycles in the past 20 years.

SWITCH_land_preservation = 1

UNITS: unitless

DOCUMENT: Switch=1, there is effect of land preservation policy;

Switch =0, there is no effect of land preservation policy.

Time_to_adjust_expected_price = 1.6

UNITS: year

DOCUMENT: The variable represents for the time to get a short-term expected price by farmers, which is assumed to be no longer than 3 years.

It is set by a comparison with the price received by farmer from USDA-National Agricultural Status Service.

We assume it as 1.6 years.

https://www.ers.usda.gov/topics/crops/corn-and-other-feed-grains/feed-grains-sector-at-a-glance/

It is also indicated by Meadows, 1971, Dynamics of commodity production 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".

So assume a value around 1 - 2 years can be reasonable range and we pick up for 1.6 by the indication from comparison of historical data of USDA.

"Time_to_adjust_long-term_expected_cost" = 6

UNITS: year

DOCUMENT: It shows the time for capital decider to get a long-term expected cost, which is assumed to be longer than short-term time to be accepted by farmer or producer.

Capital adjustment refers to all the related resource management and upgrade, which is much complex than the decision for utilization rate. So it is assumed to be longer than the price accepting time by farmer or producer. It is set no shorter than 5 years. We use 6 years here, which is half of a circle of cattle cycles as the plant is mainly used for feeding cattle.

The value is an estimation, which refers to parameters/ delays discussion of Sterman in Business Dynamics, Chapter 20.

"Time_to_adjust_long-term_expected_price" = 6

UNITS: year

DOCUMENT: The variable represents for the delay time for capital deciders to get a long-term expected price because they need integrate the information and estimate an trend from the past few years of price and cost. Capital adjustment refers to all the related resource management and upgrade, which is much complex than the decision for utilization rate. So it is assumed to be longer than the price accepting time by farmer or producer. It is set no shorter than 5 years. We use 6 years here, which is half of a circle of cattle cycles as the plant is mainly used for feeding cattle.

The value is an estimation, which refers to parameters/ delays discussion of Sterman in Business Dynamics, Chapter 20.

Time_to_adjust_planting = time_to_adjust_planting_for_large_farm*Proportion_of_large_farm_in_total_land+time_to_adjust_planting_normal_farm*(1-Proportion_of_large_farm_in_total_land)

UNITS: year

DOCUMENT: The variables represents for the general adjustment time that farmers need to adjust the planting land or change planting types. It is the average of adjustment time from two type of farm sizes with their corresponding proportion.

time_to_adjust_planting_for_large_farm = 5

UNITS: year

DOCUMENT: The parameters represents for the adjustment time for large farms to adjust planting types in land. It is assumed to be 5 years. We have considered the less sensitive of large farms to markets, long-term contracts with retailers and corresponding equipment and machines for some type of planting use, which are all seen as prevent large farms to adjust planting in land as quickly as normal-sized farms.

time_to_adjust_planting_normal_farm = 1.5

UNITS: year

DOCUMENT: The delay time for producers/farmers to adjust planting type in land. Planting needs long time to adjust as long as seeds are broadcast to land. and planting needs preparation of months before broadcast. It is set as 2 years, which is estimated to include two types of plants that grow up in different season. Thus we estimate farmers spend 2 years to adjust the utilization rate.

"Time_to_adjust_short-term_expected_cost" = 2

UNITS: year

DOCUMENT: The variable represents for the time to get a short-term expected cost by farmers, which is assumed to be no longer than 3 years. We assume the farmers would estimate variable cost or operational cost of the recent two years.

The value is an estimation, which refers to parameters/ delays discussion of Sterman in Business Dynamics, Chapter 20.

It is also indicated by Meadows, 1971, Dynamics of commodity production 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".

So we assume a 2 years' delay is a reasonable value.

total_cost = IF TIME<21 OR TIME=21 THEN "total_cost_2000-2021(soybean)" ELSE (HISTORY("total_cost_2000-2021(soybean)", TIME-1)+HISTORY("total_cost_2000-2021(soybean)", TIME-2)+HISTORY("total_cost_2000-2021(soybean)", TIME-3))/3 { 8.03}

UNITS: dollar/bushel

DOCUMENT: The variable means the total cost for corn planting. The data before 2021 comes from historical data of USDA, and the data after 2021 comes from average cost of the last three years.

"total_cost_2000-2021(soybean)" = GRAPH(TIME)

Points: (2000.00, 6.197560976), (2001.00, 6.141395349), (2002.00, 5.80), (2003.00, 6.624722222), (2004.00, 5.533555556), (2005.00, 5.625319149), (2006.00, 6.045434783), (2007.00, 6.601111111), (2008.00, 7.783488372), (2009.00, 7.622765957), (2010.00, 7.746595745), (2011.00, 8.705454545), (2012.00, 10.41880952), (2013.00, 10.65837209), (2014.00, 9.723333333), (2015.00, 9.652083333), (2016.00, 8.528076923), (2017.00, 9.051020408), (2018.00, 9.355849057), (2019.00, 9.9528), (2020.00, 9.107777778), (2021.00, 9.845740741)

UNITS: dollar/bushel

DOCUMENT: The data comes from external data from USDA--

soybean production costs and returns per planted acre, excluding Government payments, Eastern Uplands, Total cost.

total_land_in_preservation_in_Frederick = Agricultural_preservation+Critical_farms+Critical_farms+installment_purchase_program+Maryland_Agricultural_Land_Preservation_Foundation_MALPF+Rural_Legacy+Conservation_reserve_enhancement_program

UNITS: Acres

DOCUMENT: The variable represents for the total land under preservation policies in Frederick. It is the sum of all the polices conducted in the past years.

trigger_planting = IF TIME MOD 1=planting_month THEN 1 ELSE 0

UNITS: unitless

DOCUMENT: The variable means the only in the specific month that planting would starts. The equitation limits the specific month that planting can be given.

utilization_adjustment_time = 2

UNITS: year

DOCUMENT: The delay time for producers/farmers to decide to accept and change the indicated capacity utilization by market price and cost effect. Planting needs long time to adjust as long as seeds are broadcast to land. and planting needs preparation of months before broadcast. It is set as 2 years, which is estimated to include two types of plants that grow up in different season. Thus we estimate farmers spend 2 years to adjust the utilization rate.

variable_cost = IF TIME<2021 OR TIME=2021 THEN "variable_cost_2000-2021(soybean)" ELSE HISTORY("variable_cost_2000-2021(soybean)", 2021)

UNITS: dollar/bushel

DOCUMENT: This variable represents for the variable cost of corn planting. It equals historical data from USDA before 2022 and from estimation after 2022.

"variable_cost_2000-2021(soybean)" = GRAPH(TIME)

Points: (2000.00, 4.73), (2001.00, 4.16), (2002.00, 4.69), (2003.00, 5.20), (2004.00, 3.51), (2005.00, 3.41), (2006.00, 3.63), (2007.00, 3.93), (2008.00, 4.11), (2009.00, 3.67), (2010.00, 2.91), (2011.00, 3.00), (2012.00, 3.11), (2013.00, 2.97), (2014.00, 2.22), (2015.00, 1.95), (2016.00, 1.73), (2017.00, 1.67), (2018.00, 1.47), (2019.00, 1.47), (2020.00, 1.52), (2021.00, 1.43)

UNITS: dollar/bushel

DOCUMENT: The data comes from external data from USDA--

Data source:

U.S. Department of Agriculture,2023, https://www.ers.usda.gov/

with_price_prediction_1_stable_after_2021 = IF TIME<2022 THEN "historical_price_2000-2021(soybean)" ELSE HISTORY("historical_price_2000-2021(soybean)", 2021)

UNITS: dollar/bushel

DOCUMENT: The variable describes that before 2021 the simulation refers to historical data and after 2021 the price is assumed to be steady as the level of 2021.

with_price_prediction_2_price_cycle_assumption_after_2021 = IF TIME< 2022 THEN"historical_price_2000-2021(soybean)" ELSE price_estimate_after_2021

UNITS: dollar/bushel

DOCUMENT: The variable describes that before 2021 the simulation refers to historical data and after 2021 the price is estimated by the trend of price cycles with a period of 10 years. The shape is captured from the historical price data trend.