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Appendix A. Soil Carbon, Nitrogen, and Phosphorus Benchmarking Results

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The Cycles Agroecosystem Model was used to develop soil organic carbon benchmark levels for different crop rotations and management practices in five representative locations of the Chesapeake Bay watershed in Pennsylvania and Maryland. One of the goals of the benchmarking was to use the model outputs to identify combinations of management practices that optimize for high soil carbon, low N losses in leaching and volatilization, and balanced P inputs. A secondary goal was to provide target soil organic carbon levels that could be achieved under different management practices so that farmers could have a reference point for interpreting their own soil C levels and determine the potential room for improvement.

We developed simulations for 6 crop rotations that are common within the Chesapeake Bay watershed: continuous corn grain, corn grain rotated with soybean, continuous corn silage, continuous corn silage with a harvested rye cover crop, corn silage rotated with alfalfa, and corn silage rotated with alfalfa with a harvested rye cover crop between corn plantings. Within each type of crop rotation, we evaluated the effect of tillage through management scenarios that were either continuous no-till or with annual tillage. Within each tillage type, we then tested a baseline scenario where crops were managed with nitrogen fertilizer, a scenario that added a cereal rye winter cover crop, and scenarios that added the cover crop and either manure applied to meet the P removal of non-legume crops in the rotation or manure added to meet the N requirement of non-legume crops in the rotation.

We took a systems approach to determining the manure types and application rates used in the different rotations and tillage scenarios. In the corn grain and corn-soybean rotations we used poultry litter, because cash grain operations in this region are often producing grains for the poultry industry. In the corn silage and corn silage-alfalfa rotations we used dairy manure, since these crop rotations are primarily used on farms with dairy herds. The nitrogen, phosphorus, and potassium content of the manures were based on typical nutrient values contained in the Penn State Agronomy Guide. The fraction of ammonium N and organic N in each manure type was based on an analysis of a historical manure sample databased from the Penn State Agricultural Analytical Services lab, resulting in a distribution of 20% ammonium N and 80% organic N for poultry litter and 50% ammonium N and 50% organic N for dairy manure. The carbon content of manures was also estimated based on an analysis of the Penn State Agricultural Analytical Services lab manure database, resulting in a relationship where the carbon concentration is 35% of the dry matter content of the manure. In our simulations, poultry litter had 67% dry matter and dairy manure had 7.5% dry matter based on typical values in the Penn State Agronomy Guide.

To determine P-based manure application rates to non-legumes in the rotation, we used typical P2O5 removal values for different crops from the Penn State Agronomy Guide and applied a manure rate to match the P removal based on the manure P2O5 analysis. The N availability from manure applied at the P-based rate was determined using ammonium N and organic N availability factors from the Penn State Agronomy Guide, which account for volatilization losses of the ammonium content and partial decomposition of the organic N content in the year of application. For scenarios with annual tillage, the ammonium N availability factor for incorporation after 1 day was used, while no-till scenarios used the ammonium N availability factor for no incorporation. Because P-based manure rates typically do not

supply enough N to the crop, we calculated the additional amount of N fertilizer needed to meet the crop requirement after accounting for the N available in the manure applied and any N credits for a previous legume crop and the residual manure history of the previous five years, using legume and historical manure N credits from the Penn State Agronomy Guide. Because no-till management of manures typically have greater volatilization losses of ammonium, the N fertilizer required to meet the crop needs was always greater in the no-till scenarios.

To determine N-based manure application rates to non-legumes, we calculated the net crop N requirement based on N fertilizer recommendations in the Penn State Agronomy Guide and subtracting N credits for a previous legume crop in rotation and the frequency of manure applications in the last 5 years. The net crop N requirement was then fulfilled with manure application rates calculated to supply the necessary quantity of available N, using ammonium N availability factors based on 1 day incorporation for tillage scenarios and no incorporation for no-till scenarios. Using this systems approach to manure application rates, manure applied to meet N requirements in the no-till scenarios was always greater than in the tillage scenarios, because manure that is not incorporated has greater volatilization losses and less available N compared to manure that is incorporated. The increased manure application rates in no-till scenarios also result in increased carbon and phosphorus applied relative to tillage scenarios. This is an important point to remember when interpreting and comparing the outcomes of no-till and tillage scenarios.

In our scenarios we chose to only apply manure to non-legumes in the rotation, because legumes in the rotation would not benefit from any N contained in the manure. For each scenario, we calculated the system level annual P balance as manure P applied to non-legumes over the rotation minus crop P removal by all crops in the rotation, divided by the number of years in the rotation. In scenarios without manure applied, the system level P balance is always negative, reflecting the potential for crop P removal to draw down soil P levels. In P based manure scenarios, rotations with only non-legumes will have a zero P balance because manure rates are applied to meet the P removals of non-legumes. Rotations with legumes that are managed with P-based manure rates in our scenarios will have a negative P balance due to the additional P removal of the legumes. System level P balances in the N-based manure scenarios are dependent on the manure rates needed to achieve N requirements for the non-legumes and the extent of legume crop P removal in the rotation.

The Cycles agroecosystem model operates by taking management practices specified by the user, such as crop rotation, tillage, fertilizer and manure applications, and implementing them on a daily time step. Users also specify a soil profile description with varying soil depth segments that have a specific sand, silt, and clay content. The lowest depth segment represents the bottom of the soil profile, and is the furthest extent to which roots can grow and to which water, carbon and nitrogen can be stored. Water and nitrogen that drains out of the last layer is lost from the system as leaching. Deeper soil profiles can generally support higher crop yields due to available water holding capacity and can achieve a higher soil profile C mass from the contribution of increased subsoil C. Cycles uses a historical weather file to determine temperature, humidity, rainfall, solar radiation and wind speed on each day of the simulation. We generated weather files from the NASA National Land Data Assimilation System database that span from 1980 to 2020 for the five representative locations: Tioga, Union, and Lebanon counties in Pennsylvania and Carroll and Caroline counties in Maryland. Based on the weather that occurs and the management practices specified by the user, Cycles calculates crop growth, crop nutrient and water uptake, crop residue recycling, and transformations of carbon and nitrogen in each soil layer

each day. Detailed outputs from the model for crop growth and soil carbon and nitrogen pools are available on daily and annual time scales.

In our benchmarking results, we report soil organic C concentration (%) in 0-2", 2-4", and 4-8" depth segments of the topsoil to illustrate issues of stratification in no-till systems, as well as a weighted average soil C concentration of the 0-8" layer, which can be compared to typical soil sampling depths used for soil fertility monitoring. We also report the entire soil profile C storage, which is a measurement of soil C concentration (%) multiplied by the soil mass of each layer, summed to the bottom of the soil profile. This value represents the potential for different management systems to sequester C in the entire profile, which is the most relevant metric for soil C sequestration to mitigate climate change. Finally, we report the system level annual P balance, calculated as previously described, and the annual nitrate leaching and ammonia volatilization rates as calculated by the Cycles model.

Tioga County, Pennsylvania

Geographic Location: Tioga County, PA; 41°47'N, 77° 07'W, Mean Annual Temp: 47 °F and 36.7" Precipitation

Soil Series/Profile Description: The soil at this site was a Volusia series. Soil depth at the site was 52 inches and was comprised of four distinct layers. The 0–8-inch layer was 18% clay and 22% sand. The 8–16-inch layer was 20% clay and 20% sand. The 16–28-inch layer was 22% clay and 33% sand. The 28–52-inch layer was 21% clay and 35% sand.

Crop Rotation Description: Continuous Corn Grain

Results in the table below are for a continuous corn grain rotation. Corn was planted on May 20th in each year of the rotation and corn residues were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on May 12th. In scenarios with manure, poultry litter was applied on May 13th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. Average corn grain yield was 184 bushels/acre. Cover crop biomass ranged from 196 to 598 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2"	1.9	1.9	2.0	2.3	1.0	1.0	1.1	1.4
%C, 2-4"	1.2	1.2	1.3	1.4	1.0	1.0	1.1	1.3
%C, 4-8"	0.4	0.4	0.4	0.4	1.0	1.0	1.1	1.3
%C, 0-8"	1.0	1.0	1.0	1.1	1.0	1.0	1.1	1.3
Profile C (Mg/ha)	59.9	60.6	62.9	67.9	61.0	62.1	66.8	74.7
Manure P balance (lbs P_2O_5/acre/yr)	-60	-60	0	147	-60	-60	0	108
NO_3^- leaching (lbs/acre/yr)	1.6	1.6	1.7	3.4	1.8	1.7	1.7	2.6
NH_3 volatilization (lbs/acre/yr)	17.2	17.4	21.1	33.8	13.4	13.8	15.3	21.7

Tioga County, Pennsylvania

Crop Rotation Description: Corn Grain – Soybean

Results in the table below are for a corn grain – soybean rotation. Corn and soybeans were planted on May 20th in their respective years in the rotation and residues from both were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on May 12th. In scenarios with manure, poultry litter was applied to corn on May 13th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. There was no manure applied in soybean years. Average corn grain yield was 197 bushels/acre and average soybean grain yield was 63 bushels/acre. Cover crop biomass ranged from 437 to 571 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.7	1.8	1.9	2.0	0.9	0.9	1.0	1.1
%C, 2-4”	1.1	1.1	1.2	1.3	0.8	0.9	1.0	1.0
%C, 4-8”	0.3	0.4	0.4	0.4	0.8	0.9	1.0	1.0
%C, 0-8”	0.9	0.9	0.9	1.0	0.9	0.9	1.0	1.1
Profile C (Mg/ha)	52.8	55.6	56.4	58.5	52.1	55.1	57.0	60.1
Manure P balance (lbs P_2O_5/acre/yr)	-110	-110	-50	47	-110	-110	-50	17
NO_3^- leaching (lbs/acre/yr)	2.6	2.5	2.3	2.9	2.7	2.4	2.2	2.5
NH_3 volatilization (lbs/acre/yr)	11.7	12.0	12.9	17.6	10.3	11.2	10.6	12.7

Tioga County, Pennsylvania

Crop Rotation Description: Continuous Corn Silage

Results in the table below are for a continuous corn silage rotation. Corn was planted on May 20th and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on May 12th. In scenarios with manure, liquid dairy manure was applied on May 13th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 23,016 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,902 gal/acre. Average corn silage yield was 20.05 tons/acre. Average cover crop biomass ranged from 732 to 2,801 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	0.9	1.1	2.1	2.4	0.5	0.6	1.1	1.3
%C, 2-4”	0.7	0.8	1.5	1.7	0.5	0.6	1.1	1.3
%C, 4-8”	0.4	0.4	0.6	0.6	0.5	0.6	1.1	1.3
%C, 0-8”	0.6	0.7	1.2	1.3	0.5	0.6	1.1	1.3
Profile C (Mg/ha)	49.9	53.5	80.0	85.0	46.5	53.2	75.8	80.8
Manure P balance (lbs P_2O_5/acre/yr)	-100	-100	0	199	-100	-100	0	42
NO_3^- leaching (lbs/acre/yr)	0.8	0.9	9.3	233.8	1.0	0.8	2.1	5.8
NH_3 volatilization (lbs/acre/yr)	32.6	32.6	56.6	109.0	16.3	18.0	31.3	38.2

Tioga County, Pennsylvania

Crop Rotation Description: Continuous Corn Silage – Cover Crop Harvested

Results in the table below are for a continuous rotation of corn silage and a harvested cover crop. Corn was planted on June 3rd in each year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on September 7th and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received manure to meet either P removal or N requirements. For corn, manure was applied on May 27th as liquid dairy manure. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 21,418 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,145 gal/acre. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,524 gal/acre. Average corn silage yield was 18.86 tons/acre and average cereal rye forage yield was 2,603 lbs/acre dry matter.

	No-Tillage			Tillage		
	+ Harvested Cover Crops	+ CC Harvested + Manure P	+ CC Harvested +Manure N	+ Harvested Cover Crops	+ CC Harvested + Manure P	+ CC Harvested +Manure N
%C, 0-2”	1.1	2.1	2.5	0.6	1.2	1.5
%C, 2-4”	0.9	1.4	1.6	0.6	1.2	1.4
%C, 4-8”	0.5	0.5	0.5	0.6	1.2	1.5
%C, 0-8”	0.7	1.2	1.3	0.6	1.2	1.5
Profile C (Mg/ha)	58.0	76.8	81.3	55.5	77.6	85.0
Manure P balance (lbs P_2O_5/acre/yr)	-142	0	234	-142	0	88
NO_3^- leaching (lbs/acre/yr)	0.6	4.0	189.3	0.8	3.3	20.3
NH_3 volatilization (lbs/acre/yr)	55.3	100.5	189.2	38.0	60.4	87.7

Tioga County, Pennsylvania

Crop Rotation Description: Corn Silage – Alfalfa Hay

Results in the table below are for a corn silage – alfalfa rotation, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on May 20th in each corn year of the rotation and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on May 12th. In scenarios with manure, liquid dairy manure was applied on May 13th in corn years. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 7,937 gal/acre in the first year of corn and 25,397 gal/acre in years two and three. In the tillage scenarios, The P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 3,759 gal/acre in the first year of corn and 12,030 gal/acre in years two and three. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 19.42 tons/acre. Cover crop biomass ranged from 1,838 to 1,927 lbs/acre dry matter at the time of termination. Average alfalfa forage yield was 2,498 lbs/acre/cutting dry matter with 4-5 cuttings per year.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.3	1.6	1.9	2.2	0.8	1.0	1.2	1.2
%C, 2-4”	1.0	1.1	1.3	1.4	0.8	0.9	1.2	1.2
%C, 4-8”	0.7	0.8	0.8	0.8	0.8	0.9	1.2	1.2
%C, 0-8”	0.9	1.1	1.2	1.3	0.8	0.9	1.2	1.2
Profile C (Mg/ha)	86.3	96.5	100.5	103.7	81.8	89.3	96.7	98.2
Manure P balance (lbs P_2O_5/acre/yr)	-85	-85	-70	84	-85	-85	-70	-49
NO_3^- leaching (lbs/acre/yr)	3.7	1.4	1.9	6.2	4.5	2.2	2.9	2.3
NH_3 volatilization (lbs/acre/yr)	27.2	27.2	37.4	57.9	19.8	22.0	27.0	27.6

Tioga County, Pennsylvania

Crop Rotation Description: Corn Silage- Alfalfa Hay – Cover Crop Harvested

Results in the table below are for a corn silage – alfalfa rotation and a harvested cover crop, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on June 3rd in each corn year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on September 7th in the first and second corn year and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received liquid dairy manure to meet either P removal or N requirements. For corn, manure was applied on May 27th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 5,534 gal/acre in the first year of corn and 22,995 gal/acre in years two and three. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre in all three years and the N-based manure rate was 2,622 gal/acre in the first year of corn and 10,892 gal/acre in years two and three. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,905 gal/acre. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 17.65 tons/acre. Average cereal rye forage yield was 3,524 lbs/acre dry matter. Average alfalfa forage yield was 2,516 lbs/acre/cutting dry matter with 4-5 cuttings per year.

	No-Tillage			Tillage		
	+ Harvested Cover Crops	+ CC Harvested + Manure P	+ CC Harvested +Manure N	+ Harvested Cover Crops	+ CC Harvested + Manure P	+ CC Harvested +Manure N
%C, 0-2”	1.4	2.0	2.3	0.9	1.2	1.3
%C, 2-4”	1.1	1.3	1.4	0.9	1.2	1.3
%C, 4-8”	0.8	0.8	0.8	0.9	1.2	1.3
%C, 0-8”	1.0	1.2	1.3	0.9	1.2	1.3
Profile C (Mg/ha)	93.8	98.9	102.2	88.1	97.7	101.1
Manure P balance (lbs P_2O_5/acre/yr)	-99	-70	114	-99	-70	-3
NO_3^- leaching (lbs/acre/yr)	1.2	2.4	6.0	1.8	3.0	2.4
NH_3 volatilization (lbs/acre/yr)	34.6	52.3	82.5	27.2	36.8	44.5

Union County, Pennsylvania

Geographic Location: Union County, PA; 40°58'N, 77° 04'W, Mean Annual Temp: 52 °F and 43.6" Precipitation

Soil Series/Profile Description: The soil at this site was an Edom series. The soil depth at the site was 39 inches and was comprised of two distinct layers. The 0–8-inch soil layer was 25% clay and 24% sand. The 8–39-inch soil layer was 39% clay and 6% sand.

Crop Rotation Description: Continuous Corn Grain

Results in the table below are for a continuous corn grain rotation. Corn was planted on May 5th in each year of the rotation and corn residues were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on April 29th. In scenarios with manure, poultry litter was applied on April 30th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. Average corn grain yield was 192 bushels/acre. Cover crop biomass ranged from 185 to 791 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2"	2.0	2.1	2.2	2.5	1.1	1.1	1.3	1.5
%C, 2-4"	1.2	1.2	1.3	1.5	1.1	1.1	1.2	1.5
%C, 4-8"	0.4	0.4	0.4	0.5	1.1	1.1	1.2	1.5
%C, 0-8"	1.0	1.0	1.1	1.2	1.1	1.1	1.2	1.5
Profile C (Mg/ha)	61.4	62.4	64.6	69.8	62.6	63.7	68.7	78.8
Manure P balance (lbs P_2O_5/acre/yr)	-60	-60	0	147	-60	-60	0	108
NO_3^- leaching (lbs/acre/yr)	4.4	4.5	5.6	12.5	5.0	4.9	6.1	10.0
NH_3 volatilization (lbs/acre/yr)	13.2	13.4	17.2	28.4	10.2	10.5	12.1	17.5

Union County, Pennsylvania

Crop Rotation Description: Corn Grain – Soybean

Results in the table below are for a corn grain – soybean rotation. Corn and soybeans were planted on May 5th in their respective years in the rotation and residues from both were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on April 29th. In scenarios with manure, poultry litter was applied to corn on April 30th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. There was no manure applied in soybean years. Average corn grain yield was 211 bushels/acre and average soybean grain yield was 67 bushels/acre. Cover crop biomass ranged from 516 to 735 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.9	2.0	2.1	2.2	1.0	1.1	1.1	1.2
%C, 2-4”	1.1	1.1	1.2	1.3	1.0	1.0	1.1	1.2
%C, 4-8”	0.3	0.4	0.4	0.4	1.0	1.0	1.1	1.2
%C, 0-8”	0.9	1.0	1.0	1.1	1.0	1.0	1.1	1.2
Profile C (Mg/ha)	53.7	57.1	57.9	60.3	54.8	58.1	59.7	63.2
Manure P balance (lbs P_2O_5/acre/yr)	-110	-110	-50	47	-110	-110	-50	17
NO_3^- leaching (lbs/acre/yr)	10.0	9.5	9.5	11.2	10.0	9.4	9.5	10.7
NH_3 volatilization (lbs/acre/yr)	9.7	9.6	10.6	14.5	8.3	8.9	8.5	10.2

Union County, Pennsylvania

Crop Rotation Description: Continuous Corn Silage

Results in the table below are for a continuous corn silage rotation. Corn was planted on May 5th and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on April 29th. In scenarios with manure, liquid dairy manure was applied on April 30th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 23,016 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,902 gal/acre. Average corn silage yield was 22.51 tons/acre. Average cover crop biomass ranged from 650 to 4,149 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.1	1.3	2.4	2.7	0.6	0.7	1.3	1.5
%C, 2-4”	0.8	0.9	1.6	1.8	0.6	0.7	1.3	1.5
%C, 4-8”	0.4	0.5	0.6	0.6	0.6	0.7	1.3	1.5
%C, 0-8”	0.7	0.8	1.3	1.4	0.6	0.7	1.3	1.5
Profile C (Mg/ha)	52.7	57.2	79.4	88.0	49.5	54.7	75.9	83.0
Manure P balance (lbs P_2O_5/acre/yr)	-100	-100	0	199	-100	-100	0	42
NO_3^- leaching (lbs/acre/yr)	3.0	2.2	17.8	218.9	3.6	2.2	6.3	10.1
NH_3 volatilization (lbs/acre/yr)	26.8	26.1	40.2	70.8	13.0	13.8	23.7	28.3

Union County, Pennsylvania

Crop Rotation Description: Continuous Corn Silage – Cover Crop Harvested

Results in the table below are for a continuous rotation of corn silage and a harvested cover crop. Corn was planted on May 19th in each year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on October 1st and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received manure to meet either P removal or N requirements. For corn, manure was applied on May 14th as liquid dairy manure. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 21,418 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,145 gal/acre. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,524 gal/acre. Average corn silage yield was 20.94 tons/acre and average cereal rye forage yield was 2,965 lbs/acre dry matter.

	No-Tillage			Tillage		
	+ Cover Crops Harvested	+ CC Harvested + Manure P	+ CC Harvested +Manure N	+ Cover Crops Harvested	+ CC Harvested + Manure P	+ CC Harvested +Manure N
%C, 0-2”	1.4	2.4	2.7	0.7	1.4	1.7
%C, 2-4”	1.0	1.6	1.8	0.7	1.4	1.7
%C, 4-8”	0.5	0.6	0.6	0.7	1.4	1.7
%C, 0-8”	0.8	1.3	1.4	0.7	1.4	1.7
Profile C (Mg/ha)	62.4	80.9	85.7	58.4	83.3	91.9
Manure P balance (lbs P_2O_5/acre/yr)	-142	0	234	-142	0	88
NO_3^- leaching (lbs/acre/yr)	3.5	19.4	55.0	3.9	10.4	21.9
NH_3 volatilization (lbs/acre/yr)	43.8	75.9	106.3	32.2	49.7	71.9

Union County, Pennsylvania

Crop Rotation Description: Corn Silage – Alfalfa Hay

Results in the table below are for a corn silage – alfalfa rotation, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on May 5th in each corn year of the rotation and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on April 29th. In scenarios with manure, liquid dairy manure was applied on April 30th in corn years. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 7,937 gal/acre in the first year of corn and 25,397 gal/acre in years two and three. In the tillage scenarios, The P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 3,759 gal/acre in the first year of corn and 12,030 gal/acre in years two and three. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 21.94 tons/acre. Cover crop biomass ranged from 1,972 to 2,980 lbs/acre dry matter at the time of termination. Average alfalfa forage yield was 2,245 lbs/acre/cutting dry matter with 5-7 cuttings per year.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.4	1.7	2.2	2.5	0.9	1.1	1.3	1.4
%C, 2-4”	1.0	1.2	1.3	1.5	0.9	1.0	1.3	1.3
%C, 4-8”	0.7	0.8	0.8	0.8	0.9	1.0	1.3	1.3
%C, 0-8”	1.0	1.1	1.3	1.4	0.9	1.0	1.3	1.4
Profile C (Mg/ha)	84.5	92.6	99.0	102.8	81.3	88.8	97.6	99.0
Manure P balance (lbs P_2O_5/acre/yr)	-85	-85	-70	84	-85	-85	-70	-49
NO_3^- leaching (lbs/acre/yr)	8.7	5.7	11.7	34.8	10.0	6.6	8.6	8.3
NH_3 volatilization (lbs/acre/yr)	22.9	21.8	29.7	42.9	16.4	17.8	22.0	22.5

Union County, Pennsylvania

Crop Rotation Description: Corn Silage- Alfalfa Hay – Cover Crop Harvested

Results in the table below are for a corn silage – alfalfa rotation and a harvested cover crop, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on May 19th in each corn year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on October 1st in the first and second corn year and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received liquid dairy manure to meet either P removal or N requirements. For corn, manure was applied on May 14th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 5,534 gal/acre in the first year of corn and 22,995 gal/acre in years two and three. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre in all three years and the N-based manure rate was 2,622 gal/acre in the first year of corn and 10,892 gal/acre in years two and three. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,905 gal/acre. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 19.71 tons/acre. Average cereal rye forage yield was 3,903 lbs/acre dry matter. Average alfalfa forage yield was 2,257 lbs/acre/cutting dry matter with 5-7 cuttings per year.

	No-Tillage			Tillage		
	+ Cover Crops Harvested	+ CC Harvested + Manure P	+ CC Harvested +Manure N	+ Cover Crops Harvested	+ CC Harvested + Manure P	+ CC Harvested +Manure N
%C, 0-2”	1.6	2.1	2.5	1.0	1.3	1.5
%C, 2-4”	1.1	1.3	1.4	1.0	1.3	1.4
%C, 4-8”	0.8	0.8	0.8	1.0	1.3	1.4
%C, 0-8”	1.1	1.3	1.4	1.0	1.3	1.4
Profile C (Mg/ha)	91.6	97.9	101.47	87.5	97.2	100.7
Manure P balance (lbs P_2O_5/acre/yr)	-99	-70	114	-99	-70	-3
NO_3^- leaching (lbs/acre/yr)	5.8	11.3	36.4	6.6	10.1	10.2
NH_3 volatilization (lbs/acre/yr)	27.8	40.5	61.7	23.1	30.7	36.9

Lebanon County, Pennsylvania

Geographic Location: Lebanon County, PA; 40°19'N, 76° 20'W, Mean Annual Temp: 53 °F and 46" Precipitation

Soil Series/Profile Description: The soil at this site was a Duffield series. Soil depth at the site was 61 inches and was comprised of three distinct layers. The 0-8 inch soil layer was 23% clay and 22% sand. The 8-51 inch soil layer was 32% clay and 18% sand. The 51-61 inch soil layer was 26% clay and 20% sand.

Crop Rotation Description: Continuous Corn Grain

Results in the table below are for a continuous corn grain rotation. Corn was planted on April 25th in each year of the rotation and corn residues were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on April 19th. In scenarios with manure, poultry litter was applied on April 20th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. Average corn grain yield was 205 bushels/acre. Cover crop biomass ranged from 147 to 624 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2"	2.0	2.0	2.1	2.4	1.0	1.0	1.2	1.5
%C, 2-4"	1.2	1.2	1.2	1.4	1.0	1.0	1.2	1.4
%C, 4-8"	0.4	0.4	0.4	0.4	1.0	1.0	1.2	1.4
%C, 0-8"	1.0	1.0	1.0	1.1	1.0	1.0	1.2	1.4
Profile C (Mg/ha)	63.6	64.5	66.4	71.1	63.9	64.8	69.7	78.5
Manure P balance (lbs P_2O_5/acre/yr)	-60	-60	0	147	-60	-60	0	108
NO_3^- leaching (lbs/acre/yr)	3.1	3.1	3.5	6.9	3.3	3.3	3.7	5.3
NH_3 volatilization (lbs/acre/yr)	12.8	13.0	17.4	29.9	10.7	10.9	12.6	18.4

Lebanon County, Pennsylvania

Crop Rotation Description: Corn Grain – Soybean

Results in the table below are for a corn grain – soybean rotation. Corn and soybeans were planted on April 25th in their respective years in the rotation and residues from both were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on April 19th. In scenarios with manure, poultry litter was applied to corn on April 20th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. There was no manure applied in soybean years. Average corn grain yield was 226 bushels/acre and average soybean grain yield was 69 bushels/acre. Cover crop biomass ranged from 410 to 595 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.9	1.9	2.0	2.1	1.0	1.0	1.1	1.2
%C, 2-4”	1.1	1.1	1.1	1.2	0.9	0.9	1.0	1.1
%C, 4-8”	0.3	0.3	0.3	0.4	0.9	0.9	1.0	1.1
%C, 0-8”	0.9	0.9	1.0	1.0	0.9	1.0	1.0	1.1
Profile C (Mg/ha)	55.4	58.1	58.8	60.9	56.2	58.7	60.4	63.5
Manure P balance (lbs P_2O_5/acre/yr)	-110	-110	-50	47	-110	-110	-50	17
NO_3^- leaching (lbs/acre/yr)	7.0	6.7	6.5	8.1	6.9	6.4	6.3	7.2
NH_3 volatilization (lbs/acre/yr)	10.0	10.1	11.2	15.5	8.7	9.2	8.9	10.7

Lebanon County, Pennsylvania

Crop Rotation Description: Continuous Corn Silage

Results in the table below are for a continuous corn silage rotation. Corn was planted on April 25th and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on April 19th. In scenarios with manure, liquid dairy manure was applied on April 20th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 23,016 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,902 gal/acre. Average corn silage yield was 24.34 tons/acre. Average cover crop biomass ranged from 513 to 3,542 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.1	1.2	2.2	2.6	0.5	0.6	1.1	1.3
%C, 2-4”	0.8	0.8	1.4	1.7	0.5	0.6	1.1	1.3
%C, 4-8”	0.4	0.4	0.5	0.5	0.5	0.6	1.1	1.3
%C, 0-8”	0.7	0.7	1.1	1.3	0.5	0.6	1.1	1.3
Profile C (Mg/ha)	55.0	57.9	75.0	85.2	51.1	55.1	73.9	80.5
Manure P balance (lbs P_2O_5/acre/yr)	-100	-100	0	199	-100	-100	0	42
NO_3^- leaching (lbs/acre/yr)	1.9	1.7	14.9	208.8	2.3	1.8	4.2	7.7
NH_3 volatilization (lbs/acre/yr)	27.5	27.0	44.9	79.9	13.6	14.3	24.7	29.6

Lebanon County, Pennsylvania

Crop Rotation Description: Continuous Corn Silage – Cover Crop Harvested

Results in the table below are for a continuous rotation of corn silage and a harvested cover crop. Corn was planted on May 9th in each year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on October 1st and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received manure to meet either P removal or N requirements. For corn, manure was applied on May 4th as liquid dairy manure. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 21,418 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,145 gal/acre. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,524 gal/acre. Average corn silage yield was 22.97 tons/acre and average cereal rye forage yield was 2,571 lbs/acre dry matter.

	No-Tillage			Tillage		
	+ Cover Crops Harvested	+ CC Harvested + Manure P	+ CC Harvested +Manure N	+ Cover Crops Harvested	+ CC Harvested + Manure P	+ CC Harvested +Manure N
%C, 0-2”	1.3	2.2	2.6	0.6	1.3	1.5
%C, 2-4”	0.9	1.4	1.6	0.6	1.3	1.5
%C, 4-8”	0.5	0.5	0.5	0.6	1.3	1.5
%C, 0-8”	0.8	1.2	1.3	0.6	1.3	1.5
Profile C (Mg/ha)	61.8	79.4	84.3	57.8	81.3	88.8
Manure P balance (lbs P_2O_5/acre/yr)	-142	0	234	-142	0	88
NO_3^- leaching (lbs/acre/yr)	2.9	22.2	227.6	3.3	8.9	25.7
NH_3 volatilization (lbs/acre/yr)	45.4	77.2	142.9	32.9	49.9	72.0

Lebanon County, Pennsylvania

Crop Rotation Description: Corn Silage – Alfalfa Hay

Results in the table below are for a corn silage – alfalfa rotation, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on April 25th in each corn year of the rotation and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on April 19th. In scenarios with manure, liquid dairy manure was applied on April 20th in corn years. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 7,937 gal/acre in the first year of corn and 25,397 gal/acre in years two and three. In the tillage scenarios, The P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 3,759 gal/acre in the first year of corn and 12,030 gal/acre in years two and three. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 23.90 tons/acre. Cover crop biomass ranged from 1,740 to 2,703 lbs/acre dry matter at the time of termination. Average alfalfa forage yield was 2,336 lbs/acre/cutting dry matter with 5-6 cuttings per year.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.4	1.6	2.0	2.3	0.9	1.0	1.2	1.3
%C, 2-4”	0.9	1.0	1.2	1.3	0.8	0.9	1.2	1.2
%C, 4-8”	0.7	0.7	0.7	0.7	0.8	0.9	1.2	1.2
%C, 0-8”	0.9	1.0	1.2	1.3	0.8	0.9	1.2	1.2
Profile C (Mg/ha)	86.0	91.7	97.0	101.1	83.0	88.4	96.0	97.5
Manure P balance (lbs P_2O_5/acre/yr)	-85	-85	-70	84	-85	-85	-70	-49
NO_3^- leaching (lbs/acre/yr)	4.8	3.1	6.6	21.8	5.4	3.3	4.7	4.5
NH_3 volatilization (lbs/acre/yr)	24.0	23.7	32.3	47.7	17.6	18.8	23.3	23.9

Lebanon County, Pennsylvania

Crop Rotation Description: Corn Silage- Alfalfa Hay – Cover Crop Harvested

Results in the table below are for a corn silage – alfalfa rotation and a harvested cover crop, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on May 9th in each corn year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on October 1st in the first and second corn year and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received liquid dairy manure to meet either P removal or N requirements. For corn, manure was applied on May 4th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 5,534 gal/acre in the first year of corn and 22,995 gal/acre in years two and three. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre in all three years and the N-based manure rate was 2,622 gal/acre in the first year of corn and 10,892 gal/acre in years two and three. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,905 gal/acre. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 21.73 tons/acre. Average cereal rye forage yield was 3,647 lbs/acre dry matter. Average alfalfa forage yield was 2,338 lbs/acre/cutting dry matter with 5-6 cuttings per year.

	No-Tillage			Tillage		
	+ Cover Crops Harvested	+ CC Harvested + Manure P	+ CC Harvested +Manure N	+ Cover Crops Harvested	+ CC Harvested + Manure P	+ CC Harvested +Manure N
%C, 0-2”	1.6	2.0	2.3	1.0	1.2	1.4
%C, 2-4”	1.0	1.2	1.3	0.9	1.2	1.3
%C, 4-8”	0.7	0.7	0.7	0.9	1.2	1.3
%C, 0-8”	1.0	1.2	1.3	0.9	1.2	1.3
Profile C (Mg/ha)	91.9	97.0	100.3	87.8	97.1	100.3
Manure P balance (lbs P_2O_5/acre/yr)	-99	-70	114	-99	-70	-3
NO_3^- leaching (lbs/acre/yr)	4.1	8.4	27.6	5.0	7.8	7.1
NH_3 volatilization (lbs/acre/yr)	29.3	42.3	64.1	24.4	31.9	38.2

Carroll County, Maryland

Geographic Location: Carroll County, MD; 39°37'N, 77° 06'W, Mean Annual Temp: 54 °F and 44" Precipitation

Soil Series/Profile Description: The soil at this site was a Brinklow series. Soil depth at the site was 17 inches and was comprised of two distinct soil layers. The 0-8-inch soil layer was 17% clay and 32% sand. The 8-17-inch soil layer was 27% clay and 38% sand.

Crop Rotation Description: Continuous Corn Grain

Results in the table below are for a continuous corn grain rotation. Corn was planted on April 25th in each year of the rotation and corn residues were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on April 19th. In scenarios with manure, poultry litter was applied on April 20th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. Average corn grain yield was 150 bushels/acre. Cover crop biomass ranged from 268 to 972 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2"	1.7	1.8	1.9	2.2	0.8	0.9	1.0	1.2
%C, 2-4"	1.1	1.1	1.2	1.3	0.8	0.8	1.0	1.2
%C, 4-8"	0.4	0.4	0.4	0.5	0.8	0.8	1.0	1.2
%C, 0-8"	0.9	0.9	1.0	1.1	0.8	0.9	1.0	1.2
Profile C (Mg/ha)	41.3	43.0	45.3	49.7	39.0	40.3	44.6	52.4
Manure P balance (lbs P_2O_5/acre/yr)	-60	-60	0	147	-60	-60	0	108
NO_3^- leaching (lbs/acre/yr)	21.7	18.1	19.4	44.6	22.2	19.0	19.4	33.3
NH_3 volatilization (lbs/acre/yr)	22.1	22.2	28.6	49.7	15.8	16.5	19.0	28.0

Carroll County, Maryland

Crop Rotation Description: Corn Grain – Soybean

Results in the table below are for a corn grain – soybean rotation. Corn and soybeans were planted on April 25th in their respective years in the rotation and residues from both were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on April 19th. In scenarios with manure, poultry litter was applied to corn on April 20th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. There was no manure applied in soybean years. Average corn grain yield was 163 bushels/acre and average soybean grain yield was 51 bushels/acre. Cover crop biomass ranged from 491 to 749 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.6	1.6	1.7	1.9	0.7	0.8	0.9	0.9
%C, 2-4”	1.0	1.0	1.1	1.1	0.7	0.8	0.8	0.9
%C, 4-8”	0.3	0.4	0.4	0.4	0.7	0.8	0.8	0.9
%C, 0-8”	0.8	0.8	0.9	0.9	0.7	0.8	0.8	0.9
Profile C (Mg/ha)	35.9	38.7	39.7	42.2	33.4	35.8	37.5	40.5
Manure P balance (lbs P_2O_5/acre/yr)	-110	-110	-50	47	-110	-110	-50	17
NO_3^- leaching (lbs/acre/yr)	29.1	23.6	21.7	26.3	29.8	24.2	21.7	24.4
NH_3 volatilization (lbs/acre/yr)	15.9	16.2	17.9	25.5	11.8	12.9	12.7	15.5

Carroll County, Maryland

Crop Rotation Description: Continuous Corn Silage

Results in the table below are for a continuous corn silage rotation. Corn was planted on April 25th and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on April 19th. In scenarios with manure, liquid dairy manure was applied on April 20th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 23,016 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,902 gal/acre. Average corn silage yield was 16.79 tons/acre. Average cover crop biomass ranged from 1,080 to 4,657 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	0.8	1.1	2.0	2.4	0.4	0.5	1.0	1.2
%C, 2-4”	0.6	0.8	1.3	1.6	0.4	0.5	1.0	1.2
%C, 4-8”	0.4	0.4	0.5	0.6	0.4	0.5	1.0	1.2
%C, 0-8”	0.6	0.7	1.1	1.3	0.4	0.5	1.0	1.2
Profile C (Mg/ha)	31.0	36.8	51.3	57.5	26.5	31.7	48.3	53.5
Manure P balance (lbs P_2O_5/acre/yr)	-100	-100	0	199	-100	-100	0	42
NO_3^- leaching (lbs/acre/yr)	20.8	12.0	80.4	327.6	30.1	17.4	41.5	63.0
NH_3 volatilization (lbs/acre/yr)	34.4	33.9	58.1	109.7	17.6	20.0	34.3	40.7

Carroll County, Maryland

Crop Rotation Description: Continuous Corn Silage – Cover Crop Harvested

Results in the table below are for a continuous rotation of corn silage and a harvested cover crop. Corn was planted on May 9th in each year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on October 1st and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received manure to meet either P removal or N requirements. For corn, manure was applied on May 4th as liquid dairy manure. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 21,418 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,145 gal/acre. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,524 gal/acre. Average corn silage yield was 16.02 tons/acre and average cereal rye forage yield was 2,797 lbs/acre dry matter.

	No-Tillage			Tillage		
	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.0	2.0	2.4	0.5	1.1	1.3
%C, 2-4”	0.8	1.3	1.5	0.5	1.1	1.3
%C, 4-8”	0.5	0.5	0.5	0.5	1.1	1.3
%C, 0-8”	0.7	1.1	1.2	0.5	1.1	1.3
Profile C (Mg/ha)	36.0	51.4	56.4	30.9	50.4	58.1
Manure P balance (lbs P_2O_5/acre/yr)	-142	0	234	-142	0	88
NO_3^- leaching (lbs/acre/yr)	21.0	79.4	280.7	29.7	67.7	107.6
NH_3 volatilization (lbs/acre/yr)	56.9	106.9	208.0	39.8	63.7	91.1

Carroll County, Maryland

Crop Rotation Description: Corn Silage – Alfalfa Hay

Results in the table below are for a corn silage – alfalfa rotation, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on April 25th in each corn year of the rotation and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on April 19th. In scenarios with manure, liquid dairy manure was applied on April 20th in corn years. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 7,937 gal/acre in the first year of corn and 25,397 gal/acre in years two and three. In the tillage scenarios, The P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 3,759 gal/acre in the first year of corn and 12,030 gal/acre in years two and three. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 15.74 tons/acre. Cover crop biomass ranged from 2,578 to 3,801 lbs/acre dry matter at the time of termination. Average alfalfa forage yield was 1,624 lbs/acre/cutting dry matter with 6-8 cuttings per year.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.2	1.6	1.9	2.2	0.8	0.9	1.2	1.2
%C, 2-4”	0.9	1.1	1.2	1.3	0.8	0.9	1.1	1.2
%C, 4-8”	0.7	0.8	0.8	0.8	0.8	0.9	1.1	1.2
%C, 0-8”	0.9	1.0	1.2	1.3	0.8	0.9	1.1	1.2
Profile C (Mg/ha)	51.6	58.7	62.5	66.1	47.5	54.0	60.5	61.7
Manure P balance (lbs P_2O_5/acre/yr)	-85	-85	-70	84	-85	-85	-70	-49
NO_3^- leaching (lbs/acre/yr)	41.4	29.4	53.4	133.3	45.2	29.6	40.9	40.9
NH_3 volatilization (lbs/acre/yr)	32.5	33.1	44.4	65.2	23.9	26.7	32.7	33.7

Carroll County, Maryland

Crop Rotation Description: Corn Silage- Alfalfa Hay – Cover Crop Harvested

Results in the table below are for a corn silage – alfalfa rotation and a harvested cover crop, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on May 9th in each corn year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on October 1st in the first and second corn year and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received liquid dairy manure to meet either P removal or N requirements. For corn, manure was applied on May 4th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 5,534 gal/acre in the first year of corn and 22,995 gal/acre in years two and three. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre in all three years and the N-based manure rate was 2,622 gal/acre in the first year of corn and 10,892 gal/acre in years two and three. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,905 gal/acre. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 15.11 tons/acre. Average cereal rye forage yield was 3,589 lbs/acre dry matter. Average alfalfa forage yield was 1,667 lbs/acre/cutting dry matter with 6-8 cuttings per year.

	No-Tillage			Tillage		
	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.3	1.8	2.1	0.8	1.1	1.2
%C, 2-4”	1.0	1.2	1.3	0.8	1.1	1.2
%C, 4-8”	0.8	0.8	0.8	0.8	1.1	1.2
%C, 0-8”	0.9	1.1	1.2	0.8	1.1	1.2
Profile C (Mg/ha)	54.8	60.7	64.0	50.3	59.0	62.1
Manure P balance (lbs P_2O_5/acre/yr)	-99	-70	114	-99	-70	-3
NO_3^- leaching (lbs/acre/yr)	31.1	55.5	117.8	35.8	52.1	54.5
NH_3 volatilization (lbs/acre/yr)	39.9	60.3	94.9	31.1	41.4	49.5

Caroline County, Maryland

Geographic Location: Caroline County, MD; 38°51'N, 75° 53'W, Mean Annual Temp: 56 °F and 46" Precipitation

Soil Series/Profile Description: The soil at this site was a Hambrook series. Soil depth at the site was 79 inches and was comprised of five distinct layers. The 0-8-inch layer was 9% clay and 60% sand. The 8-16-inch layer was 18% clay and 47% sand. The 16-28-inch layer was 26% clay and 51% sand. The 28-63-inch layer was 8% clay and 87% sand. The 63-79-inch layer was 18% clay and 29% sand.

Crop Rotation Description: Continuous Corn Grain

Results in the table below are for a continuous corn grain rotation. Corn was planted on April 25th in each year of the rotation and corn residues were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on April 19th. In scenarios with manure, poultry litter was applied on April 20th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. Average corn grain yield was 207 bushels/acre. Cover crop biomass ranged from 526 to 1740 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2"	1.4	1.5	1.6	1.9	0.6	0.6	0.7	0.9
%C, 2-4"	0.8	0.8	0.9	1.0	0.6	0.6	0.7	0.8
%C, 4-8"	0.2	0.3	0.3	0.3	0.6	0.6	0.7	0.8
%C, 0-8"	0.7	0.7	0.8	0.9	0.6	0.6	0.7	0.8
Profile C (Mg/ha)	48.9	50.7	52.5	57.5	45.9	47.5	50.1	56.3
Manure P balance (lbs P_2O_5/acre/yr)	-60	-60	0	147	-60	-60	0	108
NO_3^- leaching (lbs/acre/yr)	2.7	2.6	2.8	6.4	3.1	2.9	3.1	5.0
NH_3 volatilization (lbs/acre/yr)	33.6	33.8	42.7	70.8	22.1	23.2	26.2	38.8

Caroline County, Maryland

Crop Rotation Description: Corn Grain – Soybean

Results in the table below are for a corn grain – soybean rotation. Corn and soybeans were planted on April 25th in their respective years in the rotation and residues from both were returned to the soil. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on November 1st and terminated on April 19th. In scenarios with manure, poultry litter was applied to corn on April 20th. In the no-till scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 4.8 T/acre. In the tillage scenarios, the P-based manure rate was 1.4 T/acre, and the N-based manure rate was 3.9 T/acre. There was no manure applied in soybean years. Average corn grain yield was 226 bushels/acre and average soybean grain yield was 68 bushels/acre. Cover crop biomass ranged from 1,312 to 1,722 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	1.3	1.5	1.5	1.6	0.5	0.6	0.6	0.7
%C, 2-4”	0.7	0.8	0.8	0.9	0.5	0.5	0.6	0.6
%C, 4-8”	0.2	0.2	0.2	0.3	0.5	0.5	0.6	0.6
%C, 0-8”	0.6	0.7	0.7	0.7	0.5	0.6	0.6	0.6
Profile C (Mg/ha)	43.1	48.1	48.6	50.5	39.3	44.0	44.9	46.8
Manure P balance (lbs P_2O_5/acre/yr)	-110	-110	-50	47	-110	-110	-50	17
NO_3^- leaching (lbs/acre/yr)	8.2	7.1	6.7	8.7	9.0	7.6	6.8	8.0
NH_3 volatilization (lbs/acre/yr)	26.0	25.2	27.2	37.1	17.1	19.7	19.2	23.1

Caroline County, Maryland

Crop Rotation Description: Continuous Corn Silage

Results in the table below are for a continuous corn silage rotation. Corn was planted on April 25th and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on April 19th. In scenarios with manure, liquid dairy manure was applied on April 20th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 23,016 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,902 gal/acre. Average corn silage yield was 23.69 tons/acre. Average cover crop biomass ranged from 1,026 to 7,584 lbs/acre dry matter at the time of termination.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	0.7	0.8	1.8	2.1	0.3	0.4	0.7	0.8
%C, 2-4”	0.5	0.5	1.1	1.2	0.3	0.4	0.7	0.8
%C, 4-8”	0.3	0.3	0.4	0.4	0.3	0.4	0.7	0.8
%C, 0-8”	0.4	0.5	0.9	1.0	0.3	0.4	0.7	0.8
Profile C (Mg/ha)	40.1	43.7	64.2	69.8	36.5	41.1	55.7	61.1
Manure P balance (lbs P_2O_5/acre/yr)	-100	-100	0	199	-100	-100	0	42
NO_3^- leaching (lbs/acre/yr)	3.0	1.6	30.5	262.1	4.2	2.0	5.3	13.2
NH_3 volatilization (lbs/acre/yr)	48.7	47.5	76.2	134.0	26.1	28.4	49.5	60.3

Caroline County, Maryland

Crop Rotation Description: Continuous Corn Silage – Cover Crop Harvested

Results in the table below are for a continuous rotation of corn silage and a harvested cover crop. Corn was planted on May 9th in each year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on October 1st and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received manure to meet either P removal or N requirements. For corn, manure was applied on May 4th as liquid dairy manure. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 21,418 gal/acre. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre and the N-based manure rate was 10,145 gal/acre. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,524 gal/acre. Average corn silage yield was 23.96 tons/acre and average cereal rye forage yield was 2,304 lbs/acre dry matter.

	No-Tillage			Tillage		
	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	0.7	1.6	2.0	0.3	0.7	0.8
%C, 2-4”	0.5	0.9	1.1	0.3	0.6	0.8
%C, 4-8”	0.3	0.3	0.3	0.3	0.6	0.8
%C, 0-8”	0.5	0.8	0.9	0.3	0.6	0.8
Profile C (Mg/ha)	43.3	57.9	62.9	39.6	53.3	58.8
Manure P balance (lbs P_2O_5/acre/yr)	-142	0	234	-142	0	88
NO_3^- leaching (lbs/acre/yr)	2.3	8.3	156.8	3.4	11.0	36.2
NH_3 volatilization (lbs/acre/yr)	76.3	148.1	287.5	51.9	86.4	122.5

Caroline County, Maryland

Crop Rotation Description: Corn Silage – Alfalfa Hay

Results in the table below are for a corn silage – alfalfa rotation, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on April 25th in each corn year of the rotation and the entire aboveground biomass was harvested for silage. In the baseline scenario, fertilizer was used to meet crop requirements and no cover crops were planted. In scenarios with a cover crop, cereal rye was planted on October 1st and terminated on April 19th. In scenarios with manure, liquid dairy manure was applied on April 20th in corn years. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 7,937 gal/acre in the first year of corn and 25,397 gal/acre in years two and three. In the tillage scenarios, The P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 3,759 gal/acre in the first year of corn and 12,030 gal/acre in years two and three. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 23.96 tons/acre. Cover crop biomass ranged from 4,853 to 6,486 lbs/acre dry matter at the time of termination. Average alfalfa forage yield was 2,302 lbs/acre/cutting dry matter with 6-8 cuttings per year.

	No-Tillage				Tillage			
	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	Baseline	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	0.9	1.3	1.6	1.8	0.5	0.7	0.8	0.8
%C, 2-4”	0.6	0.8	0.9	1.0	0.5	0.6	0.8	0.8
%C, 4-8”	0.4	0.5	0.5	0.5	0.5	0.6	0.8	0.8
%C, 0-8”	0.6	0.8	0.9	1.0	0.5	0.6	0.8	0.8
Profile C (Mg/ha)	65.0	73.5	78.3	81.5	60.6	69.5	74.2	74.9
Manure P balance (lbs P_2O_5/acre/yr)	-85	-85	-70	84	-85	-85	-70	-49
NO_3^- leaching (lbs/acre/yr)	4.2	1.8	2.5	14.8	6.0	2.3	3.2	2.6
NH_3 volatilization (lbs/acre/yr)	47.9	49.7	63.7	87.5	35.3	39.9	48.8	49.5

Caroline County, Maryland

Crop Rotation Description: Corn Silage- Alfalfa Hay – Cover Crop Harvested

Results in the table below are for a corn silage – alfalfa rotation and a harvested cover crop, which consisted of three years of corn silage, followed by three years of alfalfa hay. Corn was planted on May 9th in each corn year of the rotation and the entire aboveground biomass was harvested for silage. A cereal rye cover crop was planted on October 1st in the first and second corn year and all aboveground biomass was harvested when the cover crop reached the boot stage. In scenarios without manure, corn and the rye cover crop received nitrogen fertilizer. In scenarios with manure, corn and the rye cover crop both received liquid dairy manure to meet either P removal or N requirements. For corn, manure was applied on May 4th. In the no-till scenarios, the P-based manure rate was 7,692 gal/acre in all three years, and the N-based manure rate was 5,534 gal/acre in the first year of corn and 22,995 gal/acre in years two and three. In the tillage scenarios, the P-based manure rate was 7,692 gal/acre in all three years and the N-based manure rate was 2,622 gal/acre in the first year of corn and 10,892 gal/acre in years two and three. For cereal rye, manure was applied again on November 15th. The P-based manure rate was 3,230 gal/acre and the N-based manure rate was 7,905 gal/acre. Alfalfa was planted on April 1st the year following the third corn year. Average corn silage yield was 23.52 tons/acre. Average cereal rye forage yield was 3,196 lbs/acre dry matter. Average alfalfa forage yield was 2,338 lbs/acre/cutting dry matter with 6-8 cuttings per year.

	No-Tillage			Tillage		
	+ Cover Crops	+ CC + Manure P	+ CC +Manure N	+ Cover Crops	+ CC + Manure P	+ CC +Manure N
%C, 0-2”	0.9	1.4	1.7	0.5	0.7	0.8
%C, 2-4”	0.6	0.8	0.9	0.5	0.7	0.7
%C, 4-8”	0.5	0.5	0.5	0.5	0.7	0.7
%C, 0-8”	0.6	0.8	0.9	0.5	0.7	0.7
Profile C (Mg/ha)	67.1	72.4	75.8	62.7	68.6	70.7
Manure P balance (lbs P_2O_5/acre/yr)	-99	-70	114	-99	-70	-3
NO_3^- leaching (lbs/acre/yr)	2.6	4.7	17.1	3.4	6.2	5.3
NH_3 volatilization (lbs/acre/yr)	56.9	86.7	135.8	43.7	58.5	68.8