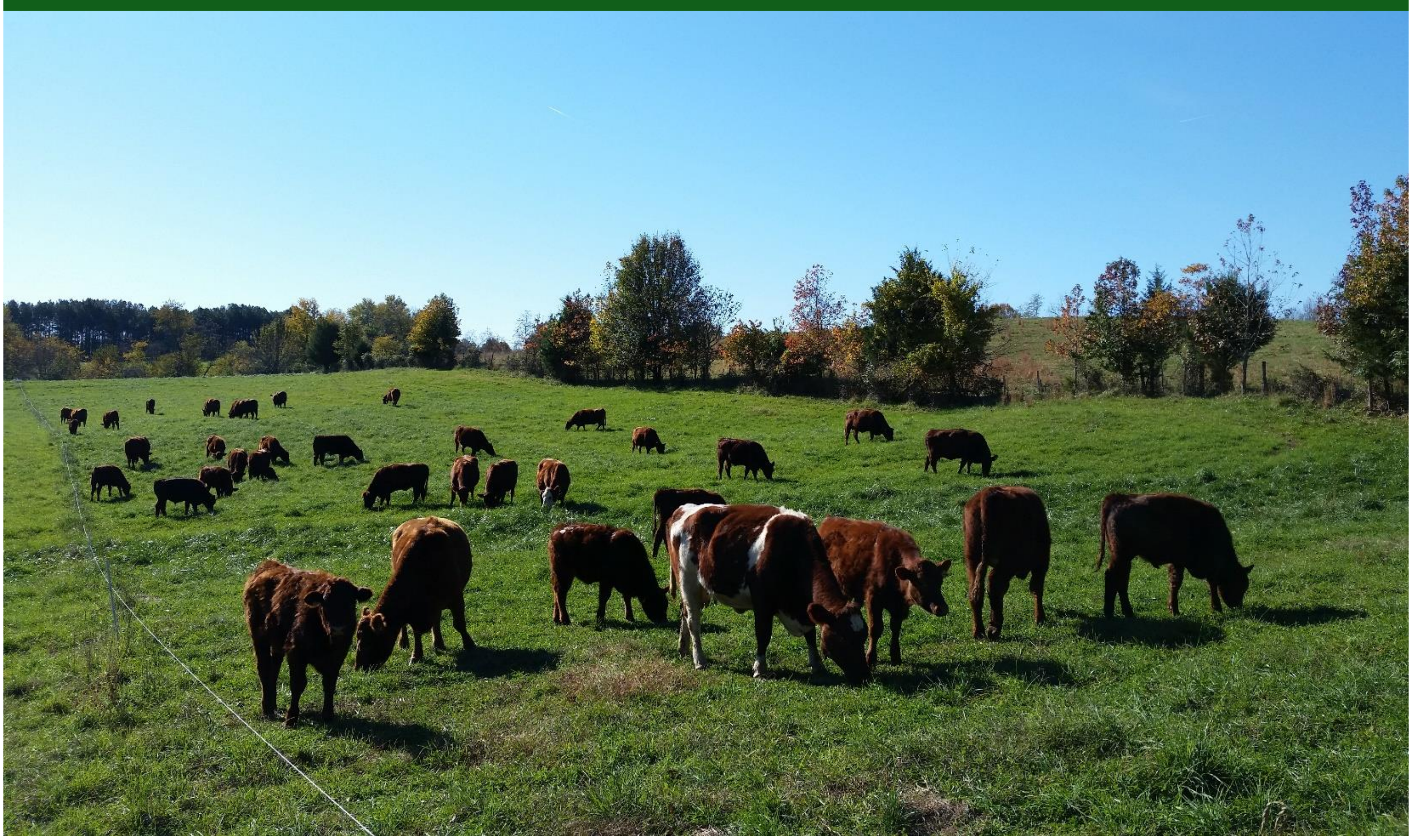
Promoting Rotational Grazing in the Chesapeake Bay Watershed and Quantifying the Environmental Benefits: Results for Six Case Study Farms



CHESAPEAKE BAY FOUNDATION

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Introduction

Rotational grazing has multiple environmental benefits including to water quality, greenhouse gas mitigation, and soil health. Planting grass instead of corn for feed or moving from continuous grazing to rotational grazing can substantially reduce farm nutrient and sediment runoff. Because of these water quality benefits, Chesapeake Bay jurisdictions have committed to implement rotational grazing on over 1.2 million acres within the Bay watershed. This transition also helps reduce greenhouse gases by sequestering carbon in soil through increases in soil organic matter. In addition, fertilizer use is often reduced or eliminated, leading to lower emissions of nitrous oxide, a very potent greenhouse gas. Rotational grazing improves soil health and fertility. It makes farms more resilient to weather extremes like drought and heavy rainfall, since healthy soils have higher water holding capacity. Despite these many benefits, adoption of this practice is relatively low among producers in the Chesapeake Bay watershed.

Greenhouse gases and agriculture

Gases that trap heat in the atmosphere are called greenhouse gases. We list the most common ones and some agricultural sources and sinks.

CARBON DIOXIDE (CO_2) is the most abundant greenhouse gas, but the least potent in terms of its ability to trap heat. CO_2 enters the atmosphere primarily through the burning of fossil fuels. It is removed from the atmosphere (or "sequestered") when it is absorbed by plants and soils.	Converting to rotational grazing increases soil organic matter and functioning. Organic matter is directly related to soil organic carbon, so higher values indicate higher amounts of soil carbon sequestration. There is national and global interest in building "healthy soils" because of the huge capacity of soils to sequester carbon. Fossil fuel use can also be lower in grazing systems due to reduced use of farm equipment for planting and harvesting.
NITROUS OXIDE (N_2O) is 265 times as potent as carbon dioxide. N_2O is predominately produced in the soil by microbial processes and is heavily influenced by nitrogen fertilizer and manure application. The storage and handling of livestock manure is another source of on-farm emissions.	Converting fields from grain crops to pasture usually means less use of nitrogen fertilizer. As a result, on-farm emissions of N_2O can decrease substantially.
METHANE (CH_4) is 28 times as potent as CO_2 in terms of its ability to trap heat.[1] "Enteric" emissions of methane from are a by-product of the fermentation process cows use to extract nutrition from the food they eat. Methane is also emitted from manure management systems.	Enteric emissions of methane typically increase when cows are converted to a grass-based diet. Fortunately, these increases are often offset by increases in carbon sequestration and decreases in N_2O emissions.

One objective of the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service Conservation Innovation Grant to the Chesapeake Bay Foundation entitled *Promoting Rotational Grazing in the Chesapeake Bay Watershed and Quantifying the Economic and Environmental Benefits* (69-3A75-16-038) was to increase adoption of rotational grazing by quantifying and sharing the environmental benefits on actual farms in the Chesapeake Bay region.

Locations of six case study farms. Chesapeake Bay watershed is delineated in blue.

Specifically, we estimated changes in whole farm greenhouse gas emissions, loads of nitrogen, phosphorus, and sediment and soil health parameters for six "case study" farms (see figure above for general locations). The farms represent different geographies (3 in Maryland, 2 in Virginia, 1 in Pennsylvania), animal types (dairy, beef), and transitions (i.e., continuous grazing to rotational, cropland converted to pasture).

For each farm, Chesapeake Bay Foundation (CBF) staff worked with the producers to obtain the necessary agronomic information to run two scenarios: the "baseline scenario" that reflected on-farm conditions and practices before the conversion to rotational grazing and the "current scenario" that reflects conditions after the conversion.

We entered farm management information into two farm-scale models: *COMET-Farm* for greenhouse gas emissions (http://cometfarm.nrel.colostate.edu/) and the *Chesapeake Bay Nutrient Trading Tool (*CBNTT, http://www.cbntt.org/*)* for nutrient and sediment loads. COMET-Farm is an online model that uses information on management practices on an operation together with spatially-explicit information on climate and soil conditions from USDA databases to run a series of models that evaluate sources of greenhouse gas emissions and carbon sequestration. In addition, for some farms we also used A-Microscale, an Excel-based calculation tool that is included in the American Carbon Registry Methodology for Grazing Land and Livestock Management, https://americancarbonregistry.org/carbon-accounting/standards-methodologies/grazing-land-and-livestock-management-gllm-ghg-methodology, allowing us to compare results with COMET-Farm.

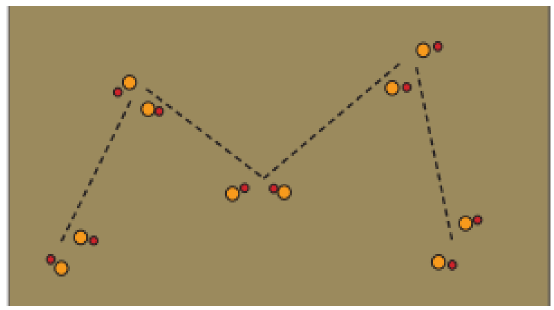
Like COMET-Farm, the CBNTT is an online model that uses information on management practices on an operation together with spatially-explicit information on climate and soil conditions from USDA databases to run a model that estimates farm nutrient and sediment loads from the farm. It was originally developed for use in Maryland's Nutrient Trading Program and was been expanded to include PA and VA through a previous CIG to CBF that was attempting to harmonize state nutrient trading programs. Current farm loads will also be compared to an estimate of farm loads that would need to be achieved to participate in nutrient trading markets.

We used the Cornell Soil Health Lab Basic Soil test (http://soilhealth.cals.cornell.edu/testing-services/comprehensive-soil-health-assessment/) to evaluate changes in soil health due to on-farm management changes. The Cornell Soil Health Test measures several indicators of soil physical, biological and chemical health. Results are presented as the measured value for the parameter and a rating, on a scale of 0 to 100 where higher scores are better. Ratings are based on scoring curves developed for the indicators from regional soils with similar textures that represent over 60% of the United States. Ratings range from red, which indicates a problem that is likely limiting yields or crop quality or can reflect the likelihood of environmental loss, to dark green which indicates the parameter is within the optimal or near optimal condition. The soil is also given an overall quality score that reflects the average of the ratings and is intended to reflect the soil's overall health status.

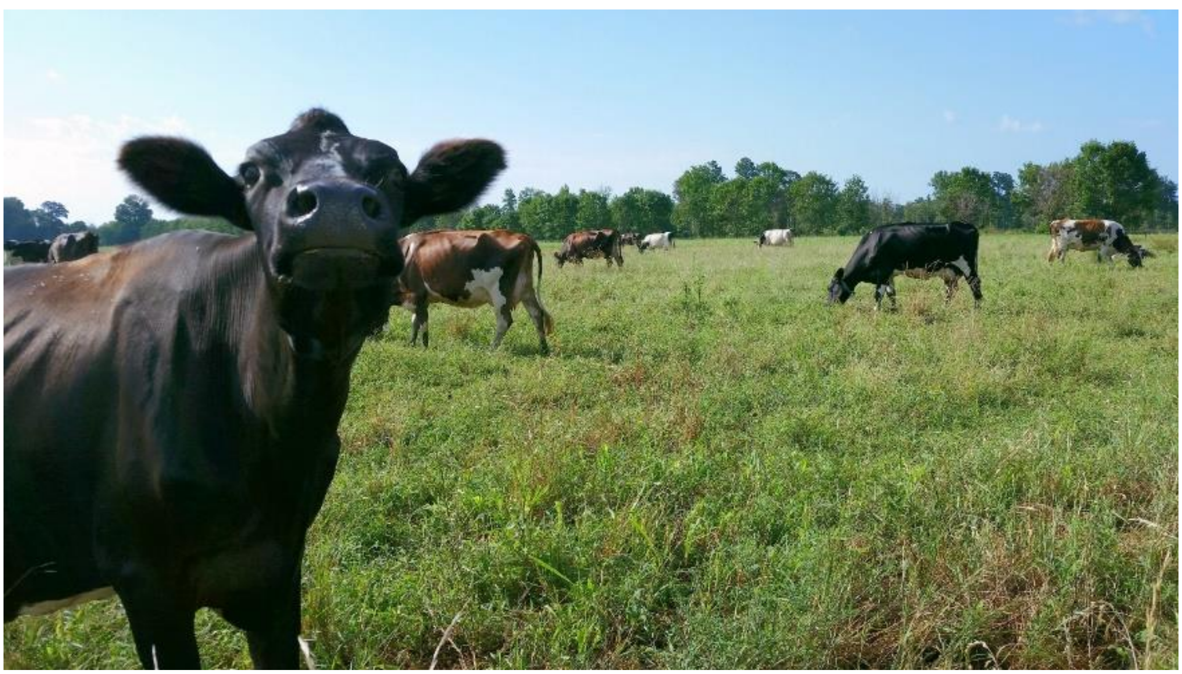
We present the results for four key soil health parameters: soil organic matter, wet aggregate stability, soil respiration, and extractable phosphorus. Detailed results were provided to the participating farmers and are available upon request.

Organic matter is a slow-release pool for nutrients and soils with higher organic matter generally require fewer external inputs. In addition, organic matter is directly related to soil organic carbon, so higher values indicate higher amounts of soil carbon sequestration. Aggregate stability refers to the ability of soil aggregates to resist disruption when outside forces (like water) are applied. Good soil aggregate stability helps prevent runoff and erosion, while facilitating aeration, infiltration, and water storage capacity. Soil respiration is expressed as CO_2 released in mg per gram of soil over a 4-day respiration period. It measures the metabolic activity of the soil microbial community by quantifying the carbon dioxide production of the microbes. Healthy soils will have a high level of microbial activity. Lastly, extractable phosphorus indicates the potential for phosphorus to runoff to the environment. Decreases over time indicate a reduced likelihood of phosphorus mobilization.

Soil samples were collected before and after the change in grazing management. Four composite samples, composed of 10 bulk samples (4" depth) from within a 200' x 200' area, were sampled per farm (see figure). These sites were geo-located so we could return to roughly the same within-field locations during the post-conversion sampling.



Summary results for these six case studies are presented below.



Case Study 1: Fair Hill Farm, Kent County, MD

Fair Hill Farm is owned and operated by the Fry Family - Ed and Marian Fry, their son Matt and his wife Meg. The extended family business includes a Holstein milking herd, an Angus beef herd, over 1,400 acres of certified organic cropland, vegetables, facility rentals and agri-tourism. For our project, we focused on the roughly 600-acre dairy farm in Kent County, Maryland, that in 2016 started to transition cropland to pasture to comply with the USDA organic dairy standard. As noted in the table below, roughly 200 acres were converted from cropland to permanent pasture. In addition, between the baseline and current scenario, the herd size increased from 569 mature dairy cows to 599. We assumed the manure storage system was the same in the two scenarios, but less manure was managed in the current grazing scenario since animals were spending more time on pasture.

Summary table of baseline and current crops for each field. A=alfalfa, C=corn, GH= grass/hay, TRI=triticale, SORG=sorghum, SB=soybean, Rot Past=rotationally grazed pasture. Note: Farm and field acreage may differ slightly from conservation plan.

Field	Baseline Scenario	Current Scenario		Acres
F20A	C-TRI-SB	SB/C/TRI	Rot Past	32
F20BCD	C-TRI	C/TRI	Rot Past	58
F21A	C-TRI	C/TRI		23
F21BC	C-TRI	C/TRI		69
F22AB	A	Rot Past		46
F23	C-TRI-A	A		17
F24A	C-TRI-SORG-GH	A		22
F24B	C-TRI-SORG-GH	Rot Past		48
F24C	C-TRI-SORG-GH	Rot Past		\
F24D	A	Rot Past		31
F25	C-TRI-SORG-GH	Rot Past		23
F26	SORG-GH-GH	Rot Past		11
Field 5	SORG	Rot Past		31
P17-P24	GH	Rot Past		67

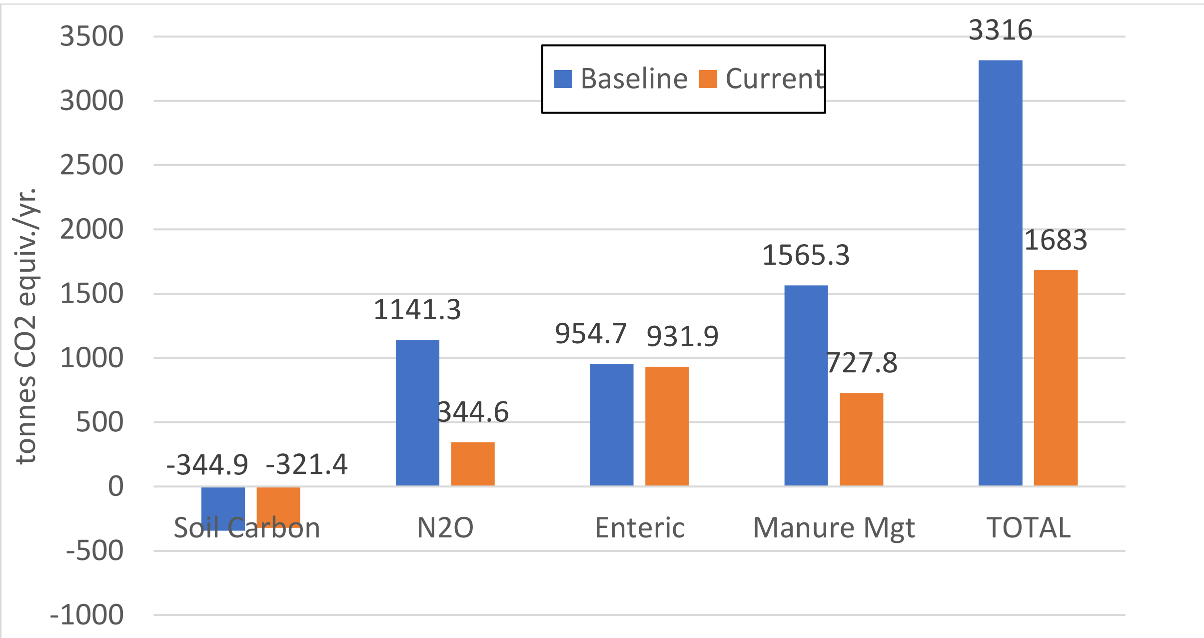
Results

Overall, greenhouse gas (GHG) emissions from the farm decreased by roughly 1,600 tonnes of CO_2 equivalents per year [1], or roughly 50% from the baseline to the current grazing scenario, indicating significant benefits in GHG reduction from transition to organic, rotational grazing.

[1] "CO_2 equivalents" is a standard unit for measuring carbon footprints. It allows us to account for the different potencies of greenhouse gases and express them in common units. For example, 1 ton of methane would be 28 tonnes of CO_2 equivalents, since methane is 28 times as potent as carbon dioxide.

For context, this reduction is roughly equivalent to the amount of carbon that would be sequestered annually by 16 acres of mature (i.e., 40-year-old) forest.[2]

COMET-Farm estimates GHG emissions from several on-farm "source and sinks," so we can assess where changes in GHG emissions occurred and due to what actions.



COMET-Farm results for Fair Hill Farm baseline and current scenarios after conversion to rotational grazing.

Carbon sequestration in the soil remained relatively similar in the baseline and current scenarios (negative values indicate carbon sequestration), with -345 and -321 tonnes of CO_2 equivalents sequestered per year in the baseline and current scenarios, respectively. Sequestration benefits acquired in some fields were cancelled out by losses in other fields. One consistent observation was an increase in soil carbon sequestration when fields with corn in the rotation switched to pasture, but these gains were offset by model estimates of losses in other fields e.g., those that converted from grass/hay to rotationally grazed pastures. We have no clear explanation for these results. During this project, we consulted extensively with the COMET-Farm modeling team and intend to continue to work with them in the coming months to better understand and explain model outputs.

Nitrous oxide (N_2O) emissions decreased from 1141 to 345 tonnes of CO_2 equivalents per year. The decrease resulted mostly from the decrease in applied nitrogen in the current grazing scenario. Enteric emissions of methane remained similar, 955 and 932 tonnes of CO_2 equivalents per year, respectively, for baseline and current scenarios, despite an increase in herd size and in the proportion of the cows' diet coming from grass. It is commonly understood that a diet high in

[2] https://www.winrock.org/wp-content/uploads/2016/03/Opportunities_for_improving_carbon_storage_through_afforestation_of_agricultural_lands.pdf

grass results in higher methane emissions from livestock, in this case, however, cows in the current scenario were fed a variety of feed, including grain. The manure management system emissions decreased from 1565 to 728 tonnes of CO_2 equivalents per year in the baseline and current scenarios. Although the manure management system did not change between the scenarios, less manure was collected in the current scenario since animals spent more time on pasture.

Like COMET-Farm, results from A-Microscale indicate an overall reduction in greenhouse gas emissions from the farm, but the estimated change was far less, only 118 tonnes of CO_2 equivalents per year. One reason for the difference is that not all farm acres were simulated in A-Microscale, only those that transitioned from crop to pasture. We are unable to indicate the percentage reduction from baseline because A-Microscale only lists the differences in emissions between scenarios, not emissions for the baseline and project conditions.

Like COMET-Farm, results also indicated a decrease in nitrous oxide emissions from fertilizer use. Contrary to COMET-farm, however, A-Microscale estimated a significant increase in soil carbon sequestration, due to conversion from cropland to rotational grazing, increases in emissions from enteric fermentation, and a slight increase in emissions from manure management.

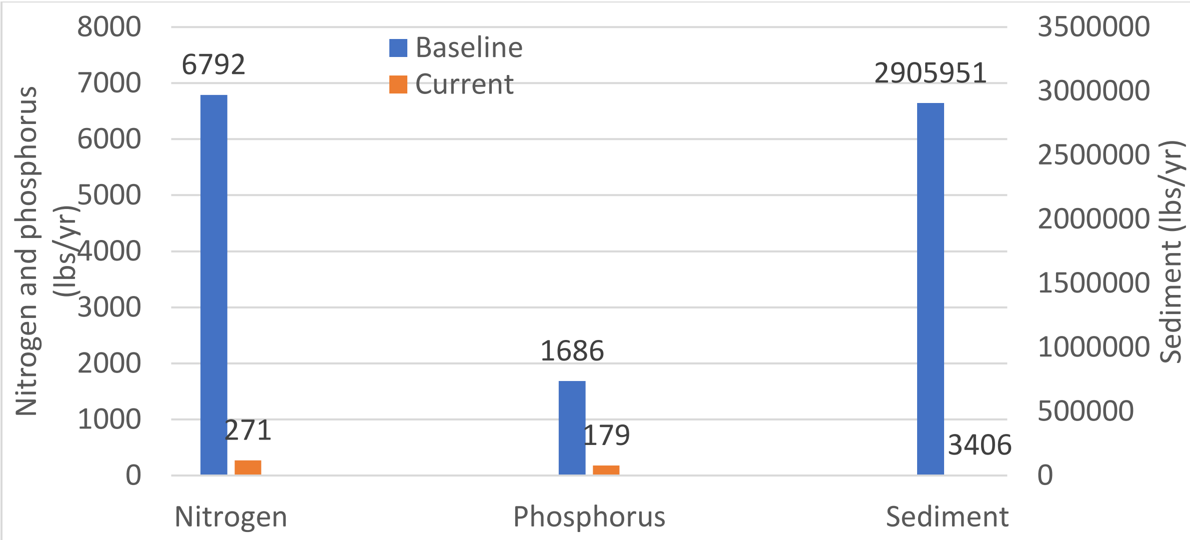
Results of A-Microscale scenarios for Fair Hill Farm. Units are tonnes of CO_2 equivalents per year.

Soil Carbon	Enteric Fermentation	Manure Mgt	N2O	Farm Total
--185	126	18	-76	--118

We also estimated GHG emissions on a per hundred weight (cwt) of annual milk production. Annual milk production was roughly 14.1 million pounds in 2015 prior to conversion to organic/grazing and 12.4 million pounds in 2017. Based on COMET-Farm estimates, the farm was emitting roughly 52 lbs CO_2 equivalents/cwt prior to converting and reduced emissions by 42% to 30 lbs CO_2 equivalents/cwt after conversion.

Nitrogen, phosphorus, and sediment pollution all decreased in the current grazing scenario by 96.0%, 89.4%, and 99.9%, respectively. Results indicated that Fair Hill Farm achieved the nutrient trading baseline loads for nitrogen and phosphorus, making them eligible to participate in Maryland's Nutrient Trading Program.[3] Reduction in nitrogen application rates in the current scenario contributed to the reductions in nitrogen losses. In addition, improvements in soil health likely led to better nutrient cycling, making nitrogen and phosphorus more plant available and less likely to run off. Similarly, increased water holding capacity of healthier soils helps reduce nutrient and sediment losses to the environment.

[3] http://mdnutrienttrading.com/



Results of Chesapeake Bay Nutrient Trading Tool baseline and current scenarios for Fair Hill Farm.

A summary of results for key soil health parameters is found below. Soil samples were collected in fields F24Band C, with a cropping history of corn, triticale, sorghum, hay rotation before transitioning to rotational grazing. Many of the key soil parameters measured in both 2016 and 2018 were either classified as red or yellow, reflecting fields with a significant need for improvement. Organic matter, while still needing improvement, increased significantly (p-value = 0.003) during the study from 2.4% to 3.3%. Similarly, aggregate stability increased significantly from 9.8% to 17.6% (p-value = 0.05). Soil respiration did not significantly change during the study period, with average of 0.5 and 0.6, in 2016 and 2018, respectively. Lastly, the average value for extractable phosphorus decreased between 2016 and 2018, but the change was not statistically significant.

Select soil health parameters on Fair Hill Farm averaged from four samples collected in 2016 and 2018.

Soil Parameters	**2016**		**2018**	
	Average	**SE**	**Average**	**SE**
Aggregate Stability (%) *	9.8	1.1	17.6	2.8
Organic Matter (%) *	2.4	0.1	3.3	0.1
Soil Respiration (mg)	0.5	0.0	0.6	0.0
Extractable Phosphorus (ppm)	38.0	4.6	29.8	7.2

**indicates results that are statistically significant using a t-test (p <0.05).*

Case Study 2: Blue Mountain Farm, Lebanon County, PA

Matt Bomgardner owns and operates Blue Mountain Farm, a 198-acre dairy farm in Lebanon County, PA. His dairy herd includes roughly 100 milking cows and 20-25 dry cows. Between 2008 and 2016, Matt converted 50 acres of cropland (a mixture of corn, alfalfa, and rye) to pasture so he could increase the percentage of time his dairy herd spent foraging on grass and comply with organic dairy standards. Historically, he applied manure and fertilizer to pasture and cropland, but he eliminated synthetic fertilizer in the current scenario, also to comply with organic standards.

Summary table of baseline and current crops and fertilizer for each field. Rot Past=rotationally grazed pasture, A=alfalfa, R=Rye, C=corn, Man=manure, syn=synthetic nitrogen fertilizer. Note: Farm and field acreage may differ slightly from conservation plan.

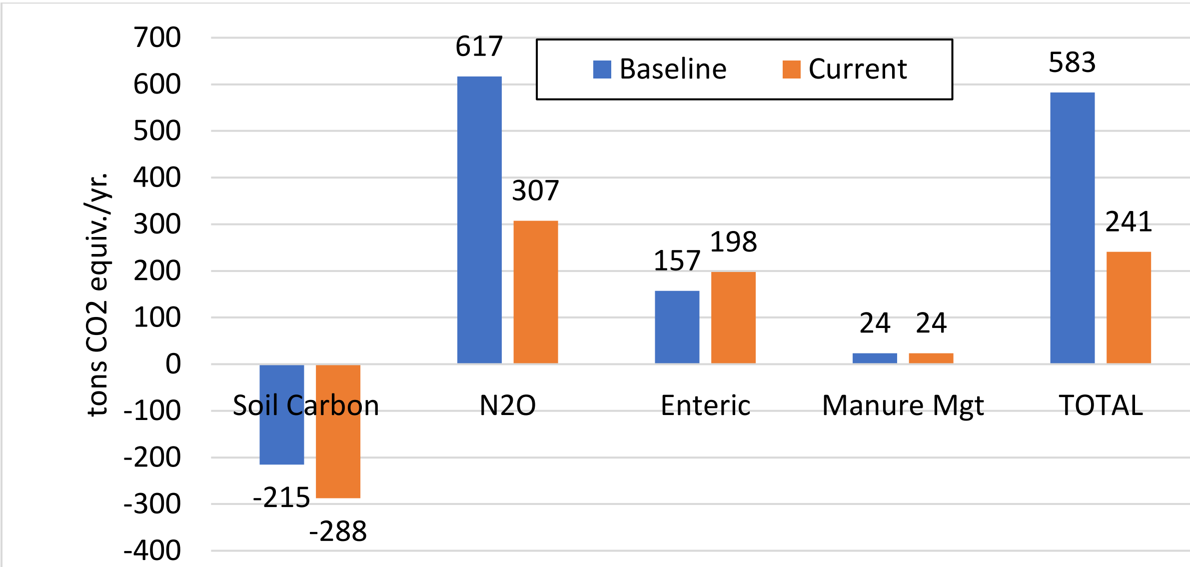
	Baseline Scenario		Future Scenario		
Field	**Crop**	**Fertilizer**	**Crop**	**Fertilizer**	**Acres**
NE1	Rot Past	Syn/Man	Same	Man	4
NE2	A-R	Syn/Man	Rot Past	Man	4
NE3	C-R	Syn/Man	Rot Past	Man	6
NE4	A-R	Syn/Man	Rot Past	Man	12
NW1	Rot Past	Syn/Man	Same	Man	7
NW2	A-R	Syn/Man	Rot Past	Man	5
NW3	A-R	Syn/Man	Rot Past	Man	7
Field 3	C-R	Syn/Man	Same	Man	11
Field 10	C-A	Syn/Man	A-R	Man	29
SE1	Rot Past	Syn/Man	Same	Man	3
SE2	Rot Past	Syn/Man	Same	Man	5
SE3	Rot Past	Syn/Man	Same	Man	5
SE4	C-R	Syn/Man	Rot Past	Man	15
SW1	Rot Past	Syn/Man	Same	Man	6
SW2	Rot Past	Syn/Man	Same	Man	3
SW3	Rot Past	Syn/Man	Same	Man	4

Results

Overall, greenhouse gas (GHG) emissions from the farm decreased by roughly 342 tonnes of CO_2 equivalents per year, or 59% from the baseline to the current grazing scenario, indicating significant benefits in GHG reduction from transition to organic, rotational grazing. For context, this reduction is roughly equivalent to the amount of carbon that would be sequestered annually by 3 acres of mature (i.e., 40-year-old) forest.[4]

[4] https://www.winrock.org/wp-content/uploads/2016/03/Opportunities_for_improving_carbon_storage_through_afforestation_of_agricultural_lands.pdf

COMET-Farm estimates GHG emissions from several on-farm "source and sinks," so we can assess where changes in GHG emissions occurred and due to what actions.



COMET-Farm results for Blue Mountain Farm baseline and current scenarios.

Carbon sequestration in the soil increased (negative values indicate carbon sequestration) from -215 to -288 tonnes of CO_2 equivalents per year, or 34%, reflecting an increase in soil organic matter. This increase was due to both the transition of multiple fields from cropland to pasture and an improvement in grazing management across the farm.

Nitrous oxide emissions decreased from 617 to 307 tonnes of CO_2 equivalents per year, a 50% reduction. The decrease resulted mostly from the elimination of synthetic nitrogen fertilizer in the current grazing scenario. Enteric emissions of methane increased from 157 to 198 tonnes of CO_2 equivalents per year (21% increase) due to the increase in the proportion of grass in the cow diet, from 28% to 49%. It is commonly understood that a diet high in grass results in higher methane emissions from livestock. The manure management system and emissions remained the same in both scenarios.

We also estimated GHG emissions on a per hundred weight (cwt) of annual milk production. Matt indicated peak milk production was 2.1 million pounds prior to the full conversion to organic/grazing and 1.8 million pounds after the transition. The farm was emitting roughly 61 lbs CO_2 equivalents/cwt prior to converting and less than half that, 30 lbs CO_2 equivalents/cwt after conversion.

Similar to COMET-Farm, results from A-Microscale indicate an overall reduction in greenhouse gas emissions from the farm due to the conversion of cropland to rotational grazing, but the estimated change was far less, only 41 tonnes of CO_2 equivalents per year. One reason for the difference is that not all farm acres were simulated in A-Microscale, only those that transitioned from crop to pasture. We are unable to indicate the percentage reduction from baseline because

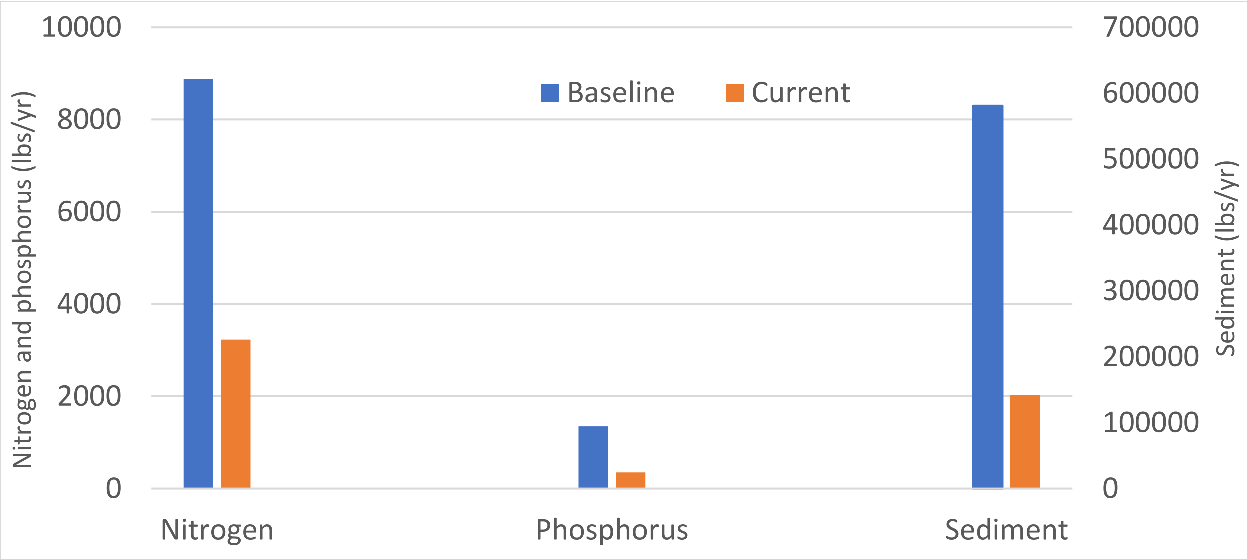
A-Microscale only lists the differences in emissions between scenarios, not emissions for the baseline and project conditions.

Like COMET-Farm, results also indicated an increase in soil carbon sequestration and a dramatic decrease in nitrous oxide emissions. The one difference observed was in manure management emissions. A-Microscale does allow the user the flexibility to enter in more than one manure management type in each scenario. In this instance, in the current scenario the manure system included part of manure going into a bedded pack. COMET-Farm does not allow the user to indicate more than one type of management system.

Table 2. Results of A-Microscale scenario for Blue Mountain Farm. Units are tonnes of CO_2 equivalents per year.

Soil Carbon	Enteric Fermentation	Manure Mgt	N2O	Farm Total
-19	39	55	-116	-41

Nitrogen, phosphorus, and sediment pollution all decreased in the current grazing scenario by 64%, 74%, and 75%, respectively. Results indicated Blue Mountain Farm achieved the nutrient trading baseline loads for nitrogen and was very close for phosphorus.[5] Elimination of synthetic nitrogen fertilizer use in the current scenario contributed substantially to the reductions in



Results of Chesapeake Bay Nutrient Trading Tool baseline and current scenarios for Blue Mountain Farm.

[5] A nutrient trading baseline is the level of conservation that a farm must achieve before participating in the regulatory nutrient trading program. Pennsylvania Department of Environmental Protection has not yet officially adopted the CBNTT in their trading program, but the most recent update on the program suggests that was their intent http://files.dep.state.pa.us/Water/BPNPSM/NutrientTrading/NutrientTradingSupplementToPhase2WIP.pdf

nitrogen losses. In addition, improvements in soil health led to better nutrient cycling, making nitrogen and phosphorus more plant available and less likely to run off. Similarly, increased water holding capacity of healthier soils helps reduce nutrient and sediment losses to the environment.

A summary of results for key soil health parameters is found below. Soil samples were collected in field NE4, with a cropping history of alfalfa and alfalfa/annual rye rotation before transitioning to rotational grazing. Most of the soil parameters measured in both 2016 and 2018 were in the ‘optimal’ range, reflecting fairly health soils, with the exception being extractable phosphorus. The extractable phosphorus measured in the 2016 samples was categorized as non-optimal, relative to regional soils with similar texture, and decreased significantly (*p*-value = 0.0296) during the two-year project period, from an average of 34.0 ppm to 23.4 ppm. Organic matter increased significantly during the study from 6.6% to 7.7% (*p*-value = 0.009). Aggregate stability decreased significantly from 65.4% to 56.9% (*p*-value = 0.0169), remaining within ‘optimal’ range, relative to regional soils with similar texture. Soil respiration did not significantly change during the study period, with average of 0.9 and 1.0, in 2016 and 2018, respectively.

Select soil health parameters for Blue Mountain Farm averaged from four fields in 2016 and 2018.

Soil Parameters	**2016**		**2018**	
	Average	**SE**	**Average**	**SE**
Aggregate Stability (%) *	65.4	2.6	56.9	3.1
Organic Matter (%) *	6.6	0.1	7.7	0.1
Soil Respiration (mg)	0.9	0.0	1.0	0.0
Extractable Phosphorus (ppm) *	17.0	1.4	23.4	2.2

** indicates results that are statistically significant using a t-test (p <0.05).*

Case Study 3: Open Book Farm, Frederick County, Maryland

Andrew and Mary Kathryn Barnett own and operate Open Book Farm, a 133-acre farm in Frederick County, Maryland. They purchased the farm four years ago to fulfill their dream of a diverse, sustainable farming operation. This vision includes converting about half of their land into rotationally grazed pasture to raise a diversity of animals, including beef steers (10), broilers (roughly 6000), layers (150), turkeys (100), and swine (20) as well as growing organic vegetables. Prior to this, the farm was a conventional dairy operation with confined animals and grain grown for feed.

There was little information regarding specific farm management practices before the Barnetts assumed ownership. Therefore, CBF worked with an agricultural expert to develop educated assumptions for the baseline scenario. We assumed the farm had a 50-cow dairy herd with roughly 133 acres in cropland. It was assumed that these crops were grown in a corn, winter wheat, soybean rotation. We assumed manure was applied to the fields prior to planting in April and before winter wheat in October. Synthetic nitrogen fertilizer was also used.

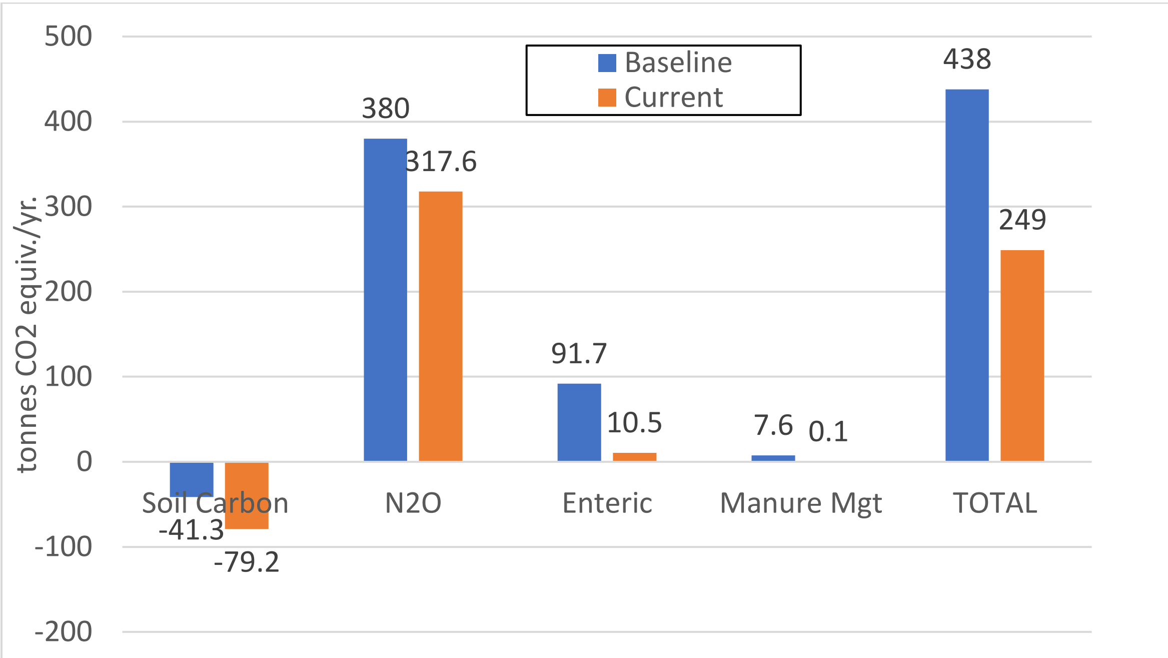
Summary table of baseline and current crops and fertilizer management for each field. C=corn, WW=winter wheat, SB=soybean, Man=manure, syn=synthetic fertilizer, Rot Past = rotationally grazed pasture. Note: Farm and field acreage may differ slightly from conservation plan.

	Baseline Scenario		Current Scenario		
Field	**Crop**	**Fertilizer**	**Crop**	**Fertilizer**	**Acres**
1	C-WW-SB	Man/Syn	Same	Same	4
2	C-WW-SB	Man/Syn	Same	Same	20
3	C-WW-SB	Man/Syn	Same	Same	19
4	C-WW-SB	Man/Syn	Same	Same	13
5	C-WW-SB	Man/Syn	Rot Past	Manure	2
6	C-WW-SB	Man/Syn	Rot Past	Manure	8
7	C-WW-SB	Man/Syn	Rot Past	Manure	9
8	C-WW-SB	Man/Syn	Rot Past	Manure	4
9	C-WW-SB	Man/Syn	Rot Past	Manure	5
10	C-WW-SB	Man/Syn	Rot Past	Manure	10
11	C-WW-SB	Man/Syn	Rot Past	Manure	13
12	C-WW-SB	Man/Syn	Rot Past	Manure	2
13	C-WW-SB	Man/Syn	Same	Same	1
14	C-WW-SB	Man/Syn	Same	Same	13

Results

Overall, greenhouse gas (GHG) emissions from the farm decreased by roughly 189 tonnes of CO_2 equivalents per year, or 43% from the baseline to the current scenario, indicating significant benefits in GHG reduction from this transition and other operational changes on the farm. For context, this reduction is roughly equivalent to the amount of carbon that would be sequestered annually by almost 2 acres of mature (i.e., 40-year-old) forest.[6]

COMET-Farm estimates GHG emissions from several on-farm "source and sinks," so we can assess where changes in GHG emissions occurred and due to what actions.



COMET-Farm results for Open Book farm for baseline and current scenarios.

Carbon sequestration in the soil increased by almost 50% due to the conversion of some of the cropland to rotationally grazed pasture. Nitrous oxide emissions were reduced by 16% due to reduced application of synthetic nitrogen as fields converted from cropland to rotational grazing pastures received no additional fertilizer. Enteric emissions of methane were reduced by almost 90%, reflecting the decrease in on-farm livestock. The transition from a confinement operation to a grazing operation with fewer animals also resulted in a decrease in greenhouse gas emissions from manure management.

Annual loads of nitrogen, phosphorus, and sediment loading decreased by 60%, 61%, and 19% in the current scenario when compared to the baseline scenario, indicating substantial water quality benefits resulted from management changes on the farm, including the transition of cropland to pasture and rotational grazing. Results indicated Open Book Farm achieved the nutrient trading baseline for nitrogen and phosphorus, making them eligible to participate in Maryland's Nutrient Trading Program.[7]

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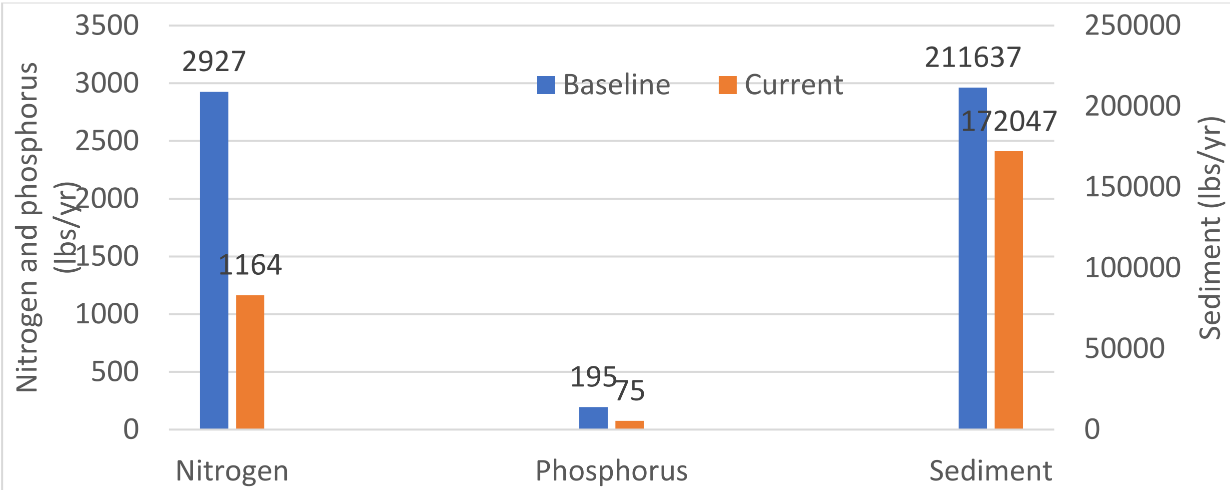
[6] https://www.winrock.org/wp-content/uploads/2016/03/Opportunities_for_improving_carbon_storage_through_afforestation_of_agricultural_lands.pdf

[7] http://mdnutrienttrading.com/



Results of Chesapeake Bay Nutrient Trading Tool baseline and current scenarios for Open Book Farm.

A summary of results for key soil health parameters is found below. Soil samples were collected in fields 9, 10, 11, and 12 with a cropping history of corn/wheat/soybean prior to conversion to rotationally grazed pasture.

Baseline 2016 soil parameter scores ranged from poor to optimal, with the poorest indicator being aggregate stability. Even though aggregate stability was the poorest indicator in terms of soil health, it showed significant improvement between 2016 and 2018 values, with the average increasing from 16.7 to 34.6 (p-value=0.011). Organic matter, which was rated as fair to optimal in the four fields, also increased significantly (p-value=0.006) from 4.2 to 4.9%. Soil respiration did not significantly change during the study period, with averages of 0.7 and 0.8, in 2016 and 2018, respectively. Extractable phosphorus was optimal in three out of the four fields, ranging from 6.4-10.1 ppm in both 2016 and 2018, however, one of the fields had high levels of extractable phosphorus measuring 132.9 and 55.4 ppm in 2016 and 2018 respectively. Overall, extractable phosphorus did not significantly change over the course of the study (p-value=0.407).

Select soil health parameters for Open Book Farm averaged from four fields in 2016 and 2018.

Soil Parameters	2016		2018	
	Average	**SE**	**Average**	**SE**
Aggregate Stability (%) *	16.7	1.9	34.6	1.8
Organic Matter (%) *	4.2	0.3	4.9	0.2
Soil Respiration (mg)	0.7	0.0	0.8	0.0
Extractable Phosphorus (ppm)	39.2	31.1	20.3	11.7

** indicates results that are statistically significant using a t-test ($p < 0.05$).*

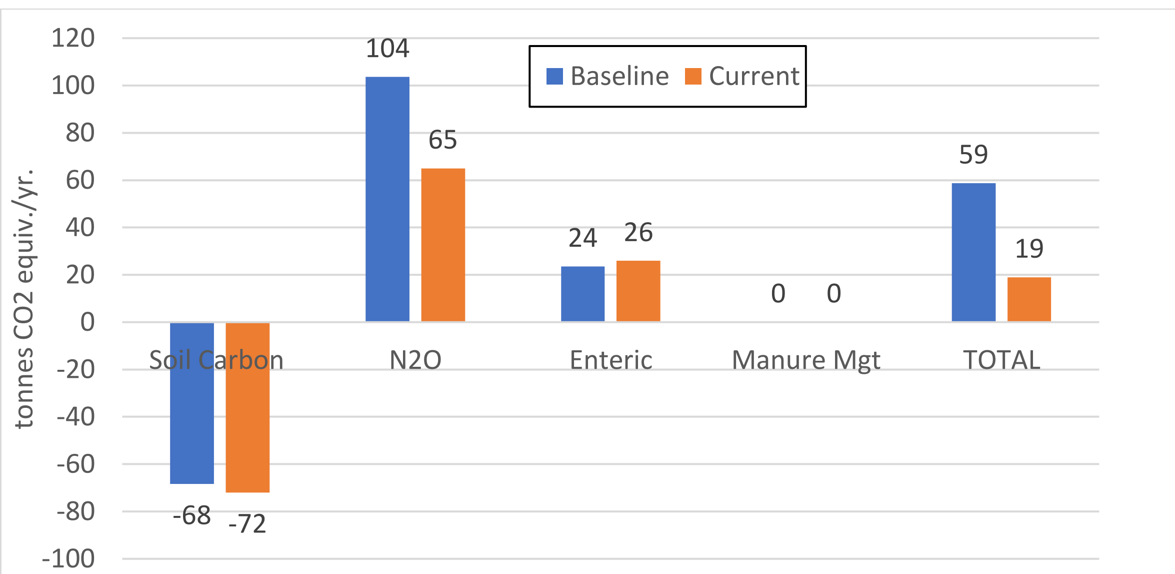
Case Study 4: Funkhouser Farm, Shenandoah County, VA

Karla Funkhouser operates a beef cattle operation, with 27 cow/calf pairs, on her 91-acre property. About half of the property is dedicated to grazing while the other half is grown in hay for the first part of the year. After harvesting in July, the hay side is grazed by the herd. Although Karla will move the herd around during the grazing season, she does not do it enough for it to be considered rotational grazing. For our purposes, the baseline scenario is continuous grazing. Prior to this project, she did not have a permanent water system for the cattle and was manually refilling a portable tank in the field. With assistance from CBF's Carbon Reduction Fund, she installed a permanent water line and electric fence line running down the center of the property. This addition allowed Karla to implement a more aggressive rotational grazing plan that included dividing up the current pasture field and the hayfield into smaller paddocks with a combination of polywire and permanent fencing. These changes are included in the "current" scenario. She also plans to increase her herd to 30 cow/calf pairs.

Results

Overall, greenhouse gas (GHG) emissions from the farm decreased by roughly 40 tonnes of CO_2 equivalents per year, or 68% from the baseline to the current grazing scenario, indicating significant benefits in GHG reduction from this transition. For context, this reduction is roughly equivalent to the amount of carbon that would be sequestered annually by 1/3 acre of mature (i.e., 40-year-old) forest.[8]

COMET-Farm estimates GHG emissions from several on-farm "source and sinks," so can assess where changes in GHG emissions occurred and due to what actions.

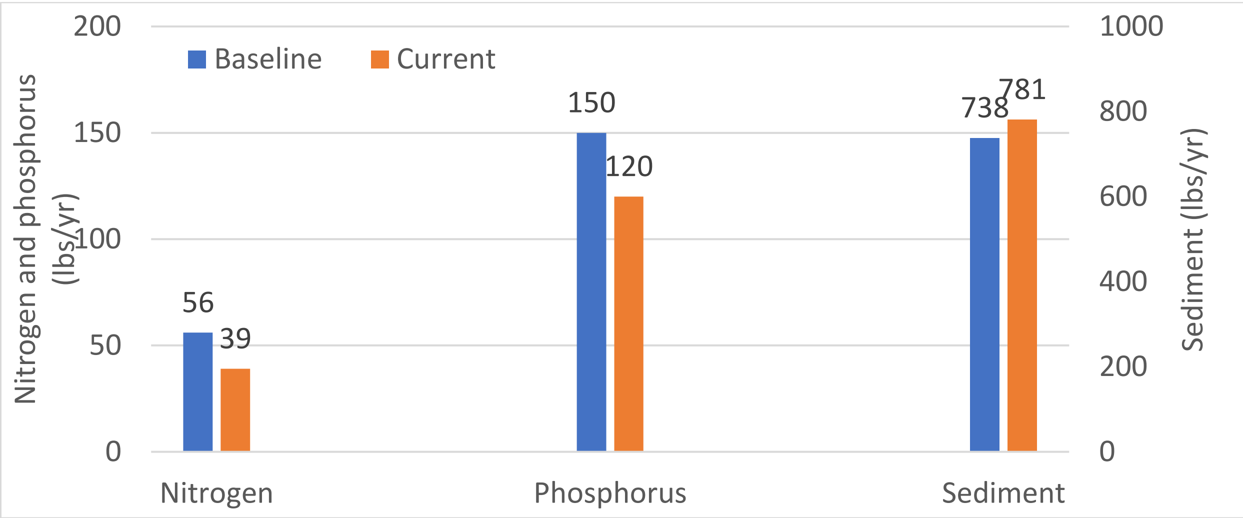


COMET-Farm results for Funkhouser farm baseline and current scenarios.

[8] https://www.winrock.org/wp-content/uploads/2016/03/Opportunities_for_improving_carbon_storage_through_afforestation_of_agricultural_lands.pdf

Carbon sequestration in the soil increased by roughly 6% reflecting benefits from moving from continuous to rotational grazing. Nitrous oxide (N2O) emissions were reduced by 38%. There were no changes in nitrogen application between the baseline and current scenario, therefore we hypothesize that the increased pasture rest times in the future grazing scenario lead to more consistent vegetative cover, more nitrogen uptake, and fewer N2O emissions. Enteric emissions of methane increased slightly as a result of the slight increase in herd size in the current scenario.

Annual loads of nitrogen and phosphorus decreased by 30% and 20%, respectively, in the rotational grazing current management scenario. Sediment loads, however, increased slightly, by 6%, potentially due to the increase of animal units on farm in the current grazing scenario. Results indicate the farm achieved the nutrient trading baseline, as defined by the CBNTT, for nitrogen and phosphorus.[9]



Results of Chesapeake Bay Nutrient Trading Tool baseline and current scenarios for Funkhouser Farm.

A summary of results for key soil health parameters is found below. Soil samples were collected from both the hayfield and the pasture. The hayfield was kept in grass half the year and harvested in July, then grazed half of the year. The pasture was also in grass and was grazed the other half of the year, prior to conversion to rotationally grazed pasture. Most of the soil parameters measured in both 2016 and 2018 were in the 'optimal' range, with the exception being much lower aggregate stability and organic matter values in two out of the four sampling fields in 2018.

Lower measured values from these two fields led to significantly lower 2018 average farm values for aggregate stability (p-value = 0.0198) and organic matter (p-value = 0.001) when compared to 2016 values. We believe this was due to higher than average 2018 rainfall combined

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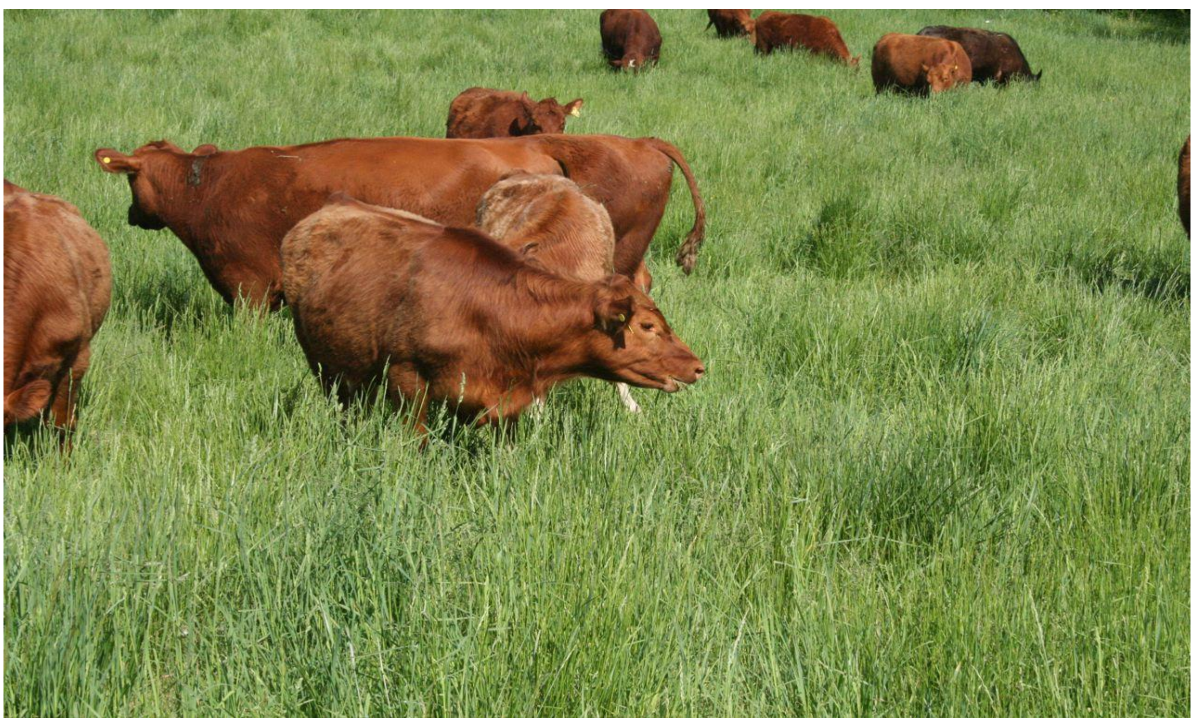
[9] Virginia does not use currently use CBNTT in their nutrient trading program, but an earlier CIG to CBF, that attempted to harmonize trading programs across the Chesapeake Bay states, adapted the CBNTT for use in Virginia.

with lower elevation of two of the sampling fields, leading to saturated conditions. Soil respiration did not significantly change during the study period, with average of 0.9 and 1.0, in 2016 and 2018, respectively. While extractable phosphorus measured in both 2016 and 2018 were categorized as optimal, relative to regional soils with similar texture, values decreased slightly during the 2-year study period, from an average of 6.3 ppm to 2.8 ppm.

Select soil health parameters for Funkhouser Farm averaged from four fields in 2016 and 2018.

	2016		**2018**	
Soil Parameters	**Average**	**SE**	**Average**	**SE**
Aggregate Stability (%) *	71.8	5.4	64.0	5.6
Organic Matter (%) *	4.7	0.6	3.8	0.5
Soil Respiration (mg)	0.9	0.0	0.7	0.1
Extractable Phosphorus (ppm) *	6.3	0.5	2.8	0.2

** indicates results that are statistically significant using a t-test (p <0.05).*



Case Study 5: Strite Farm, Washington County, MD

Originally, Harry Strite was milking about 145 cows using a conventional system of grown/purchased feed from grains and using the open areas on the farm as cropland and exercise areas for the cattle. The fields were used to spread manure from the manure pit several times per year and as result, soil phosphorus levels in many fields were high. Between 1997 and 2014 the Strite family changed their farming system, gradually converting cropland to pasture and, eventually selling their conventional dairy herd and purchasing a much smaller (45) herd of organic cows better suited to grazing. No commercial fertilizer is used, only the dairy manure, and occasionally chicken litter is brought in if the soil test notes additional N is needed.

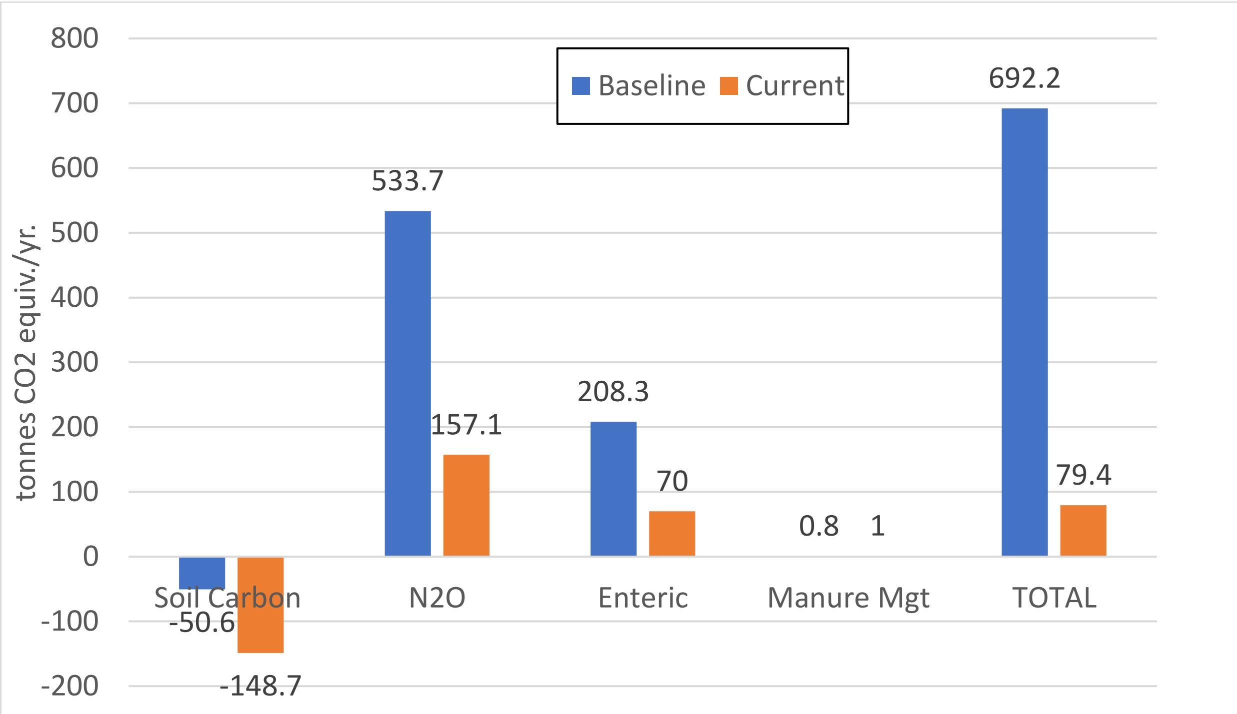
Summary table of baseline and current management for each field. C=corn, WW=winter wheat, Alf=alfalfa, Man=manure, syn=synthetic fertilizer. Note: Farm and field acreage may differ slightly from conservation plan.

	Baseline Scenario		**Current Scenario**		
Field	**Crop**	**Fertilizer**	**Crop**	**Fertilizer**	**Acres**
Field 1	C-WW	Syn	Pasture	Man/Poultry Litter	18.36
Field 2	C-WW	Syn	Pasture	Man/Poultry Litter	27.05
Field 3	C-WW	Syn	Pasture	Man/Poultry Litter	24.60
Field 4	C-WW	Syn	Pasture	Man	9.80
Field 5	C-WW	Syn	Pasture	Man/Poultry Litter	22.43
Field 6	C-WW	Syn	Pasture	Man	4.63
Field 7	C-WW	Syn	Pasture	Man	10.70
Field 8	C-WW	Syn	Pasture	Man	4.91
Hanna 10	Alf/Rye	Man	Pasture	Man/Poultry Litter	17.40
Hanna 11	Alf/Rye	Man	Pasture	Man/Poultry Litter	12.00
Hanna 12	Alf/Rye	Man	Pasture	Man/Poultry Litter	6.50
Hanna 13	Alf/Rye	Man	Pasture	Man/Poultry Litter	10.40
Hanna 14	Alf/Rye	Man	Pasture	Man/Poultry Litter	13.80
Hanna 15	Alf/Rye	Man	Pasture	Man/Poultry Litter	8.00
Hanna 16	Alf/Rye	Man	Pasture	Man/Poultry Litter	10.00

Results

Overall, greenhouse gas (GHG) emissions from the farm decreased by roughly 613 tonnes of CO_2 equivalents per year (Figure 1), or 88% from the baseline to the current grazing scenario, indicating significant benefits in GHG reduction from this transition. For context, this reduction is roughly equivalent to the amount of carbon that would be sequestered annually by 5.5 acres of mature (i.e., 40-year-old) forest.[10]

COMET-Farm estimates GHG emissions from several on-farm "source and sinks," so we can assess where changes in GHG emissions occurred and due to what actions.

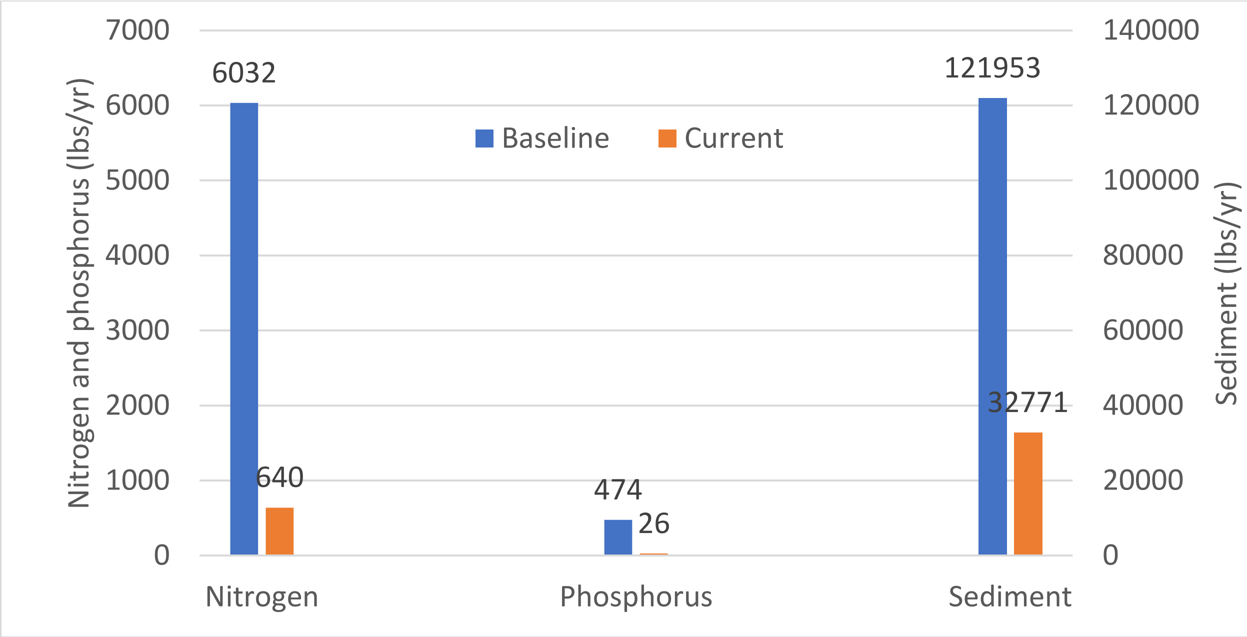


COMET-Farm results for Strite farm baseline and current scenarios.

Carbon sequestration in the soil increased by almost 200% reflecting significant benefits from moving from cropland to rotational grazing. Nitrous oxide emissions were reduced by 70%, reflecting substantial reductions in manure application and the elimination of synthetic nitrogen fertilizer. Enteric emissions of methane were reduced by 67%, a reflection of a substantial reduction in herd size.

Annual loads of nitrogen, phosphorus, and sediment decreased in the rotational grazing future management scenario by 89%, 95%, and 73%, respectively, when compared to the baseline cropland scenario, indicating substantial water quality benefits associated with this farm's changes in management. Results indicate the Strite Farm achieved the trading baseline for nitrogen and phosphorus and would be eligible to participate in Maryland's Nutrient Trading Program.

[10] https://www.winrock.org/wp-content/uploads/2016/03/Opportunities_for_improving_carbon_storage_through_afforestation_of_agricultural_lands.pdf



Results of Chesapeake Bay Nutrient Trading Tool baseline and current scenarios for Strite Farm.

Since this farm had already transitioned to grazing prior to the start of our project, we did not collect samples for soil health analyses.

Case Study 6: Bee Tree Farm, Frederick County, VA

Bee Tree Farm is a 140-acre beef operation owned and operated by Kim and Marietta Walls. Currently, the Walls raise 31 cow/calf pairs and 11 heifers/replacements. In the baseline scenario, about 111 acres are in pasture, 9 acres in alfalfa, and 20 acres are in continuous hayland. In the current scenario, the farm has 120 acres in rotationally grazed pasture and 20 acres in continuous hayland. Synthetic fertilizer was applied every other year to the pastures in both the baseline and current scenarios.

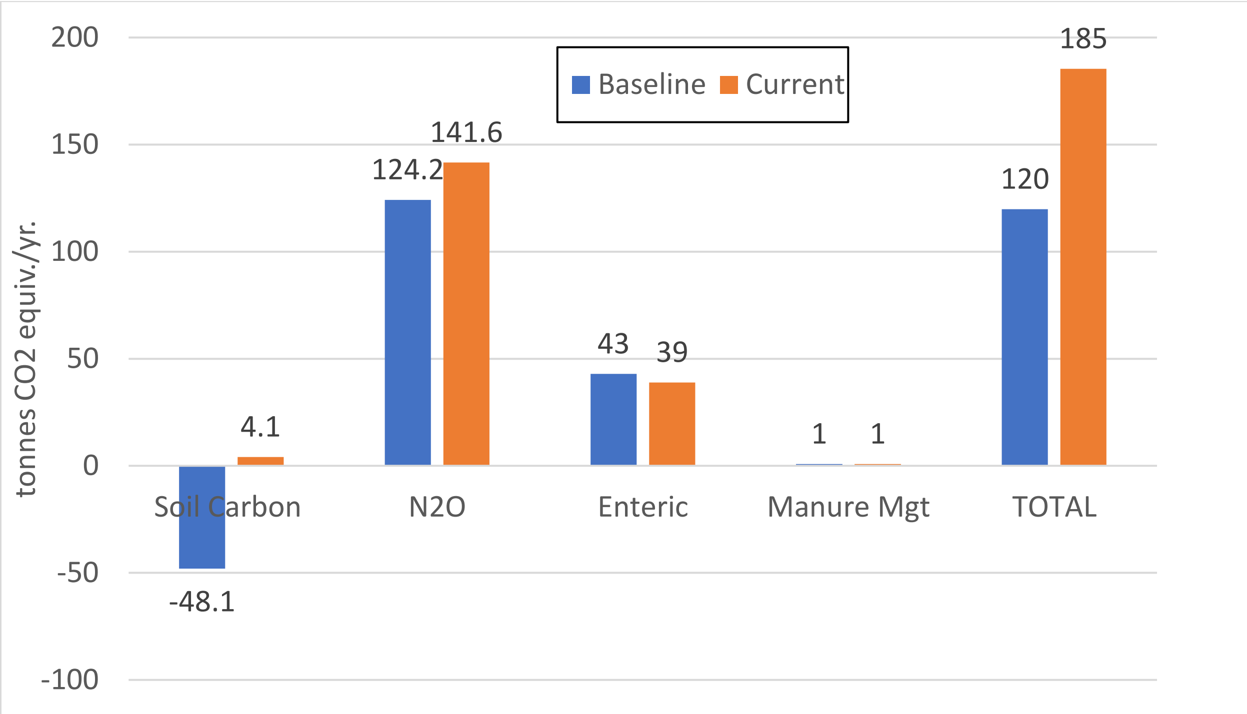
Summary table of baseline and current management for each field. Con past=continuous pasture, syn=synthetic fertilizer, man=manure, Rot Past = rotational grazing, A=alfalfa.
Note: Farm and field acreage may differ slightly from conservation plan.

	Baseline Scenario		Future Scenario		
Field	**Crop**	**Fertilizer**	**Crop**	**Fertilizer**	**Acres**
1	Hay	Syn/Man	Hay	Syn/Man	14
2A	Con Past	Syn/Man	Rot Past	Syn/Man	11
2B	Con Past	Syn/Man	Rot Past	Syn/Man	15
3A	Con Past	Syn/Man	Rot Past	Syn/Man	8
3B	Con Past	Syn/Man	Rot Past	Syn/Man	7
4	Con Past	Syn/Man	Rot Past	Syn/Man	5
5	Con Past	Syn/Man	Rot Past	Syn/Man	7
6	A	None	Rot Past	Syn/Man	5
7	Con Past	Syn/Man	Rot Past	Syn/Man	8
8A	Con Past	Syn/Man	Rot Past	Syn/Man	13
8B	Con Past	Syn/Man	Rot Past	Syn/Man	11
S1	Con Past	Syn/Man	Rot Past	Syn/Man	7
S3	A	None	Rot Past	Syn/Man	4
S5	Con Past	Syn/Man	Rot Past	Syn/Man	4
S6	Con Past	Syn/Man	Rot Past	Syn/Man	6
F11	Hay	Syn/Man	Hay	Syn/Man	6

Results

Overall, greenhouse gas (GHG) emissions from the farm increased by 65 tonnes of CO_2 equivalents per year, or 54% from the baseline to the current grazing scenario. This increase was largely due to the change in soil carbon that changed from sequestration to release between the baseline and current scenarios. We were unable to explain these modeling results, as we expected that increased rest time and health of the pastures would result in an increase in soil carbon sequestration. We consulted extensively with the COMET-Farm modeling team. Ultimately, we concluded that it was a likely a function of the need for us to use two separate project scenarios to garner the results (because COMET-Farm does not allow you to change field boundaries between the baseline and current scenarios) and the way we simulated the baseline scenarios in these two projects (see details below under recommendations).

Nitrous oxide emissions increased by about 15%, perhaps reflecting a slight (roughly 10%) increase in synthetic fertilizer use on fields that were converted from alfalfa to pasture and/or issues with modeling, as noted above. Enteric emissions of methane decreased slightly.



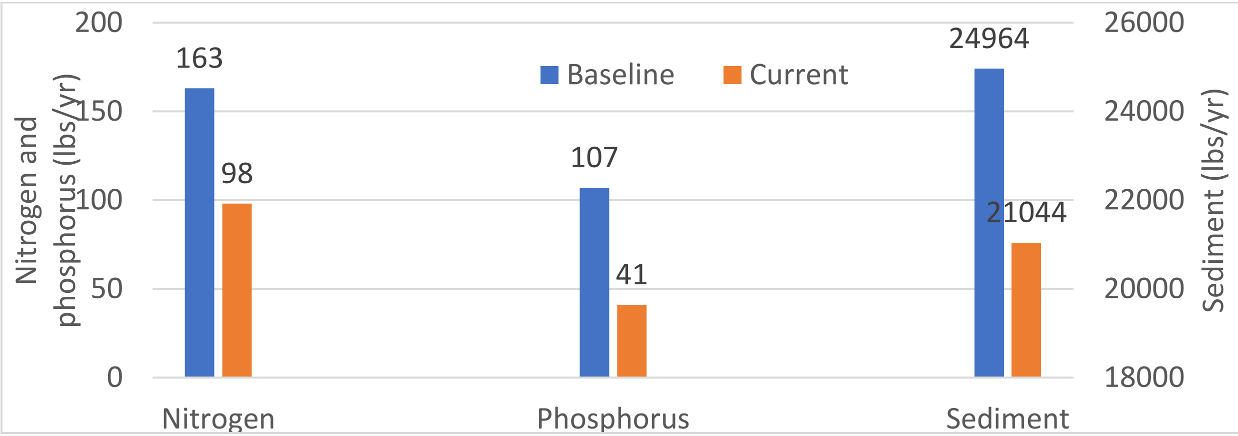
Results of COMET-Farm for Bee Tree farm baseline and current scenarios.

Results using A-Microscale indicate an overall reduction in greenhouse gas emissions from the farm of 33 tonnes of CO2 equivalents per year. This reduction of greenhouse gas emissions was entirely attributed to an increase in soil carbon sequestration.

Results of A-Microscale Estimates of On-Farm GHG Emissions (tonnes CO_2 equivalents/year)

Soil Carbon	Enteric Fermentation	Manure Mgt	N2O	Farm Total
-33	0	0	0	-33

Annual loads of nitrogen, phosphorus, and sediment decreased in the rotational grazing future management scenario by 40%, 62%, and 16%, respectively, when compared to the baseline cropland scenario, indicating water quality benefits associated with this farm’s changes in management. Results indicate the farm achieved the nutrient trading baseline, as defined by the CBNTT, for nitrogen and phosphorus. [11]



Results of Chesapeake Bay Nutrient Trading Tool for Bee Tree Farm transition to rotational grazing.

A summary of results for key soil health parameters is found below. All the soil parameters measured in 2017 were in the 'optimal' range, compared to soils with similar textures and geographical location. We were not able to sample after the conversion because the grant period had expired.

Soil Parameters	2016	
	Average	**SE**
Aggregate Stability (%)	72.7	3.3
Organic Matter (%)	5.5	0.8
Soil Respiration (mg)	1.5	0.2
Extractable Phosphorus (ppm)	5.0	1.2

[11] Virginia does not use currently use CBNTT in their nutrient trading program, but an earlier CIG to CBF, that attempted to harmonize trading programs across the Chesapeake Bay states, adapted the CBNTT for use in Virginia.

Conclusions and Recommendations

These case studies have confirmed and put some numbers behind the multiple environmental benefits of converting to rotational grazing systems in the Chesapeake Bay region. This is one reason that USDA has committed to increasing the implementation of rotational grazing as part of their Climate Smart Agriculture and Forest strategy. In addition, the Chesapeake Bay watershed states are relying on this practice to help them achieve their pollution reduction goals for nitrogen, phosphorus, and sediment. Farmer participants appreciated the insights gained from the analyses on their farms, though there still is some skepticism regarding the model results, especially those that we could not readily explain (see details below).

Modeling Tools:

Both CBNTT and COMET-Farm require a great deal of agronomic information, some of which is not always available. On the positive side, they yield field level results that provide greater insights into the effects of management changes.

One objective of this project was to improve the way CBNTT handled grazing systems – both in terms of ease of entering data as well as how the model simulated grazing systems. To that end, we were successful. It is relatively easy to simulate the transition from continuous grazing to rotational. It is still challenging, however, to simulate the transition from cropland to rotational grazing because of the changes to field size/paddocks. In addition, CBNTT does not allow you to alter animal numbers between the current and "future" scenarios and so we sometimes had to enter two different projects to obtain the results.

As noted earlier, it is challenging to simulate the conversion to rotational grazing in COMET-Farm due, as noted earlier, to the fact that field boundaries cannot be altered between the baseline and current scenarios. As a “work around,” in some cases we ran two projects – one for the baseline conditions and one for the current conditions. When we did this, within the project we kept the scenarios (baseline and current) the same and then compared the outputs from these two projects. We found out late in the grant period, when discussing the results of Bee Tree Farm with the COMET-Farm modelers, that the baseline condition can affect the current condition results.

Other recommended improvements to COMET-Farm include:

1. Provide information regarding which input parameters are most important to the outputs i.e., conduct a sensitivity analysis. As noted above, the tool has high data requirements so providing users with an understanding about which parameters are most important could help guide data collection efforts.
2. Provide guidance on the COMET-Farm website on the best way to treat subdivision of pastures into smaller paddocks to simulate transitions from continuous to rotational grazing.
3. Have a manual save button. Whenever making any adjustments in COMET-farm it automatically saves, and this can take some time, especially when you need to make many quick small adjustments. For example, when adjusting pasture size and shapes, it would be helpful to make several adjustments at one time before saving, rather than having the program automatically save after each adjustment.
4. It would be helpful to have some sort of comparison screen, where you can see and compare what the current and future inputs are for a paddock, rather than having to click back and forth in between the current module and the future module.
5. There is currently a feature that allows you to copy current management into future management. It would be very useful to have the inverse of this feature, allowing you to copy future management to current management.
6. Add the capability to add more than one manure management system.
7. Provide a way to easily download the results by field into Excel.

Comparisons between the results of COMET-Farm and A-Microscale indicate that farm scale results are comparable, although there were some differences for the various on-farm sources and sinks. We will continue to explore these differences with the COMET-Farm modelers. A-Microscale is much simpler to use and requires far less agronomic information. It is useful for a “quick and dirty” evaluation of the benefits of changes in grazing management practices. While farm-scale results were similar, COMET-Farm has the advantages of providing detailed GHG information at the field scale and incorporates more agronomic information that is useful to enhance understanding of the effect of management actions on GHG sources and sinks. In addition, COMET-Farm allows you to assess projects in which the baseline condition does not contain livestock (e.g., Open Book Farm). This was the original reason for including COMET-Farm in our project.

Soil Health
We found the Basic Cornell Soil Health Lab results to be useful, easy to understand, and inclusive of key soil health parameters. A somewhat surprising result was the significant change in organic matter and wet aggregate stability, in the "before and after" soil samples in 3 of 4 case study farms in only 2 years. Looking back, we should have included sample collection in sites/fields where management changes did not occur. This would allow us to factor out differences related to non-management-related variables such as precipitation, temperature, season, and/or the timing of manure application, among others.

Acknowledgments

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For more information:

Dr. Beth McGee
Director of Science and Agricultural Policy
Chesapeake Bay Foundation
6 Herndon Avenue
Annapolis, MD 21403
bmcgee@cbf.org