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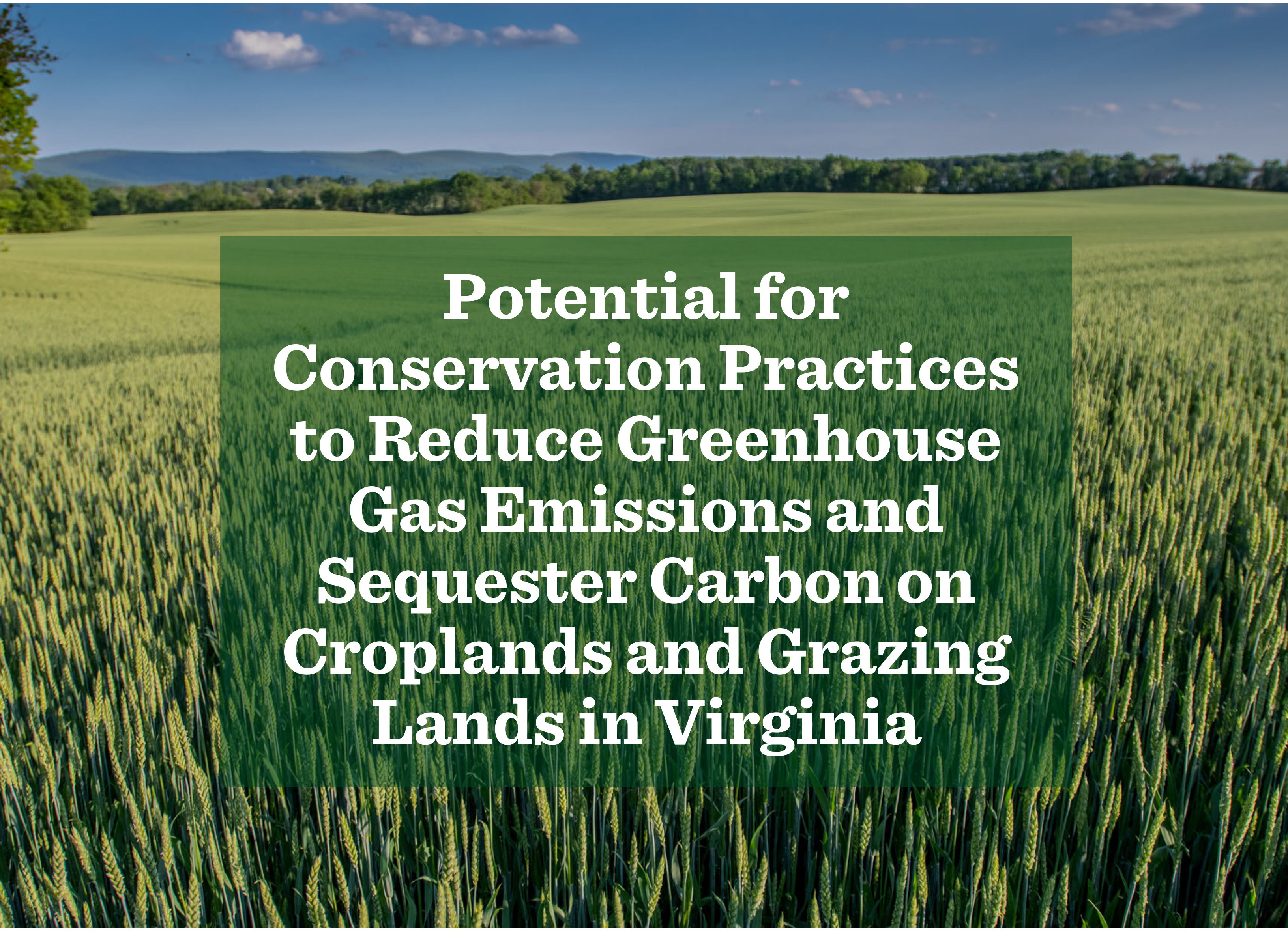

Potential for Conservation Practices to Reduce Greenhouse Gas Emissions and Sequester Carbon on Croplands and Grazing Lands in Virginia

Report prepared by: B.M. McGill

American Farmland Trust, Washington, DC

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Image: Wheat field. Credit: Kelly van Dellen via Canva.

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Executive Summary

This report provides an overview of county-level greenhouse gas (GHG) emission estimates for croplands and grazing lands under current and projected conservation management practice scenarios in Virginia. It is intended to be used to help evaluate potential GHG reductions, inform current and future conservation programs to provide greater GHG offset benefits, and assess the impact of existing and new programs. The analysis presented here showcases that Virginia cropland management has significant potential to reduce GHG emissions and sequester carbon. All values and climate benefits in this report are estimates and should be used for general planning purposes only.

To evaluate the current and projected GHG mitigation potential, the Carbon Reduction Potential Evaluation Tool (CaRPE Tool™)[1] was used to quantify and visualize GHG emission reductions resulting from the implementation of a suite of cropland and grazing land conservation practices. CaRPE Tool scales the emission reduction coefficients (ERC) extracted from the COMET-Planner tool to the county level by coupling the coefficients with cropland acres from the 2017 USDA Census of Agriculture (AgCensus).This report focuses on cropland practices with an emphasis on reduced tillage, no-till and cover crop adoption because those adoption rates are specifically provided in the 2017 Ag Census data. However, this report also includes estimated carbon dioxide equivalent (CO_2e) reduction potentials resulting from a maximum acres adoption scenario for a total of nine conservation practices. The CO_2e reduction potential is the net effect of practice implementation on GHG emissions and carbon sequestration. This report has an accompanying two-page brief summarizing results[2] .

Highlights:

- As of 2017, Virginia has approximately 3 million acres in cropland and 2 million acres in grazing land.
- Eight cropland conservation practice standards are summarized with net CO_2e reduction potential ranging from 0.1 to 0.5 metric tons (t) per acre per year depending upon practice.
- Relative to fields without cover crops and under intensive tillage, the 400,000 acres currently in cover crops and 1.2 million acres in reduced or no-till are estimated to reduce CO_2e by approximately 561,000 to 752,000 t annually. This range in reduction is equivalent to the amount of C sequestered by 9.2 – 12 million tree seedlings grown for 10 years[3].
- With up to 1.5 million more acres that could implement cover crops, there is great potential for additional CO_2e reductions across the state (up to 0.58 additional MMT each year).
- Acres remaining in intensive tillage (127,000) and reduced tillage (223,000), if converted to no-till, could reduce CO_2e an additional 143,000 t per year.
- A maximum acres scenario (80% of available acres) projected a reduction of nearly 2.8 million metric t (MMT) of CO_2e per year, which would offset current Virginia emissions from agriculture by 40%. Two more near-term scenarios combined estimate a CO_2e reduction potential of about 1 MMT per year; a GHG equivalent of avoiding over 5,500 railcars' worth of coal burned.

[1] *CaRPE Tool is available online at: https://farmland.org/carpetool*
[2] *The brief is available at: https://farmlandinfo.org/publications/carpe-results/*
[3] *EPA GHG Equivalencies Calculator https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator*

Barley. Credit: JESHOOTS.com from Pexels via Canva.

Introduction

Report Goal

Recognizing the societal importance of food production, land managers and policymakers must strive to balance the protection of ecosystems for climate mitigation and other environmental co-benefits with the need to optimize agricultural management to feed the nation. As states consider mitigation strategies, agricultural practices are key components of a broader natural and working lands strategy (Fargione et al., 2018).

Agricultural conservation practice implementation on croplands has the potential to provide short-and long-term reductions in greenhouse gas (GHG) emissions and increase the potential for soil carbon sequestration. How these practices differ in their mitigation potential and how they scale over the landscape are not easily estimated at the state and county level. The overarching goal of this report is to provide a framework for estimating state- and county-level net emissions and the sequestration potential of various NRCS cropland and grazing land conservation practices. All estimates provided are in units of carbon dioxide equivalents (CO_2e) in metric tons (t).

The practices explored with this framework include the cropland and grazing land management options estimated by COMET-Planner Version 2.1 Build 1 from August 2020 (Table 1) for Virginia and are scaled to maximum adoption potential for all cropland or grazing land acres as recorded in the 2017 AgCensus. Brief definitions of each practice are provided in Appendix A and details regarding the approach can be found in Appendix B and Swan et al., 2022. By combining these two datasets (i.e., the emission reduction coefficients for the practices in COMET-Planner and the cropland or grazing land acres data in the AgCensus), this report provides county-level CO_2e reduction estimates for cropland and grazing land and state-wide summaries. It should be noted that county COMET-Planner GHG emission reduction estimates are aggregated according to their Major Land Resource Area (MLRA)[4].

All reported values and climate benefits in this report are estimated values and should be used for general planning purposes only. It is assumed that once a practice is implemented, it remains in place to realize its full potential. Additionally, increases in soil carbon stocks do not continue indefinitely; thus, a 10-year duration is recommended, although longer periods may be necessary to reach a new equilibrium condition (Swan et al., 2022).

[4] *MLRAs are geographically associated land resource units, defined by the USDA, that have similarities in physiography, geology, climate, soils, biological resources, and land use (USDA-NRCS, 2006).*

Table 1. Conservation practices used in this report.

Management Focus	NRCS Conservation Practice Standard (CPS) Number & Name		Relative GHG Benefit	COMET Application
Soil Health	328	Conservation Crop Rotation	*	Decrease fallow or add perennial crops to rotation
	329	Residue and Tillage Management, No Till & Strip Till	**	Intensive or reduced tillage conversion to no-till or strip till
	340	Cover Crop	**	Add legume cover with 50% fertilizer N reduction
	340	Cover Crop	*	Add non-legume cover with 25% fertilizer N reduction
	345	Residue and Tillage Management, Reduced Till	*	Intensive tillage conversion to reduced till
	484	Mulching	*	Add high carbon organic matter to croplands (e.g., straw or crop residues)
	585	Strip cropping	*	Add perennial cover in strips
Grazing and Pasture	381	Silvopasture	*****	Add trees/shrubs on grazed grasslands
	528	Prescribed Grazing	*	Replace extensive pasture management (60% forage removal or more) with intensively managed grazing (40% forage removal)
	550	Range Planting	*	Seeding forages to improve rangeland condition

Note: For the relative GHG benefit, more stars indicate greater GHG reduction benefit potential, see Fig. 3 for exact values.

Net values, as reported by COMET-Planner, were estimated over a 10-year duration and reported on an annual basis by dividing the total model-estimated changes by 10.

This report provides the following results for Virginia:

- Average weighted CO_2e reduction coefficients for the state for a suite of cropland and grazing land conservation practices (t per acre per year). Note: The authors recognize that the agricultural sector includes other critical land management sectors (e.g., riparian, coastal habitats, and farmer-owned forestlands) and associated best management practices as well as land use, land use change and conversion, that are not considered in this assessment. Future efforts will seek to include those for a more holistic portfolio.
- Virginia's CO_2e reduction potential (t per year) in a scenario where 80% of available acres adopt a suite of conservation practices on cropland and grazing land.
- Virginia's CO_2e reduction potential (t per year) with two more near-term adoption levels in row crops and specialty crops.
- Average weighted CO_2e reduction coefficients for the state for a suite of conservation practices that can be applied to field borders.
- Detailed spatial analysis of current levels of adoption of cover cropping and conservation tillage practices across the state.
- Estimated current and remaining CO_2e reduction potential associated with cover cropping and conservation tillage.

Results from this report are intended for use by state personnel to: i) evaluate potential GHG reductions and carbon sequestration (expressed as net t CO_2e per year) for cropland and grazing land management changes; ii) assess the CO_2e reduction impact of existing and new programs; and, iii) inform current and future conservation programs to provide greater climate and soil benefits, as appropriate.

Reported values are generalized estimates that show impacts and differences across current and future programs and activities. Not all conservation practices may be suitable or practical to all land use types. County- or region-based agricultural experts (e.g., university extension, soil and water conservation districts, NRCS, certified crop consultants and other ag consultants, etc.) should be consulted to establish achievable yet ambitious goals and ensure that implementation meets NRCS practice standards. States should contact these experts to develop additional estimates for other agricultural best management practice implementation scenarios.

Soil Health for Reducing Greenhouse Gas Emissions & Sequestering Carbon

Rebuilding soil health is the keystone of enhancing agricultural climate resiliency and carbon farming efforts in the US. Soil health is defined by NRCS as "the continued capacity of a soil to function as a vital living ecosystem that sustains plants, animals, and humans." The principal practices of healthy soils, carbon farming, and climate resiliency efforts overlap with conservation and water quality practices.

The USDA-NRCS Soil Health Division identifies four soil health principles (Figure 1) that improve soil function for a variety of ecosystem outcomes (USDA-NRCS, 2018). Implementation of practices that address all four principles also results in resilient agricultural systems that sequester carbon and reduce GHG emissions (Roesch-McNally et al., 2019).

Figure 1. Summary of the four soil health principles and key practices associated with each as defined by NRCS.

Image courtesy of NRCS (Roesch-McNally et al., 2019)

The four soil health principles are:

1. Minimize disturbance (typically physical disturbance is the major focus, with a target to reduce tillage depth, intensity, and frequency).
2. Maximize soil cover, often through mulching, reduced tillage, residue retention, and cover crops.
3. Maximize the continuous presence of living roots, which is typically achieved through cover crop planting but also longer rotations, forage, and biomass plantings, and incorporation of perennial crops into the rotation.
4. Maximize biodiversity through practices similar as those described in #3; but can also include the integration of livestock into the cropping system and diversifying a cover crop mix or more diversified crop rotations.

Some organizations split the fourth principle into plants and animals. For example, New Mexico specifically has a fifth soil health principle for its healthy soils program of including animals in land management.

Although agriculture currently is a net source of GHG emissions, there are numerous cropland and grazing land conservation practices that are proven to increase the amount of carbon that plants can capture and ultimately store in the soil through soil carbon sequestration (Chambers et al., 2016; Paustian et al., 2016; Paustian et al., 2019a; 2019b). Many of these practices also directly and indirectly influence the nitrogen cycle, and they have been shown to reduce (Basche et al., 2014), have no effect (Ball et al., 2014), or, in some cases, increase (Linton et al., 2020) the amount of nitrous oxide (N_2O) emitted from soils (Guenet et al., 2021). In this report, changes in N_2O emissions are region- and practice-specific (see Figure 3). Collectively, increasing carbon sequestration in soils and reducing N_2O emissions are key strategies in addressing climate change.

Soil health, carbon farming, climate-smart agriculture, and regenerative agriculture differ somewhat in their detailed definitions. However, at a minimum, each approach promotes the four soil health principles and most associated practices have the same result of increasing soil organic matter. Recently, policymakers have designed, developed, and supported soil health programs with explicit or implicit climate benefits in mind. The practices that are included in healthy soils policies (such as cover cropping and no- or reduced till) have been used to improve water quality and achieve other conservation outcomes for decades. In addition to these two practices, there is a broad range of soil health practices supported by NRCS; many have direct climate benefits and other co-benefits (USDA-NRCS, 2020). Because these practices are supported by federal entities and therefore funding, they tend to be the starting point for agricultural programs with goals of water quality, conservation, healthy soils, and combatting climate change. For a list of climate-smart NRCS practices and definitions see Appendix A: Conservation Practices & Glossary.

A dairy cow. Credit: Pexels via Canva.

To evaluate the current and projected GHG mitigation potential across the contiguous US, AFT, in collaboration with USDA-ARS, developed the Carbon Reduction Potential Evaluation (CaRPE™ Tool). This tool combines cropland and grazing land acreage data from the 2017 Ag Census with GHG emission reduction coefficients reported in COMET-Planner for each county (details in Appendix B: Methods, Visualization & Quantification, and Equations). CaRPE Tool also provides estimated costs for implementing practice adoption scenarios based on national average, maximum, and minimum NRCS EQIP payment schedules. Users can also apply local payment schedules in CaRPE Tool.

This report focuses exclusively on the cropland and grazing land conservation practices identified in COMET-Planner (Table 1) for Virginia. The full mitigation potential of each practice is the combined effect of GHG emission reduction and soil carbon sequestration changes. Assessments using COMET-Planner are designed to be appropriate for multi-county to regional planning purposes based on the combined spatial and temporal metamodeling approach of COMET-Farm. Estimates reported by COMET-Planner are relative to baseline management and counties were grouped to their most appropriate MLRA. Baseline scenarios generally represent current management practices that are typical of the region but in which there is minimal use of conservation-focused management practices. For more details, see Swan et al. 2022.

Units for Greenhouse Gas Emissions

This report focuses on the opportunities that cropland and grazing land management can play with regards to increasing soil carbon sequestration and reducing N_2O emissions for a net reduction in GHG emissions. Values are expressed as carbon dioxide equivalents (CO_2e). Greenhouse gas emissions are expressed as CO_2e and reported in metric ton (t) increments.

Carbon dioxide equivalents are a global warming potential weighting, based on radiative forcing over a 100-year time scale, resulting from the release of 1 kg of a substance as compared to 1 kg of CO_2 (IPCC, 2006, V4 Ch11). In COMET-Planner, the three main GHGs reported for each conservation practice are CO_2, N_2O, and CH_4 (methane). Carbon dioxide has a global warming potential of 1 and is used as the reference. Nitrous oxide has a global warming potential of 298 and CH_4 a global warming potential of 25 (EPA, 2022a, which uses IPCC AR4 values).

Emission Reduction Coefficients (ERCs) from COMET-Planner are different for practices on irrigated and non-irrigated land. We calculated a weighted ERC for each practice for each county where the average of the two ERCs was weighted by the number of irrigated and non-irrigated cropland acres in the county. We also report the average weighted ERC for each practice for the state. Reported GHG reductions include the net result from changes in soil carbon, CO_2 emissions from liming, urea fertilization, and N_2O emissions from soils (including fertilizers) due to practice implementation. Estimates were generated over a 10-year duration and reported on an annual basis by dividing the total model-estimated changes by 10 (Swan et al., 2022). On-going research is studying how permanent no-till is in farm fields (as opposed to experimental farms) and how it affects carbon sequestration across deeper soil profiles, e.g., 1.0 m rather than 0.2 m depths. These studies could change our estimates of the carbon benefits of tillage management.

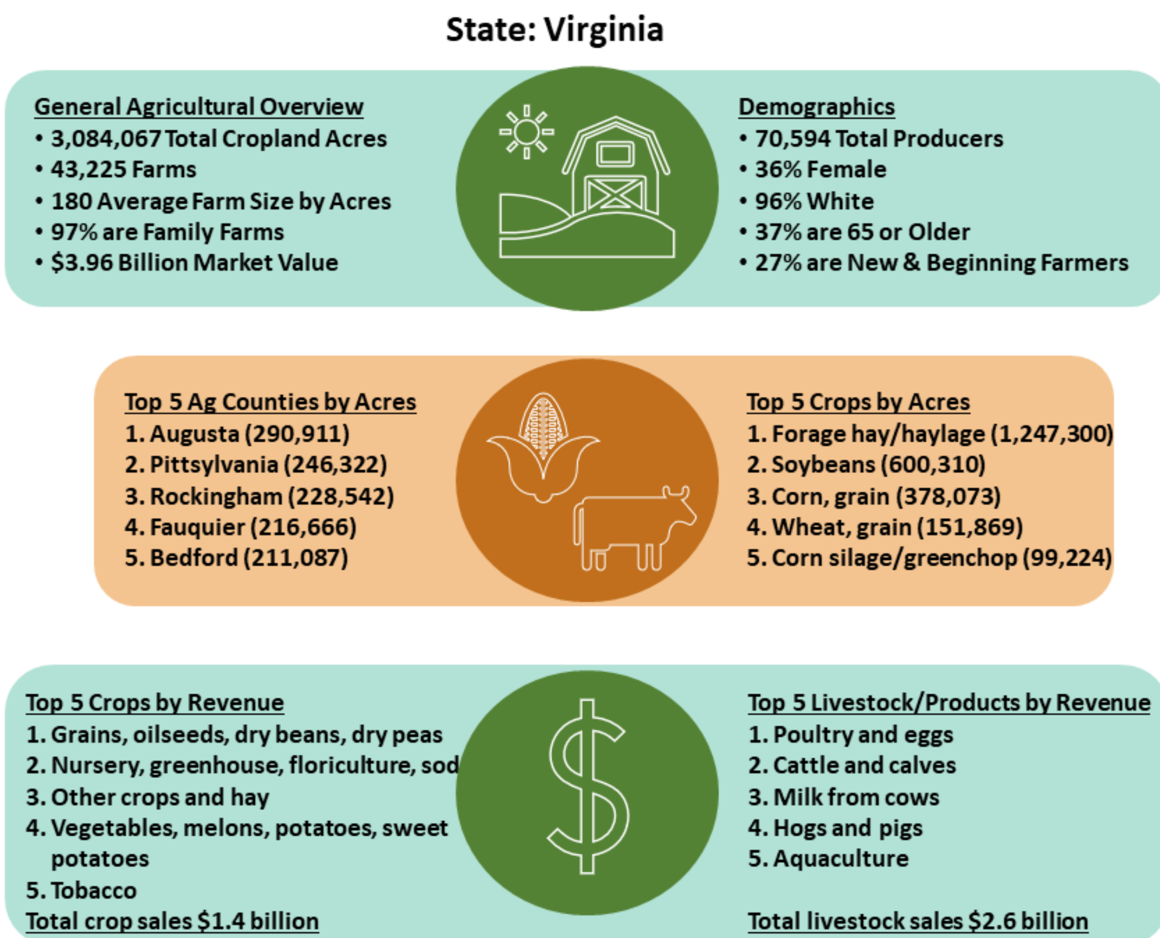
Corn field. Credit: Pexels via Canva.

Current State of Agriculture in Virginia

In 2017, the total amount of farmland in Virginia was approximately 7.8 million acres with 3 million acres under cropland (Figure 2). There were 43,225 farms total averaging 180 acres each, and 3,467 farms were greater than 500 acres. The dominant crops, by acreage, were forage, soybeans, grain corn, wheat, and silage corn. Poultry and eggs, cattle, milk (cow), hogs, and aquaculture were the predominant livestock or livestock products. Total revenue from agricultural products was $3.9 billion with 66% of those revenues from livestock, poultry, and associated products (USDA-NASS, 2017a). Approximately 34% of total agricultural revenue was from crops. Gross farm income was $547 per acre and total farm production costs were $440 per acre.

For farm demographics, 96% of Virginia producers were white compared to 94% nationally (USDA-NASS, 2017b). The percentage of female producers (36%) was similar to the national average of 36% (Figure 2), and 36% of producers were 65 years and older. The national average age of producers was 57.5 with 34% over the age of 65.

Figure 2. Virginia Agriculture at a Glance. Adapted from USDA-NASS (2017a).



Rye and clover cover crop following corn. Credit: Getty Images via Canva.

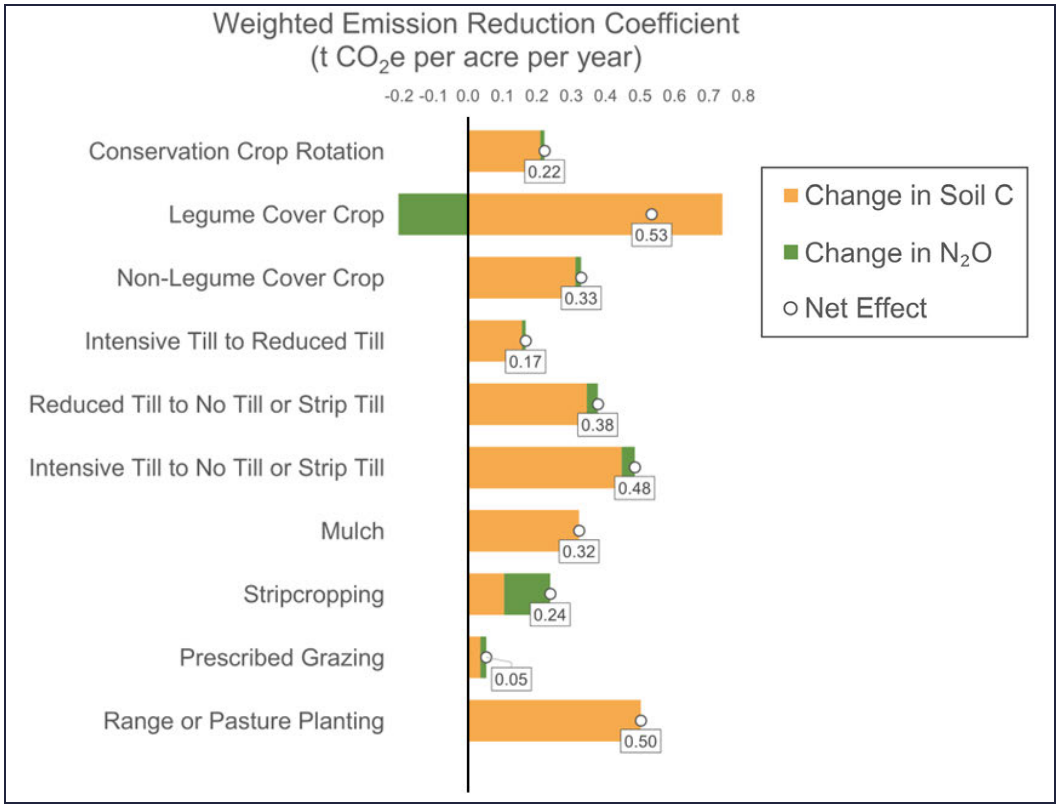
Cropland & Grazing Land Management Opportunities for Carbon Sequestration & Greenhouse Gas Reductions

Several cropland and grazing land practices identified by USDA-NRCS (Table 1) provide a co-benefit of GHG emission reductions in addition to improved soil health and conservation of soil and water resources. In Virginia, the county weighted total CO_2e reduction coefficients for cropland practices ranged from 0.17 t per acre per year for planting a non-legume cover crop to 0.53 t per acre per year for converting intensive tillage to no-till or strip till (Figure 3). For most practices, the majority of CO_2e reductions are realized through increased carbon sequestration in the soil with a smaller portion associated with changes in N_2O. In general, adding a legume cover crop tends to result in nearly twice the reduction potential as a non-legume cover crop.

Virginia has approximately two million grazing land acres (USDA-NASS, 2017c). Among the grazing land conservation options available from COMET-Planner, range planting, where degraded grasslands are seeded with improved forages, has a much greater CO_2e reduction potential (0.50 t per acre per year) than prescribed grazing at 0.05 t per acre per year (Figure 3).Although the 2017 AgCensus did not tally the total acres under prescribed or rotational grazing, a state total of 8,182 operations used this practice (total number of reported grazing land operations were approximately 29,000). The number of operations that used silvopasture or alley cropping was 1,526 (USDA-NASS, 2017c). The COMET-Planner CO_2e reduction potential for silvopasture in Virginia is 8.9 t CO_2e per acre per year.

The emission reduction coefficients for ten practices are reported in Figure 3. These values are the average of all Virginia county emission reduction coefficients, which have been adjusted for regional soil types and climate conditions (based on their Major Land Resource Area; see Swan et al., 2022). We have excluded nutrient management practices from this analysis, even though we recognize nutrient management is important in Virginia. The nutrient management practices available in COMET-Planner are limited to replacing synthetic nitrogen sources with organic ones or reducing nitrogen fertilizer by 15%. Replacing a synthetic with an organic fertilizer source without reducing nitrogen rate is not a common practice for reducing nutrient pollution to waterways or nitrous oxide emissions. We felt that including an emission reduction coefficient for this practice

Figure 3. State-weighted emission reduction coefficients (ERC) for soil CO_2, soil N_2O, and total CO_2e (t CO_2e per acre per year) for cropland and grazing land conservation practices.



Note: Net CO_2e (circles and data labels) is the sum of changes in soil C and N_2O emissions (in CO_2e) due to implementing a practice. Negative values indicate increased emissions. Positive values represent a decrease in GHG emissions and/or increased soil carbon sequestration.

is somewhat misleading since the manure increases carbon storage as well as N_2O emissions, according to COMET-Planner. Also, when fertilizer rate is reduced, COMET-Planner often estimates increases in N_2O emissions, despite evidence that reducing nitrogen fertilizer rate is one of the most effective ways of reducing N_2O emissions without affecting yields (Millar et al. 2010, Hoben et al. 2011, Shcherbak et al. 2014).

In order to estimate the full emission reduction potential of these cropland and grazing land conservation practices in Virginia based on the current best available science, we've created a "maximum acres" scenario using CaRPE Tool. This scenario aggregates Virginia county estimates assuming adoption of the selected practices on 80% of Virginia cropland and grazing land, with the exception that mulching is applied to 80% of specialty crop acres and pastureland plantings are applied to 20% of pastureland[6]. The results are summarized in Table 2. We chose 80% rather than 100% adoption knowing that 100% adoption is unrealistic and, according to the diffusion of innovation theory, 80% approximately captures innovators, early adopters, early majority, and late majority, with the remainder being laggards (Rogers 1983). Close to 80% of cropland acres in Maryland and Virginia use no-till,

[6]*We applied mulching to specialty crop acres only because this reflects a more realistic estimate of mulch production for the state. We applied pastureland plantings to only 20% of Virginia pastureland because this practice is intended for degraded rangeland/pastureland only. This could be improved with a better estimate of how many pastureland acres in the state could be considered degraded and eligible for plantings.*

suggesting the rate is achievable. We would like to emphasize that the scenario is a maximum based on acreage, the accuracy of emission reduction coefficients may improve over time, and other estimation frameworks should be considered, e.g., Moore et al. 2022.

In this maximum acres scenario, for example, adopting a conservation crop rotation on 80% of croplands in Virginia could reduce GHG emissions by 0.50 million metric tons (MMT) CO_2e per year (Table 2). Increasing cover crop adoption from the current rate of 22.5% to 80% of cropland acres, assuming these are non-legume covers and N fertilizer is reduced by 25%, could reduce GHG emissions by 0.48 MMT CO_2e mainly via increased soil organic carbon (Table 2). GHG emission reductions could be nearly 0.78 MMT CO_2e when a legume cover is used. Summing the practices together in Table 2, the maximum acres scenario could reduce about 2.8 MMT of CO_2e (Figure 4).

Table 2. Maximum acres scenario soil CO_2, soil N_2O, and total CO_2e reduction potentials (t CO_2e per year) for Virginia where soil health practices are adopted on 80% of available cropland or grazing land, with the exception that mulching is applied to 80% of specialty crop acres and pastureland plantings are applied to 20% of pastureland (with assumptions for current adoption levels noted where appropriate).

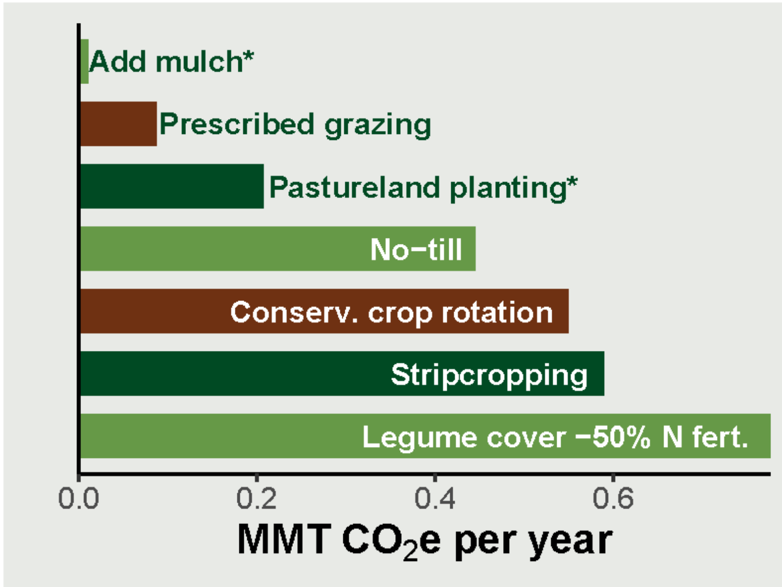
Conservation Practice Implementation	Implement on which Acres	Scenario % of Acres	Scenario Acres	Soil C (t CO_2e per year)	Soil N_2O (t CO_2e per year)	Total (t CO_2e per year)
Mulching (CPS 484)						
Add mulch	specialty crops	80	32,558	10,519	0	10,519
Conservation Crop Rotation (CPS 328)						
Decrease fallow frequency or add perennial crops to rotations	cropland	80	2,467,254	519,422	29,967	549,388
Cover Crop[1] (CPS 340)						
Add legume cover crop with 50% N fertilizer reduction (assumes acres currently in cover crop were planted to a legume cover crop)	cropland	80	1,454,344	1,075,237	-299,084	776,153
Add non-legume cover crop with 25% N fertilizer reduction (assumes acres currently in cover crop were planted to a non-legume cover crop)	cropland	80	1,454,344	453,707	24,836	478,544
Residue & Tillage[2] (CPS 329 and 345)						
Intensive or reduced tillage (CPS 329) to no-tillage (assumes acres currently in no-till started in intensive till, converts current acres in reduced or intensive till to no-till)	cropland	80	1,097,534	490,439	41,458	531,897
Intensive tillage to reduced tillage (CPS 345) (assumes acres currently in no-till started in intensive till, converts current acres in intensive till to reduced till; current reduced till acres remain as is and are accounted for)	cropland	80	101,742	16,000	1,064	17,064
Stripcropping (CPS 585)						
Add perennial cover grown in strips to annual crops	cropland	80	2,467,254	259,711	329,633	589,344
Prescribed Grazing (CPS 528)						
Replace extensive pasture management with intensively managed grazing	rangeland/ pastureland	80	1,649,332	59,588	28,105	87,693
Range Planting (CPS 550)						
Seeding forages to improve rangeland condition	rangeland/ pastureland	20	412,333	207,168	0	207,168
Scenario total						
Sum of practice totals using the first option for practices with multiple options, i.e., sum of outlined cells.			9,580,609			**2,752,163**

Note: Total CO_2e is the sum of soil CO_2 and N_2O. Negative values indicate increased emissions. Positive values represent a decrease in GHG emissions and/or increased soil carbon sequestration.

[1] *Acres for cover cropping = (total cropland acres – acres in hay or haylage production) *0.8 = 1.4 million acres.*

[2] *Acres for tillage estimates = reported tillage acres, i.e., (intensive till + no-till + reduced till) *0.8 = 1.1 million acres.*

Figure 4. Maximum acres scenario reductions. Values correspond to Table 2 and the brief[7] accompanying this report.



**Mulch applied to 80% of specialty crop acres, and pastureland planting applied to 20% of pastureland.*

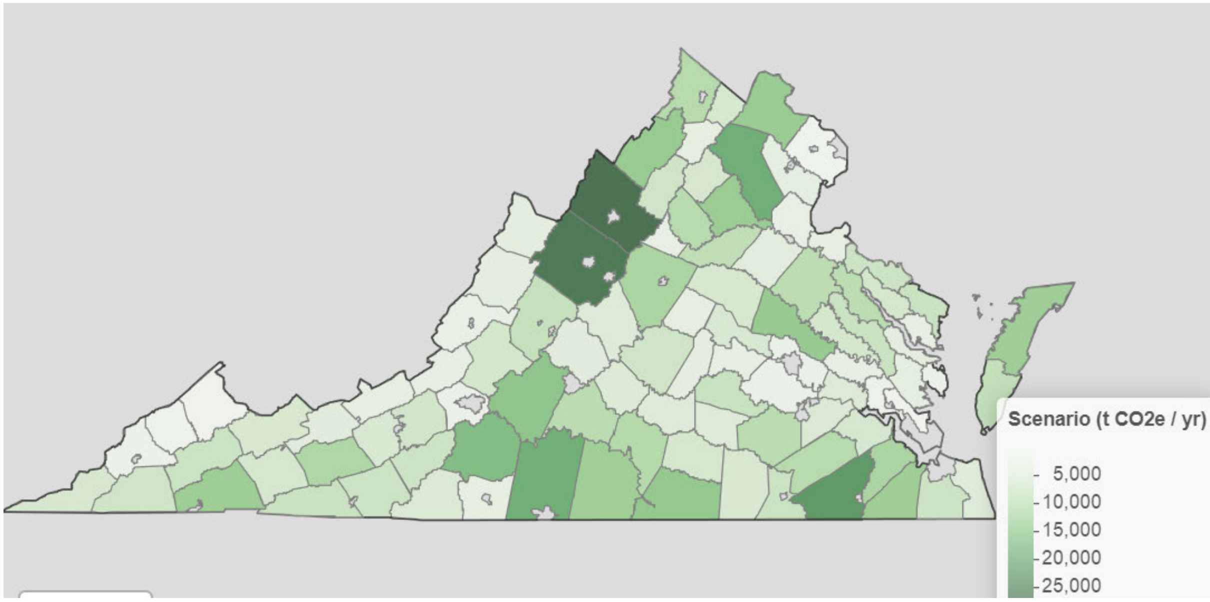
According to the National Greenhouse Gas Inventory, Virginia net agricultural emissions (agriculture emissions plus cropland land use and land use change) were estimated at 6.8 MMT CO_2e and overall state net emissions were 77.1 MMT CO_2e in 2017 (EPA, 2022b). We use 2017 emissions data because that is the AgCensus year the adoption data are from. Thus, the maximum acres scenario totaling nearly 2.8 MMT of CO_2e (Table 2) would offset the estimated state emissions from agriculture by 40%. (This is about 39% of the 2020, i.e., most recent, estimate of Virginia's net emissions, as stated in the brief[7] accompanying this report.) Using the EPA GHG equivalency calculator (EPA, 2022c), reducing 2.8 MMT of CO_2e emissions is equivalent to avoiding over 15,400 railcars' worth of coal burned.

The impact of these practices varies by county, driven in large part by total acreage, with smaller differences due to differing emission reduction coefficients among counties. An example illustrating the variability of impact from a given practice is shown in Figure 5, which illustrates benefits from conservation crop rotation from counties with less than 1,000 to those with 25,000 t CO_2e per year, all with differing acres and very similar emission reduction coefficients.

The above offset estimate comes from a few (not all) cropland and grazing land conservation practices that increase soil carbon. Further, sizeable opportunities for the Virginia ag sector to mitigate climate change come from reducing nitrous oxide emissions (through nutrient management, not included here) and methane emissions.

[7] *The brief is available at https://farmlandinfo.org/publications/carpe-results/*

Figure 5. Greenhouse gas reduction potential (t CO_2e per year) in a scenario where where all Virginia cropland implements conservation crop rotations. Variance between counties is driven largely by differences in the amount of cropland acres per county.



Using CaRPE Tool to Generate State-Specific Scenarios

It is beyond the scope of this report to generate multiple, state and commodity-specific scenarios but as a general guide, a list of considerations and one example are provided as a framework to build from. For more options and to utilize local expertise and goals, the user is referred to the CaRPE Tool website[8], where state-specific scenarios can be run.

The following list outlines considerations to address when developing an ambitious plan to ensure it is grounded in achievable and practical boundaries:

- Identify the maximum potential for those practices of interest (Table 2).
- For cropping system scenarios, understand cropping history at the county level to determine best management practices.
    - Evaluate both the consistency of crop(s) presence and relative abundance.
    - Cropping histories at the county level may provide insight into specific conservation practices that best optimize technical and financial assistance.
    - The USDA NASS CropScape – Cropland Data Layer online tool[9] provides field level cropping history.
- Using CaRPE Tool, restrict cropland acres to the commodity/commodities of choice and select appropriate practices for these systems.
    - For example, it may be desired to restrict acres to major row crops (e.g., cereals, oilseed crops, etc.) and focus on cover cropping, conservation crop rotation, and conservation tillage practices.
    - Other crops can be selected to run practices that are more appropriate for a smaller amount of acreage. For example, adding compost, manure, and mulches might be implemented at a higher percentage in vegetable and other specialty crops.

[8] https://farmland.org/carpetool
[9] https://nassgeodata.gmu.edu/CropScape/

- Run three different adoption rates (low, medium, high) for selected practices.
    - For some practices where current adoption levels are known (cover crops and conservation tillage), scenario adoption levels could be increased above current levels by 50, 100, and 200%. For example, in Virginia about 22.5% of cropland acres have cover crops, well above the national average of 5% (USDA-NASS 2017c), so that could be increased to 34, 45, and 67%.
    - For other practices where current adoption levels are unknown, setting adoption at 15, 25, and 50% of total acres is a good starting point.
- Currently it is not possible to restrict conservation practices to individual counties, but we hope to add this customization in future versions. One could run scenarios for counties individually.

Example Scenarios - Selection Criteria

Two example scenarios are provided below: 1) focused on row crops, and 2) focused on grazing:

- Selection criteria for scenario 1:
    - Acres are selected for the following crops: barley, corn, cotton, millet, oats, rye, sorghum, tobacco, triticale, and wheat (note: not all crops may be present in the state).
    - There were approximately 1.3 million acres of the selected row crops harvested in Virginia in 2017. This constitutes about 43% of the total 3 million cropland acres.
    - In this scenario, on these 1.3 million acres, practice adoption as a percent of acres and resulting CO_2e reduction potentials are summarized in Table 3. A similar scenario was used in a recently published national framework for estimating climate mitigation potential from agriculture in the next ten years (Moore et al. 2022).

Table 3. Scenario example with Virginia row crop-specific acres and percent adoption of five conservation practices and estimated CO_2e reduction potential.

Practice	Scenario acres	% of Selected Acres	CO_2e (t per year)
Cover crop	337,300	25	133,259
Conservation crop rotation	269,840	20	60,086
Mulching	134,920	10	43,589
Stripcropping	67,460	5	16,114
No-till	674,599	50	291,984
Sum	**1,308,722**	**N/A**	**492,910**

Note: Cover assumed 25% of cover crop acres adopted a legume cover and 75% adopted a non-legume cover. For reference, 100% adoption of legume cover on all 5.5 million acres would reduce CO_2e by 2.23 MMT per year. 100% adoption of a non-legume cover would reduce CO_2e by 2.18 MMT per year.

- Selection criteria for scenario 2:
    - All acres were selected for grazing lands.
    - There were approximately 2.0 million acres of grazing land in Virginia in 2017.
    - In this scenario, on these 2.0 million acres, prescribed grazing was implemented on 50% of the acres; and range planting was implemented under a low (15% of acres) and high adoption scenario (30% of acres) (Table 4).

Table 4. Scenario example with Virginia grazing acres and percent adoption of two conservation practices and estimated CO_2e reduction potential.

Practice	Scenario acres	% of Selected Acres	CO_2e (t per year)
Prescribed Grazing	1,030,833	50	79,584
Range Planting (low)	309,250	15	225,613
Range Planting (high)	618,500	30	451,226
Sum (low scenario)	**1,340,082**	**N/A**	**305,197**
Sum (high scenario)	**1,649,332**	**N/A**	**530,810**

In the above scenarios, each practice adoption was assumed to occur on unique acres to avoid the unknown interactions of stacking practices (more than one practice adopted on the same acre). The total acres with implementation in scenarios 1 and 2 (1.3 and 1.6 million acres, respectively) were similar to the acres of the selected crops (1.3 and 2.0 million acres, respectively). If we combine the scenarios, the total CO_2e reduction potential would be approximately 0.8-1.0 MMT per year, which would offset Virginia's 2017 agricultural emissions by about 14%. This is the equivalent of avoiding over 5,500 railcars' worth of coal burned.

Beef cattle grazing in Virginia. Credit Rebecca Drobis for AFT.

As successful adoption is demonstrated in the state, additional reduction levels could be achieved. For example a suite of perennial and edge-of-field conservation practices have relatively high sequestration potential (Table 5). These estimates focus on increasing soil carbon. Further, sizeable opportunities for the Virginia ag sector to mitigate climate change come from reducing nitrous oxide and methane emissions through improved nutrient, manure, and livestock management. Collectively, these practices implemented within the agricultural landscape not only contribute to carbon sequestration and GHG reductions, but also facilitate improved water quality (Basche and DeLonge, 2019), biodiversity, and habitat for wildlife, pollinators (Mallinger et al., 2019), and other beneficial organisms (Kladivko, 2001).

Table 5. Average weighted CO_2e reduction coefficients for Virginia for a suite of perennial and edge-of-field conservation practices.

Class	Conservation Practice	Average CO_2e reduction (t per acre per year)
Cropland to Herbaceous Cover	Contour Buffer Strips (CPS 332)	0.74
	Field Border (CPS 386)	0.74
	Filter Strip (CPS 393)	0.74
	Forage and Biomass Planting (CPS 512)	0.75
	Grassed Waterway (CPS 412)	0.74
	Herbaceous Wind Barriers (CPS 603)	0.74
	Riparian Herbaceous Cover (CPS 390)	0.74
	Vegetative Barriers (CPS 601)	0.74
	Conservation Cover (CPS 327)	0.74
Cropland to Woody Cover	Riparian Forest Buffer (CPS 391)	7.87
	Tree/Shrub Establishment (CPS 612)	22.99
	Windbreak/Shelterbelt Establishment (CPS 380)	12.19
Restoration of Disturbed Lands	Critical Area Planting (CPS 342)	1.90
	Riparian Restoration	2.19

Note: State coefficients are weighted by county size (acres) and the proportion of irrigated and non-irrigated acres within each county. Original county-average coefficients were extracted from COMET-Planner in August 2020.

Current & Future Potential GHG Benefits with Cover Crop & Conservation Tillage

The 2017 AgCensus enabled a deeper investigation into the adoption of cover crops and conservation tillage at the county level. These data provide a unique opportunity to explore the spatial distribution of adoption and estimate the CO_2e reduction potential of these practices. Estimates of the remaining potential and where efforts could be prioritized can be coupled with current estimates to develop a course of action for additional implementation.

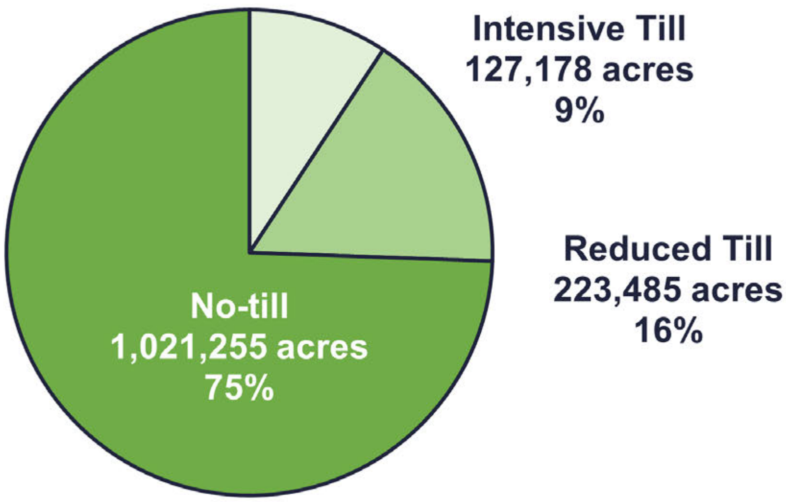
In Virginia, cover cropping was practiced on over 408,000 acres or 22.5% of the estimated 1.8 million acres available cropland for cover cropping. Percent adoption was calculated with hay and haylage acres excluded since it is not practical to apply a cover crop to these perennial acres.

Among the 14 southern states—Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and West Virginia—Virginia ranked first for cover crop adoption. The regional average across those states was 6.9% adoption, while the national average was 4.5%.

In Virginia, no-tillage was practiced on 74.4% of acres, the second highest in the region (Figure 6). Percent no-tillage adoption was greater than the regional average of 41.5% and the national average of 37%.

Reduced tillage in Virginia was adopted on 16.3% of the 1.4 million acres with tillage practices reported, which is less than the regional average (30.4%) and the national average (35%). But with such high percentage of acres in no-till, there are fewer acres available for reduced and conventional tillage.

Figure 6. Acres of intensive tillage, reduced tillage, and no-tillage practices for Virginia based on 2017 AgCensus data. Percents refer to the tillage type acres as a percent of all reported tillage acres.



Assessing the impact of current & future programs

Identifying practical solutions to financial, technical, and social barriers are critical for a successful implementation program (Roesch-McNally et al., 2018). Counties with relatively high adoption levels of cover cropping or conservation tillage can be identified in CaRPE Tool and targeted to determine the key drivers of success and then used as models to help expand adoption within that county or neighboring counties with similar cropping systems. For example, was there an aggressive soil health campaign from local (e.g., Soil Water Conservation District) or federal (e.g., NRCS) sources that provided more technical and/or financial support relative to neighboring counties? Is there an innovative farmer or network of farmers in that county that could have influenced adoption?

Percent cover crop adoption by county ranged from 0 to 59% (Figure 7). It is important, however, to consider the actual number of available acres in addition to percent of adoption to avoid possible overinterpretations. For example, Fairfax County is an anomaly where high percent adoption (46%) is largely driven by the very low cropland acres available for cover cropping (i.e., 395 acres available with 182 acres in cover crop). The five counties with the greatest percent cover crop adoption, excluding counties with low acreage, had a total of 75,909 acres in cover crops and the adoption levels ranged between 44 and 58% of acres (Table 6).

Figure 7. CaRPE Tool maps depicting adoption of cover crops as percent of available cropland acres (top) and acreage of cover crops (bottom).

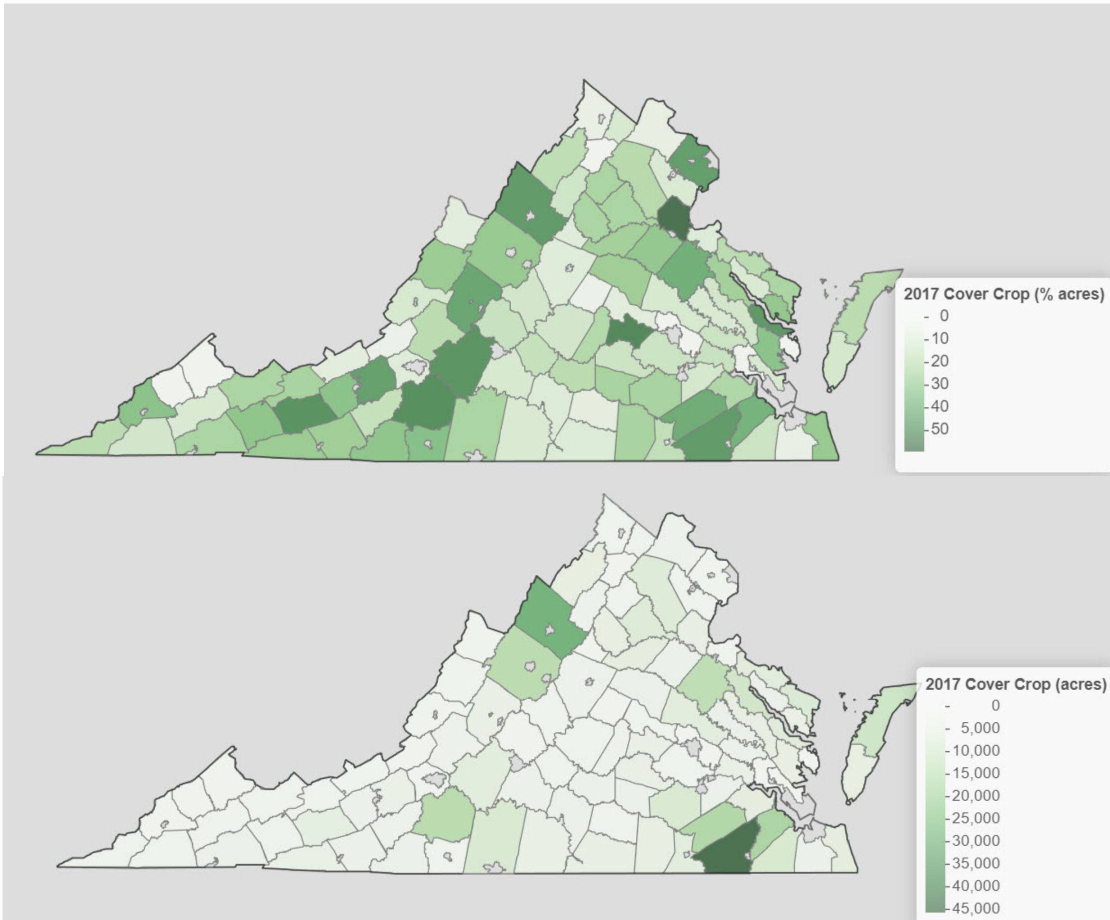


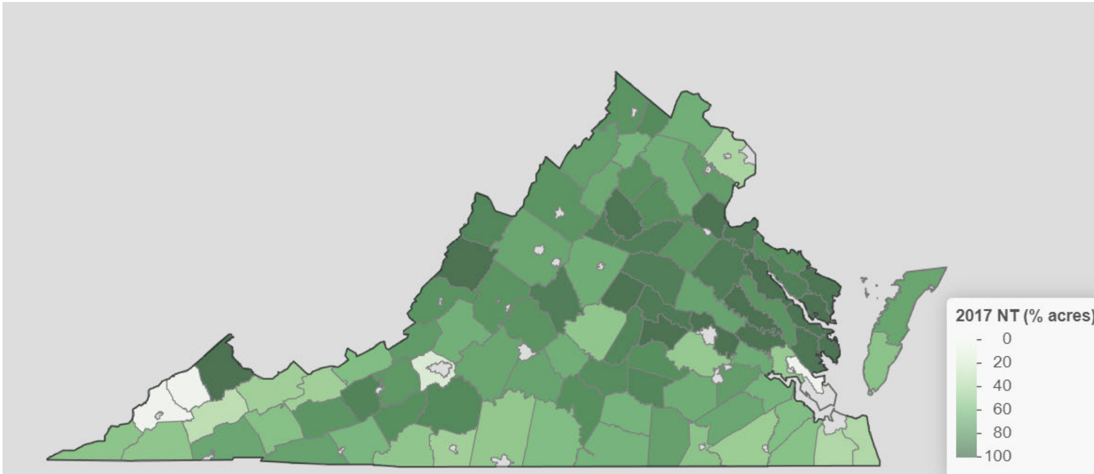
Table 6. Top five counties in Virginia as percent of adoption for cover cropping, no-tillage, and reduced tillage.

County	Total Cropland Acres	Available Acres for Practice	Current Acres in Practice	% Adoption
		Cover Crop		
Stafford	10,076	6,793	3,965	58.4
Powhatan	11,380	6,528	3,349	51.3
Middlesex	14,663	13,653	6,505	47.6
Southampton	97,580	96,706	45,585	47.1
Franklin	72,754	37,474	16,505	44.0
		No-Tillage		
Essex	42286	37613	37613	100.0
Henrico	7319	5288	5288	100.0
King William	26255	20782	20782	100.0
Lancaster	11275	9703	9703	100.0
Powhatan	11380	5012	4992	99.6
		Reduced-Tillage		
Southampton	97,580	91,607	38,567	42.1
Chesterfield	7,171	3,736	1,429	38.2
Chesapeake City	32,325	30,172	10,859	36.0
Isle Of Wight	51,545	47,217	16,153	34.2
Greensville	33,510	28,998	9,567	33.0

Note: The top five counties were identified based on percent adoption while excluding counties in the bottom 25% of counties with available cover crop or tillable acres. Available cover crops acres = total cropland acres minus hay or haylage acres. Tillable acres are the sum of acres in intensive tillage, no-tillage, and reduced tillage practices. All values are based on 2017 AgCensus data.

Adoption of no-tillage (Figure 8) and reduced tillage (Figure 9) varied at the county level. Excluding counties such as Bath and Buchanan due to relatively low acreage, the top five counties for percent no-tillage adoption had a range of 99.6-100% adoption and collectively about 78,000 acres in no-tillage (Table 6). The range was 33-42% for reduced tillage with about 76,000 acres that implemented this practice.

Figure 8. CaRPE Tool maps depicting adoption of no-tillage expressed as percent of tillable acres (top) and acreage of no-tillage (bottom).



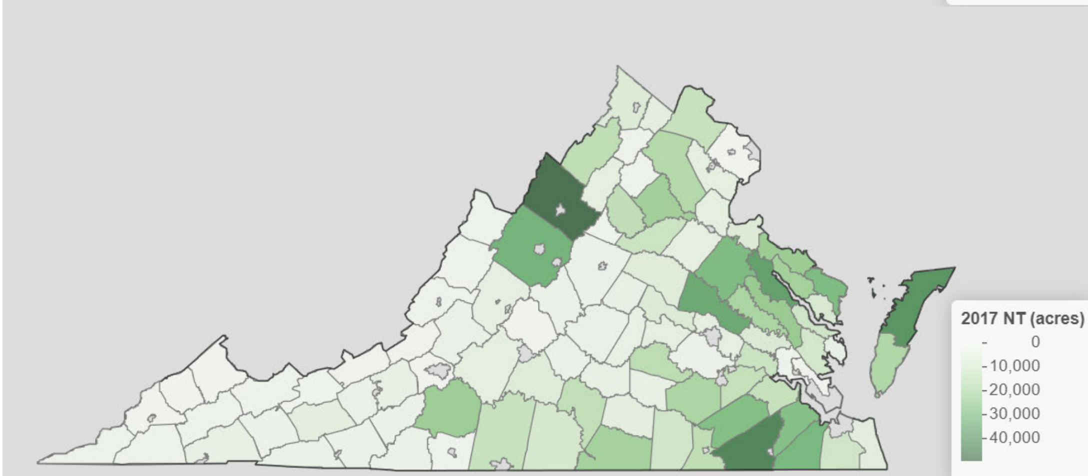
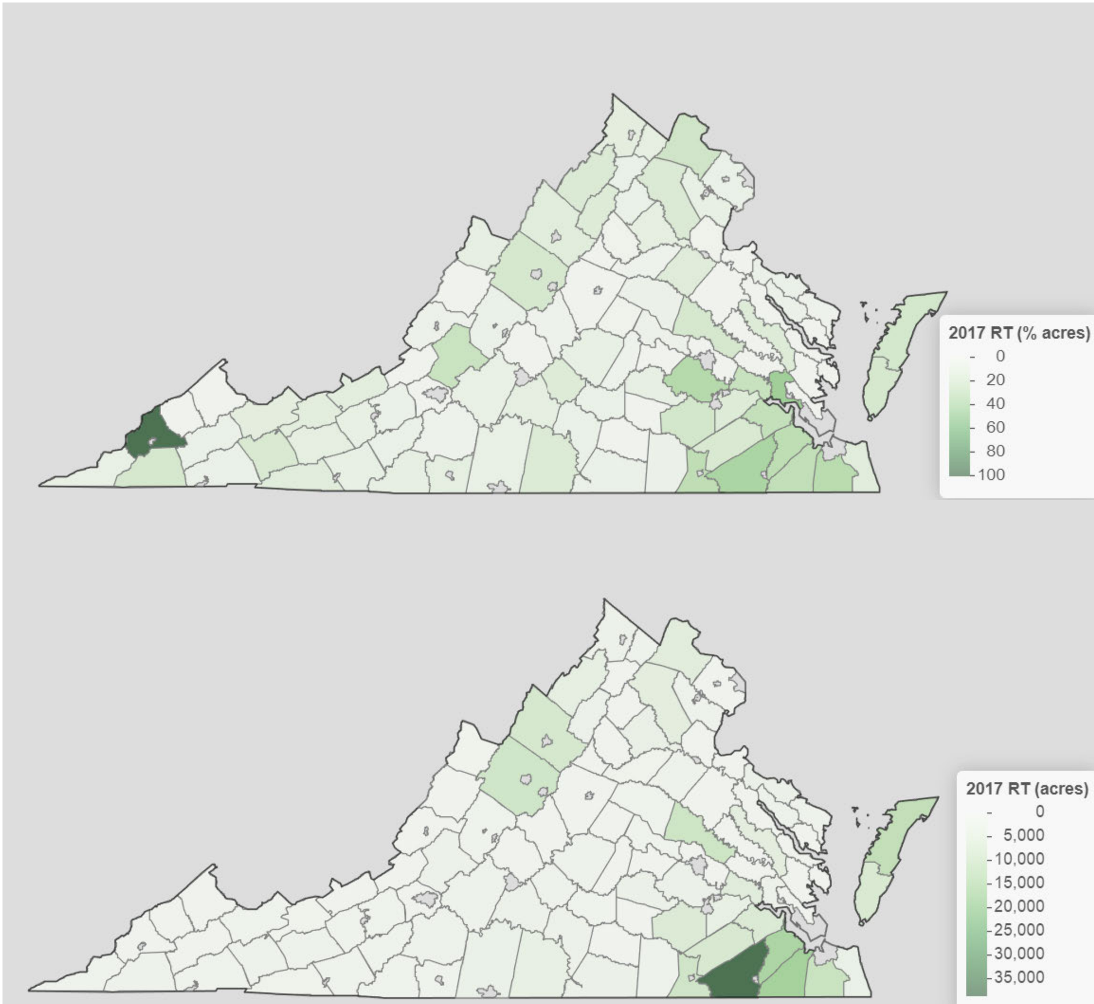
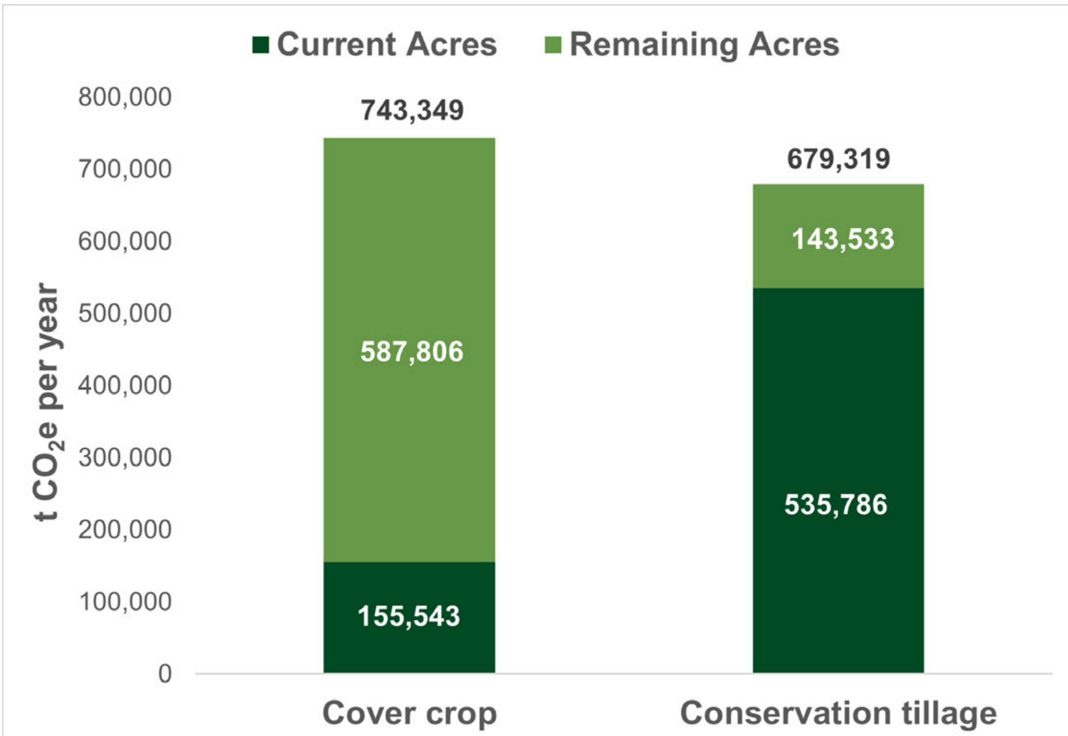


Figure 9. CaRPE Tool maps depicting adoption of reduced tillage expressed as percent of tillable acres (top) and acreage of reduced tillage (bottom).



Relative to fields without cover crops and under intensive tillage, the 408,447 acres currently in cover crops[10] and 1.2 million acres in reduced or no-till[11] are estimated to reduce CO_2e by approximately 0.56 to 0.75 MMT annually. The 2017 adoption of cover crops on the 408,447 acres was estimated to reduce CO_2e between about 0.13 and 0.21 MMT CO_2e per year, depending upon the proportion of legume to non-legume cover crops and original management of land converted to conservation tillage. Assuming 25% of current cover crop acres were planted to a legume cover and 75% to a non-legume cover, approximately 0.15 MMT CO_2e per year were potentially lowered (Figure 10). With up to 1.5 million more acres that could implement cover crops, there is great potential for additional CO_2e reductions across the state (up to 0.58 additional MMT each year). Under this scenario, current cover cropping constitutes about 21% of total theoretical maximum reduction potential of 1 MMT CO_2e per year.

Figure 10. CO_2e reduction from cover crops and tillage for Virginia.



Note: Altering the proportion of legume to non-legume cover crops will change the values for cover cropping. Current CO_2e reduction potential for no-till acres was estimated assuming acres were originally under intensive till management.

Current adoption of no-tillage and reduced tillage on approximately 1.2 million acres combined has potentially reduced CO_2e by over 0.53 MMT per year (Figure 10). Converting all remaining intensively tilled acres (about 127,000) and all acres under reduced tillage (about 223,000) to no-till could reduce an additional 0.14 MMT CO_2e per year. Current no-till and reduced till practices combined constitute approximately about 79% of the total theoretical maximum potential of 0.68 MMT CO_2e per year.

Summing current and remaining cover cropping and no-till, the total 1.4 MMT CO_2e per year reduction potential would offset about 20% of Virginia's emissions from agriculture. The total is equivalent to the amount of carbon that is sequestered by planting over 23 million tree seedlings grown for 10 years or the amount of GHG emissions avoided by not burning over 7,700 railcars' worth of coal, simply by focusing on increased adoption of two practices already in wide use. Incorporating additional practices will contribute to additional offsets towards the maximum acreage scenario discussed above.

[10] *US Department of Agriculture NRCS Conservation Practice Standard #340*
[11] *US Department of Agriculture NRCS Conservation Practice Standard #345*

Grazing sheep. Credit: Getty Images via Canva.

Summary

The analysis presented here showcases that Virginia cropland and grazing land management have significant potential to reduce GHG emissions and sequester carbon. In addition to this assessment, there are multiple options and scenarios that can be explored using the online CaRPE Tool to change and refine the analysis to assist states in achieving climate action plan goals. Developing a comprehensive, flexible plan that encourages the best practice(s) for a given agricultural system can help the state offset the 7.1 MMT CO_2e emissions from Virginia agriculture per year.

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Acronym List

AFT	American Farmland Trust
CaRPE	Carbon Reduction Potential Evaluation Tool
CH_4	Methane
CO_2	Carbon dioxide
CPS	Conservation Practice Standard
EPA	US Environmental Protection Agency
GHG	Greenhouse Gas
MLRA	Major Land Resource Area
N_2O	Nitrous oxide
NRCS	Natural Resources Conservation Service
USDA	US Department of Agriculture

Appendix A: Conservation Practices & Glossary

CaRPE Tool was designed to quantify and visualize county-level GHG emission reductions resulting from the implementation of a suite of cropland and grazing land management practices.

Available practices USDA NRCS Conservation Practice Standards in CaRPE Tool Version 2.0 include:

1. Conservation Cover (327)
2. Conservation Crop Rotation (CPS 328)
3. Residue and Tillage Management (CPS 329 and CPS 345)
4. Contour Buffer Strips (CPS 332)
5. Cover Crops (CPS 340)
6. Combustion System Improvement (CPS 372)
7. Field Border (CPS 386)
8. Riparian Herbaceous Cover (CPS 390)
9. Filter Strip (CPS 393)
10. Grassed Waterway (CPS 412)
11. Mulching (CPS 484)
12. Forage and Biomass Planting (CPS 512)
13. Stripcropping (CPS 585)
14. Nutrient Management (CPS 590)
15. Vegetative Barriers (CPS 601)
16. Herbaceous Wind Barriers (CPS 603)
17. Cover/Tillage/Nutrient Combined Practices
18. Silvopasture (CPS 381)
19. Prescribed Grazing (CPS 528)
20. Range Planting (CPS 550)

The following conservation practices are as defined in companion report to www.comet-planner.com by Swan et al. 2022 and follow the NRCS CPS definitions.

Conservation Crop Rotation (CPS 328)

Decrease fallow frequency or add perennial crops to rotations. A planned sequence of crops grown on the same ground over a period (i.e. the rotation cycle).

Cover Crops (CPS 340)

Cover crops are grasses, legumes, and forbes planted for seasonal vegetative cover. COMET-Planner explores two options where either a legume or non-legume seasonal cover crop is added to irrigated or non-irrigated cropland. When adding a legume cover crop, COMET-Planner assumes a 50% nitrogen fertilizer reduction. When adding a non-legume cover crop, COMET-Planner assumes a 25% nitrogen fertilizer reduction.

Mulching (CPS 484)

Add Mulch to Croplands. Applying plant residues or other suitable materials produced off site, to the land surface.

Nutrient Management (CPS 590)

Managing the amount (rate), source, placement (method of application), and timing of plant nutrients and soil amendments. Two example practices are included below but many exist in COMET-Planner.

- Replace Synthetic N Fertilizer with Dairy Manure on Irrigated/Non-Irrigated Croplands. COMET-Planner specific info: The management scenario assumes that synthetic nitrogen fertilizer amounts are gradually reduced by approximately 4% per year for 5 years, achieving a 20% reduction in nitrogen fertilizer use after the 5th year and remaining constant at that level in the years that follow. Manure is added at a rate that supplies 20% of the total nitrogen applied to the system.

- Replace Synthetic N Fertilizer with Compost (C:N ratio of 25) on Irrigated/Non-Irrigated Croplands. The management scenario assumes that synthetic nitrogen fertilizer amounts are gradually reduced by approximately 4% per year for 5 years, achieving a 20% reduction in nitrogen fertilizer use after the 5th year and remaining constant at that level in the years that follow. Compost is added at a rate that supplies 20% of the total nitrogen applied to the system.

Residue & Tillage Management - No-Tillage (CPS 329) - Intensive Tillage to No-Tillage or Strip Tillage on Irrigated/Non-Irrigated Cropland. Limiting soil disturbance to manage the amount, orientation, and distribution of crop and plant residue on the soil surface year around.

Residue & Tillage Management - No-Tillage (CPS 329) - Reduced Tillage to No-Tillage or Strip Tillage on Irrigated/Non-Irrigated Cropland. Limiting soil disturbance to manage the amount, orientation, and distribution of crop and plant residue on the soil surface year around.

Residue and Tillage Management - Reduced Tillage (CPS 345) - Intensive Tillage to Reduced Tillage on Irrigated/Non-Irrigated Cropland. Managing the amount, orientation and distribution of crop and other plant residue on the soil surface year-round while limiting the soil-disturbing activities used to grow and harvest crops in systems where the field surface is tilled prior to planting.

Stripcropping (CPS 585)

Add Perennial Cover Grown in Strips with Irrigated/Non-Irrigated Annual Crops. Growing planned rotations of row crops, forages, small grains, or fallow in a systematic arrangement of equal width strips across a field.

Prescribed Grazing (CPS 528)

Managing the harvest of vegetation with grazing and/or browsing animals with the intent to achieve specific ecological, economic, and management objectives.

Range Planting (CPS 550)

The seeding and establishment of herbaceous and woody species for the improvement of vegetation composition and productivity of the plant community to meet management goals.

Appendix B: Methods, Visualization, & Equations

Methods

To evaluate the current and projected GHG mitigation potential across the US, the authors developed CaRPE Tool, which couples cropland and grazing land data from the Ag Census (USDA-NASS) with county level GHG emission reduction coefficients reported in COMET-Planner for the US. The COMET-Planner tool provides general estimates of GHG emission changes resulting from the implementation of various conservation practices, many of which are supported by USDA-NRCS Farm Bill programs (Swan et al., 2022) and state programs (e.g., The Illinois Department of Agriculture Cover Crop Premium Discount Program). The full mitigation potential of each practice is the combined effect of GHG emissions and soil C sequestration changes. Assessments using COMET-Planner are designed to be appropriate for multi-county to regional planning purposes based on the combined spatial and temporal metamodeling approach of COMET-Farm. The R Shiny App[12] was used to combine the Ag Census and COMET-Planner emission reduction coefficients. County coefficients were extracted from COMET-Planner Version 2.1 Build 1 in August 2020.

Visualization & Quantification of Current Adoption: Cover Crop & Conservation Tillage

Cover Crops

For the 2017 AgCensus, survey participants were instructed to report acres planted to cover crop with cover crops defined as a crop "planted primarily to manage soil erosion, soil fertility, soil quality, water, weeds, pests, and diseases" on non-CRP acres (NASS, 2017).

Tillage

For tillage, survey participants were instructed to report acres of land under 1) no-tillage; 2) reduced tillage; and 3) intensive tillage practices (NASS, 2017). No-tillage was defined as cropland used for production from year to year without disturbing the soil through tillage other than planting. Ag Census survey participants were instructed to not include as no-tillage land that was not planted in 2017 such as existing orchards, land in berries, nursey stock, or hay harvested from existing grassland or alfalfa that was established prior to 2017. Reduced tillage was defined as conservation practices that leave at least 30% residue cover on the soil. This may involve the use of a chisel plow, field cultivators, or other implements. Intensive tillage inverts or mixes 100% of the soil surface leaving less than 15% of crop residue of small grains. Intensive tillage often involves multiple operations with implements such as a mold board, disk, and/or chisel plow.

Defining Cropland Acreage using the 2017 Census of Agriculture

For this analysis, the cover crop adoption rate was calculated from the total cropland acres minus hay and haylage acres (see Equation 1). Potential GHG benefits from current and greater adoption of cover crops was assumed to only be feasible on the non-hayland portion of the total cropland acres. This approach is slightly different than a recent analysis by LaRose and Myers (2019) where pastured cropland, hayland, haylage, and CRP acres were removed from the total cropland acreage for cover crop adoption rates. Because CRP acres were not definitely categorized in total cropland acres and when the authors attempted to subtract total CRP acres from cropland

[12]*Chang W, Cheng J, Allaire J, Sievert C, Schloerke B, Xie Y, Allen J, McPherson J, Dipert A, Borges B (2023). shiny: Web Application Framework for R. R package version 1.7.4.9002, https://shiny.rstudio.com/.*

and when the authors attempted to subtract total CRP acres from cropland acres, negative numbers were sometimes encountered at the county level, we chose to not subtract these acres for calculating percent cover crop adoption. Thus, our numbers likely slightly underestimate cover crop adoption.

Conservation tillage adoption rates were calculated by dividing each tillage category acres (i.e., intensive, reduced, or no-tillage) by the sum of the acres reporting tillage (intensive tillage acres + reduced tillage acres + no-tillage acres) (see Equation 2).

Defining Cropland Acreage using the 2017 Census of Agriculture
Irrigated and non-irrigated cropland acres were calculated for each county using the total cropland, harvested cropland, harvested irrigated cropland, and total irrigated acreage data from the 2017 AgCensus. Irrigated acreage had to be estimated from county data because the AgCensus replaces reported data with '(D)' for some counties to protect privacy when there are few farms reporting. Since the state totals for this report are calculated by summing the county data, the sum of irrigated cropland acres may not align with reported statewide irrigated land acreage (2017 AgCensus Tables 9 and 10).

Weighted Emission Reduction
For each of the cropland conservation practices in COMET-Planner, the appropriate irrigated or non-irrigated cropland acreage was multiplied by the appropriate COMET-Planner ERC to generate a weighted annual CO_2e reduction estimate (t of CO_2e per year) scaled at the county level.

Adoption calculations

Current percent cover crop adoption was calculated by subtracting hay and haylage acres from total cropland since it is not practical to apply a cover crop to these perennial acres.
Percent cover crop adoption was calculated as:

$$\frac{acres\ of\ cropland\ in\ a\ cover\ crop}{total\ cropland\ acres - (hay + haylage\ acres)} \times 100\% \qquad \textit{Equation 1}$$

Percent no-tillage, reduced tillage, and intensive tillage adoption were calculated using the sum of the reported tillable acres from the Census report. The categories included: 1) acres in no-tillage; 2) acres in reduced tillage; and 3) acres in intensive tillage. Percent no-tillage, reduced tillage, and intensive tillage levels were calculated as:

$$\frac{acres\ of\ no\ tillage, reduced, or\ intensive\ tillage}{sum\ of\ (no\ tillage + reduced\ tillage + intensive\ tillage\ acres)} \times 100\% \qquad \textit{Equation 2}$$

It should be noted that these three categories of reported tilled lands in the AgCensus do not typically sum to the total cropland acres for a given county. It is unclear what the tillage status of the unreported lands may be for the 2017 AgCensus data and thus, these lands were omitted from the calculation. Our approach is similar to that used by LaRose and Myers (2019) to summarize current US no-tillage and conservation tillage adoption.

Adoption calculations

As stated above, COMET-Planner provides emission reduction coefficients (ERC) for NRCS conservation practices on cropland and pastureland practices that either reduce emissions or increase soil carbon sequestration. County-level ERCs are adjusted for regional soil types and climate conditions based on their Major Land Resource Area (Swan et al., 2022). For cover crop practices, COMET-Planner has a different ERC depending on irrigation status and whether a legume or non-legume species was planted. Neither COMET-Planner nor CaRPE Tool accounts for mixed species cover crops. For many other practices, the ERC is different for irrigated and non-irrigated croplands. The appropriate ERC was multiplied by the estimated irrigated or non-irrigated acres to produce total CO_2e reduction values for each county and practice (t CO_2e per year). For tillage management, COMET-Planner provides ERCs for lands that were converted from (i) intensive tillage to no-tillage/strip tillage; (ii) reduced tillage to no-tillage/strip tillage; and (iii) intensive tillage to reduced tillage.

GHG equations for current adoption levels

GHG reduction potential: current cover crop adoption

$$acres\ of\ cropland\ in\ cover\ crop\ \times ERC_{cover} \qquad \textit{Equation 3}$$

The ERC applied in Equation 3 depends on county, irrigation status, and whether the cover is a legume or non-legume.

GHG reduction potential: current no-tillage (NT) & reduced tillage (RT) adoption

$$acres\ of\ cropland\ in\ reduced\ or\ no\ tillage\ \times ERC_{RT\ or\ NT} \qquad \textit{Equation 4}$$

GHG equations for remaining available acres, i.e., acres currently without a given practice

GHG reduction potential: remaining cropland adopting cover crops

$$\big(total\ cropland\ acres - (cover\ crop + hay + haylage\ acres)\big) \times ERC_{cover} \qquad \textit{Equation 5}$$

GHG reduction potential: remaining intensive tillage acres adopting no-tillage

$$(acres\ of\ cropland\ in\ intensive\ tillage\ \times ERC_{NT}) \qquad \textit{Equation 6}$$

GHG reduction potential: remaining intensive tillage acres adopting reduced tillage

$$(acres\ of\ cropland\ in\ intensive\ tillage\ \times ERC_{RT}) \qquad \textit{Equation 7}$$

GHG reduction potential: remaining reduced tillage acres adopting no-tillage

$$(acres\ of\ cropland\ in\ reduced\ tillage\ \times ERC_{NT}) \qquad \textit{Equation 8}$$