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

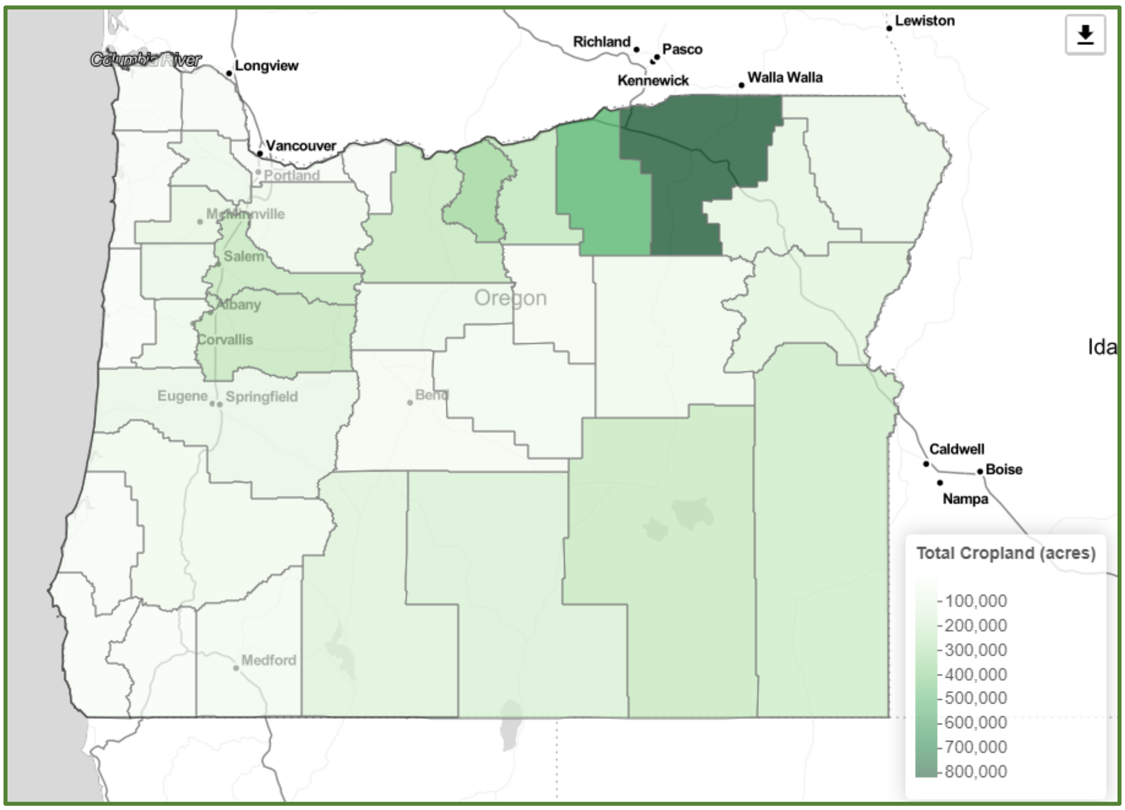


Image: Cropland acres for each county across Oregon created using the Carbon Reduction Potential Evaluation Tool (CaRPE Tool™) with 2017 AgCensus data.

Authors: J. Moore[1], D.K. Manter[2], T. Brown[1], and S.C. McClelland[1].

[1]American Farmland Trust; [2]United States Department of Agriculture - Agricultural Research Service, Fort Collins, CO

Draft report last update: 17 February 2021

Table of Contents

List of Figures

List of Tables

Executive Summary

This state report provides an overview of county-level greenhouse gas (GHG) emission estimates for cropland and grazing land under current and projected conservation management practice scenarios. It is intended to be used to help evaluate potential GHG reductions, assess the impact of existing and new programs, and inform current and future conservation programs to provide greater GHG offset benefits, as appropriate. The analysis presented here showcases that Oregon cropland management has significant potential to reduce GHG emissions and sequester carbon. All values and climate benefits in this report are estimated values 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 management practices. The 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 tillage and cover crop adoption given those adoption rates are specifically provided in the 2017 Ag Census data and are most relevant to Oregon State agriculture. However, the report includes adoption of a total of thirteen conservation practices and estimated carbon dioxide equivalent (CO_2e) reduction potential resulting from state-wide implementation. The CO_2e reduction potential is the net effect of practice implementation on GHG emissions and carbon sequestration.

Highlights:

- As of 2017, Oregon state has approximately 4.7 million (M) acres in cropland and 9.1 M acres in grazing land.
- Relative to fields without cover crops and under intensive tillage, the 100,908 acres currently in cover crops[2] and 1.7 M acres in reduced or no-till[3] are estimated to reduce CO_2e by approximately 251,000 to 305,000 tonnes annually. This range in reduction is equivalent to the amount of C sequestered by 4.1 – 5.0 M tree seedlings grown for 10 years.
- Of the 3.6 M acres that are potentially available for cover crops, if all 997,174 acres in row crop production adopted a cover crop, a reduction between 10,468 (with nonlegume cover crop) to 17,258 tonnes CO_2e (with legume cover crops) could be achieved annually.
- Acres remaining in intensive tillage (698,319) and reduced tillage (740,509), if converted to no-till, could reduce CO_2e an additional 285,312 tonnes per year.
- Recognizing that 100% adoption of any practice is not realistic or practical across all cropland, two ‘near-term’ scenarios (one on row crops and one on specialty crops using up to 7 practices) are provided as examples of how CaRPE data can be used for more regional and crop-specific goal setting. Combined, these scenarios projected a near-term CO_2e reduction potential of more than 295,053 tonnes y^{-1}; a GHG equivalent amount of 63,000+ vehicles for one year.
- Six cropland management practice standards are summarized with net CO_2e reduction potential ranging from 0.04 to 0.27 tonnes per acre per year depending upon practice.

[1] The CaRPE Tool is available online at: https://farmland.org/carpetool

[2] US Department of Agriculture NRCS Conservation Practice Standard #340

[3] US Department of Agriculture NRCS Conservation Practice Standard #345

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 a growing world population. 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 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 (tonnes).

The practices explored with this framework include the cropland and grazing land management options estimated by COMET-Planner (TABLE 1) for Oregon 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., 2019*. 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., 2019*). 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 Oregon:

- Average weighted CO_2e reduction coefficients for the state for a suite of cropland and grazing land conservation practices (tonnes per acre per year). *Note: The authors recognize that the agricultural sector includes other critical land management sectors (e.g., grazing lands, 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.*

---

[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*).

- State total CO_2e reduction potential (tonnes per year) is based on all cropland or grazing land implementing example conservation practices (i.e., 100% adoption with assumptions for current adoption levels noted where appropriate).
- Two scenario examples with specified acres and percent adoption of multiple conservation practices and estimated CO_2e reduction potential resulting from state-wide implementation.
- 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 tonnes 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. The authors encourage states to contact them to develop additional estimates for other agricultural best management practice implementation scenarios.

Table 1. Soil health practices used in this report[1]

Management Focus	NRCS Conservation Practice Standard (CPS) Number and Practice 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
Nitrogen Management	590	Nutrient Management		Reduce synthetic N application rate by 15% over 5 years by adding organic N source (e.g., manure or compost)
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

[1]This table includes NRCS conservation practice standard number and COMET-Planner application note for each. A relative GHG benefit is included for each practice – the darker hues indicate greater GHG reduction benefit potential. Not all practices may be relevant (e.g., range planting in states with minimal rangeland acres).

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 principle 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*). The four soil health principles include:

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 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.

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

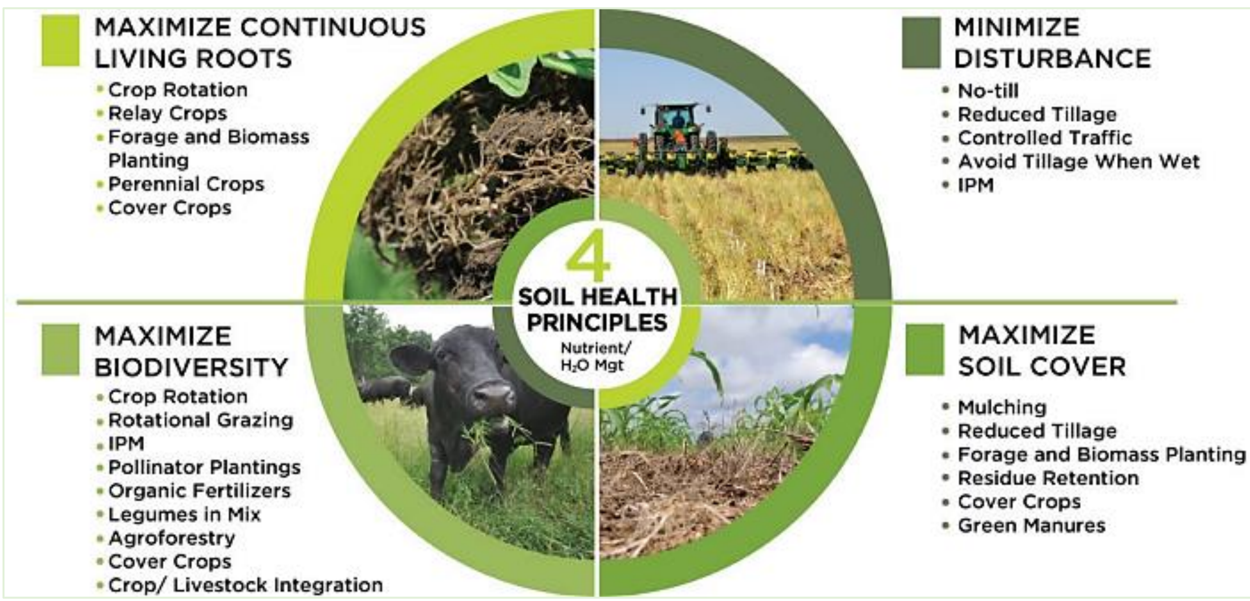


Image courtesy of NRCS (Roesch-McNally et al., 2019)

Although agriculture currently is a net source of GHG emissions, there are numerous cropland and grazing land management 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). 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, each approach promotes at a minimum, the four soil health principles and most 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 conservation 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.

To evaluate the current and projected GHG mitigation potential across the entire USA, 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.

This report focuses exclusively on the cropland and grazing land management practices identified in COMET-Planner (TABLE 1) for Oregon State. 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. 2019*.

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 (tonnes) 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, 2019).*

GHG reduction potential values were adjusted for the estimated irrigated and non-irrigated acres within each county and MLRA. Reported GHG emissions include the net result from soil carbon changes, CO_2 emissions from liming, urea fertilization, and N_2O emissions from soils (including fertilizers). 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., 2019*).

Current State of Agriculture in Oregon

In 2017, the total amount of farmland in Oregon was approximately 15.9 M acres with 4.7 M acres under cropland (FIGURE 2). There were 37,616 farms with an average size of 424 acres and 3,633 farms are greater than 500 acres. The dominant crops, by acreage, were forage, wheat for grain, field/grass seed crops, vegetables, and hazelnuts. Cattle and calves, milk (cow), poultry and eggs, aquaculture, and sheep and goat products were the predominant livestock or livestock products. Total revenue from agricultural products was $5.0 billion with 34% of those revenues from livestock, poultry, and associated products (*USDA-NASS, 2017c*). Approximately 66% of total agricultural revenue was from crops. Gross farm income was $338 per acre and total farm production costs were $292 per acre.

Compared to national farm demographics, 97% of Oregon producers were white compared to 94% nationally[5]. The percentage of female to male producers (44%) was slightly higher than 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. Oregon Agriculture at a Glance. Adapted from USDA-NASS (2017c).

State: Oregon

General Agricultural Overview
- 4,726,109 Total Cropland Acres
- 37,616 Farms
- 424 Average Farm Size by Acres
- 97% are Family Farms
- $5.0 Billion Market Value

Demographics
- 67,595 Total Producers
- 44.2% Female
- 97% White
- 36% are 65 or Older
- 28% are New & Beginning Farmers

Top 5 Ag Counties by Acres
1. Harney (1,557,103)
2. Wasco (1,388,988)
3. Umatilla (1,352,241)
4. Morrow (1,126,101)
5. Malheur (1,093,362)

Top 5 Crops by Acres
1. Forage (hay/haylage)
2. Wheat for grain
3. Field/grass seed crops
4. Vegetables harvested
5. Hazelnuts (Filberts)

Top 5 Crops by Revenue
1. Nursery, greenhouse, floriculture, sod
2. Other crops and hay
3. Fruits, tree nuts, berries
4. Vegetables, melons, potatoes, sweet potatoes
5. Grains, oilseeds, dry beans, dry peas

Top 5 Livestock/Products by Revenue
1. Cattle and calves
2. Milk from cows
3. Poultry and eggs
4. Aquaculture
5. Sheep, goats, wool, mohair, milk

[5] From 2017 Census Volume 1, Chapter 1: U.S. National Level Data. Table 52. Available online at https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US

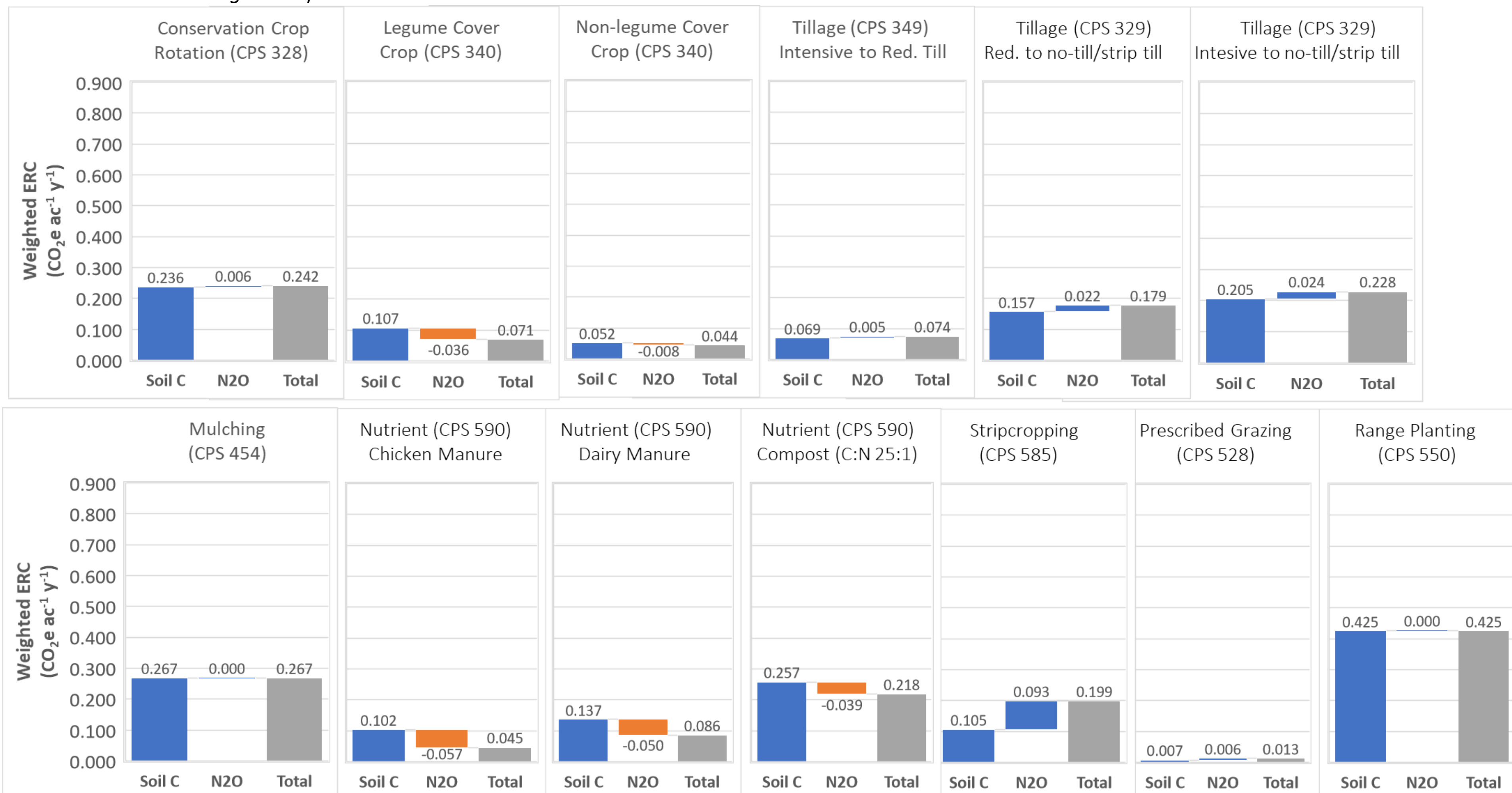
Cropland & Grazing Land Management Opportunities for Carbon Sequestration & Greenhouse Gas Reductions

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. The state weighted total CO_2e reduction coefficients for cropland practices ranged from 0.04 tonnes ac^{-1} y^{-1} for one of the cover crop options to 0.27 tonnes ac^{-1} y^{-1} for mulching (FIGURE 3). For most practices, the majority of CO_2e reductions is 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.

Oregon has approximately 9.1 M grazing land acres (USDA-NASS, 2017a). Among the two grazing land management options available from COMET-Planner, range planting, where grasslands are seeded with improved forages, has a much greater CO_2e reduction potential (0.43 tonnes ac^{-1} y^{-1}) than prescribed grazing at 0.01 tonnes ac^{-1} y^{-1} (FIGURE 3). Although the 2017 AgCensus did not tally the total acres under prescribed or rotational grazing, a state total of 6,355 operations used this practice (total number of reported grazing land operations were approximately 21,271). The number of operations that used silvopasture or alley cropping was 1,467 (USDA-NASS, 2017a). Currently, COMET-Planner does not have emission reduction coefficient estimates for silvopasture practices for the state.

The practices reported in FIGURE 3 that include the average minimum and maximum county coefficients have been adjusted for regional soil types and climate conditions (based on their Major Land Resource Area; see *Swan et al., 2019*). Thus, to estimate the state total for a given practice, it is necessary first to calculate each county and then sum all counties. State aggregated estimates assuming 100% adoption of the selected cropland management and grazing land management practices are summarized in TABLE 2. For example, adopting improved nutrient management by replacing 20% of synthetic nitrogen with compost (25:1 carbon to nitrogen ratio) on all cropland could reduce GHG emissions by more than 1.0 M tonnes CO_2e yr^{-1}. Across all cropland in the state, adopting a conservation crop rotation could reduce GHG emissions by a little over 1.1 M tonnes CO_2e yr^{-1}. The impact of these practices varies by county, driven in large part by total acreage, with smaller differences due to differing ERCs among counties. An example illustrating the variability of impact from a given practice is shown in FIGURE 4, which illustrates benefits from conservation crop rotation from counties as low as 0 to 20,000 to those with over 180,000 tonnes CO_2e yr^{-1}.

Figure 3. State-weighted emission reduction coefficients (ERC) for soil CO_2, soil N_2O, and total CO_2e (tonnes CO_2e ac^{-1} y^{-1}) for cropland and grazing land conservation management practices[1].



[1]Total CO_2e (grey bars) is the sum of soil CO_2 and N_2O. Negative values indicate increased emissions (e.g., orange bars for N_2O). Positive values represent a decrease in GHG emissions and/or increased soil carbon sequestration.

Table 2. Soil CO_2, soil N_2O, and total CO_2e reduction potential (tonnes CO_2e y^{-1}) for Oregon based on all cropland or grazing land implementing example conservation practices (i.e., 100% adoption with assumptions for current adoption levels noted where appropriate)[1].

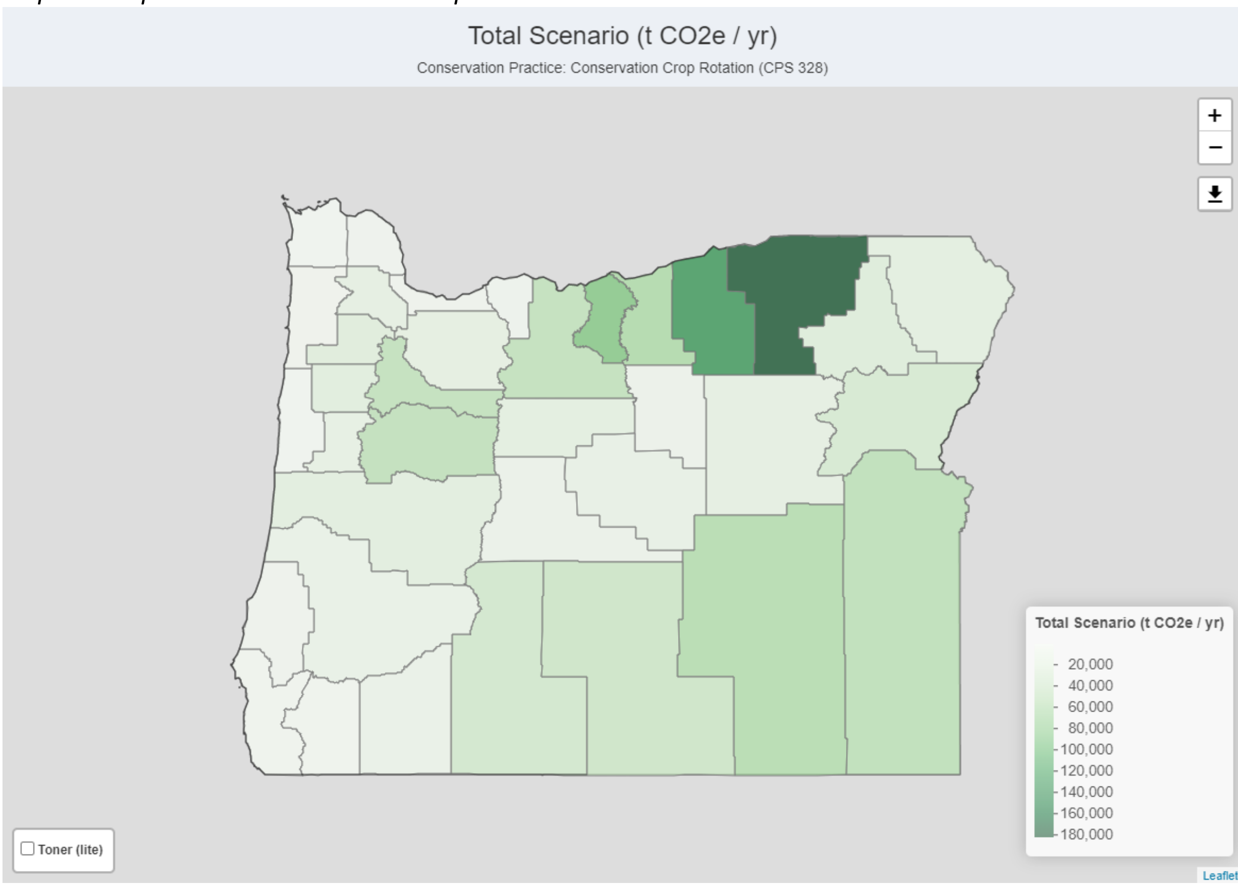
Conservation Practice Implementation	Soil C	Soil N_2O	Total
	(tonnes CO_2e yr^{-1})		
Mulching (CPS 484)			
Add mulch to cropland	1,264,165	0	1,264,165
Conservation Crop Rotation (CPS 328)			
Decrease fallow frequency or add perennial crops to rotations	1,114,558	30,223	1,144,781
Cover Crop (CPS 340)[2]			
Add legume cover crop with 50% N fertilizer reduction (assumes acres currently in cover crop were planted to a legume cover crop)	390,278	-131,503	258,775
Add non-legume cover crop with 25% N fertilizer reduction (assumes acres currently in cover crop were planted to a non-legume cover crop)	189,305	-29,680	159,625
Nutrient Management (CPS 590)			
Replace 20% synthetic N over a 5-yr period with compost (C:N = 25)	1,215,512	-184,538	1,030,975
Replace 20% synthetic N over a 5-yr period with beef feedlot manure	645,518	-237,109	408,409
Replace 20% synthetic N over a 5-yr period with dairy manure	646,262	-237,611	408,651
Replace 20% synthetic N over a 5-yr period with chicken broiler manure	483,767	-268,908	214,859
Residue & Tillage (CPS 329 and 345)[3]			
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)	346,918	40,131	574,294
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 included)	48,441	3,447	334,442
Stripcropping (CPS 585)			
Add perennial cover grown in strips to annual crops	497,485	441,170	938,655
Prescribed Grazing (CPS 528)			
Replace extensive pasture management with intensively managed grazing	63,906	55,964	119,871
Range Planting (CPS 550)			
Seeding forages to improve rangeland condition	3,888,229	0	3,888,229

[1]*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.*

[2]Acres for cover cropping = total cropland acres – acres in hay or haylage production = 2.4M acres.

[3] Acres for tillage estimates = reported tillage acres (intensive till + no-till + reduced till) = 1.9M acres

Figure 4. Greenhouse gas reduction potential (tonnes CO_2e yr^{-1}) for the state under scenario where all cropland implements conservation crop rotation.



The total CO_2e reduction potentials estimated in TABLE 2 represent the maximum opportunity for each individual practice. It is recognized that 100% adoption is not likely, and oftentimes, impractical. Given these limitations, the reported estimates provide: 1) the upper boundary of mitigation potentials, 2) the estimates of costs associated with each practice, and 3) options to land managers to select the best practice for the region and cropping system. By running scenarios that are more appropriate across the landscape, a comprehensive plan can be generated that builds flexibility, opportunity, and boundaries for what can be achieved at scale.

Using the 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 two examples 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[6], 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 (provided in TABLE 2).
- 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 help inform on specific conservation practices that best optimize technical and financial assistance.
- Using the CaRPE tool, restrict cropland acres to commodity/commodities of choice.
    - For example, it may be desired to restrict acres to major row crops (e.g., cereals, oilseed crops, and cotton). Select system-appropriate practices (e.g., cover cropping, conservation crop rotation, and conservation tillage practices) for these systems.
    - 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.
- Select desired practice(s) and run at 3 different adoption rates - low, medium, high.
    - For some practices (e.g., cover crop or conservation tillage) where current adoption levels are known, levels could be increased above current levels by 50, 100, and 200%.
    - For other practices where current adoption levels are unknown, setting adoption at 15, 25, and 50% of total acres is a good starting point.
- For nutrient management, select the manure or compost that best represents availability across the state. For example, states that have large dairy operations, could select replacing 15% of synthetic N with dairy manure. Currently it is not possible to restrict management practices to individual counties, but we hope to add this customization in future versions.

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

- **Selection criteria for scenario 1:**
    - Acres 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 are approximately 997,174 acres of the selected row crops harvested in Oregon in 2017. This constitutes about 21% of total cropland (4.7 M).
    - On these 997,174 acres, cover crops were implemented on 25% of the acres (assumed 25% of these acres adopted a legume cover and 75% adopted a nonlegume cover); conservation crop rotation was implemented on 20% of the acres; mulching adopted on 10% of the acres; there was replacement of 15% synthetic nitrogen with the addition of dairy manure or compost (with a C:N ratio of 20:1) on 10% of the acres; and no-till was adopted on 50% of the acres (assumed half of the acres converted from intensive till and half from reduced till) (TABLE 3).

[6] https://farmland.org/carpetool

- **Selection criteria for scenario 2:**
  - Acres selected for the following crops: almonds, apples, berries, Christmas trees, citrus, grapes, hazelnuts, hops, peaches, pears, pecans, and vegetables (note: not all crops may be present in the state).
  - There are approximately 302,448 acres of the selected crops harvested in Oregon in 2017. This constitutes about 6% of total cropland (4.7 M).
  - On these 302,448 acres, cover crops were implemented on 20% of the acres (assumed 25% of these acres adopted a legume cover and 75% adopted a nonlegume cover); mulching adopted on 50% of the acres; there was replacement of 15% synthetic nitrogen with the addition of dairy manure or compost (with a C:N ratio of 20:1) on 25% of the acres; and reduced till was adopted on 10% of the acres (Table 4).

Table 3. Scenario example with Oregon row crop-specific acres and percent adoption of seven conservation practices and estimated CO_2e reduction potential resulting from state-wide implementation.

Practice	Scenario acres	% of Selected Acres	CO2e (tonnes y^{-1})
Cover crop[1]	249,294	25	12,166
Conservation crop rotation	199,435	20	48,627
Mulching	99,717	10	26,220
Stripcropping	49,859	5	9,738
Dairy manure	99,717	10	9,288
Compost 20:1	49,859	5	8,995
No-till	498,587	50	107,598
Sum	**1,246,468**	**N/A**	**222,633**

[1]For reference, 100% adoption of legume cover on all 997,174 acres would reduce CO_2e by 69,032 tonnes y^{-1}. 100% adoption of a non-legume cover would reduce CO_2e by 41,873 tonnes y^{-1}.

For the proposed scenario, 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). However, total acres with implementation (1.2 M) were greater than the 997,174 acres of the selected crops. The authors felt this was an acceptable overlap given the likelihood that no-till could be coupled with other practices such as cover cropping or nutrient management. Under the given scenario, the total CO_2e reduction potential was approximately 222,633 tonnes y^{-1}.

Using the default state values in the EPA State Inventory Tool (*EPA-SIT, 2020*), total agricultural emissions were estimated at 6.1 M tonnes CO_2e in 2017. Thus, the proposed scenario would translate to reducing approximately 3.7% of the estimated state emissions from agriculture. By adding practices for the 302,448 acres of harvested specialty crops, another 72,420 tonnes CO_2e y^{-1} could be reduced (Table 4). Adding the CO_2e reductions from Table 3 (commodity crops scenario) with Table 4 (specialty crops scenario) results in an overall reduction of 295,053 tonnes CO_2e y^{-1} or about 4.8% of total state emissions from agriculture on approximately 35% of 2017 harvested cropland. Using the EPA GHG equivalency calculator (*EPA, 2020*), this equates to the amount of C sequestered by approximately 4.9 M tree seedlings grown for 10 years or the amount of GHG emission reduction from removing 63,000+ cars from the road for one year. As successful adoption is demonstrated in the state, additional reduction levels could be achieved. This combined with edge of field practices that incorporate woody and perennial vegetation that have relatively high sequestration potential (

Table 5) and improved manure and livestock management, would significantly contribute to additional reductions. 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 4. Scenario example with Oregon specialty crop acres and percent adoption of five conservation practices and estimated CO_2e reduction potential resulting from state-wide implementation.

Practice	Scenario acres	% of Selected Acres	CO_2e (Tonnes ac^{-1} y^{-1})
Cover crop[1]	60,490	20	3,394
Mulching	151,224	50	47,078
Dairy manure	75,612	25	6,806
Compost 20:1	75,612	25	13,151
Intensive till to reduced till	30,245	10	1,991
Sum	**393,182**	**N/A**	**72,420**

[1]Similar to the row crop example above, cover assumed 25% of cover crop acres adopted a legume cover and 75% adopted a nonlegume cover.

Table 5. Average weighted CO_2e reduction coefficients for Oregon for a suite of conservation practices that can be applied to field borders[1].

Class	Conservation Practice	Average CO_2e (tonnes ac^{-1} y^{-1})
Cropland to Herbaceous Cover	Contour Buffer Strips (CPS 332)	0.39
	Field Border (CPS 386)	0.39
	Filter Strip (CPS 393)	0.39
	Forage and Biomass Planting (CPS 512)	0.60
	Grassed Waterway (CPS 412)	0.39
	Herbaceous Wind Barriers (CPS 603)	0.39
	Riparian Herbaceous Cover (CPS 390)	0.39
	Vegetative Barriers (CPS 601)	0.39
	Conservation Cover (CPS 327)	0.39
Cropland to Woody Cover	Hedgerow Planting (CPS 422)	4.89
	Riparian Forest Buffer (CPS 391)	5.56
	Tree/Shrub Establishment (CPS 612)	8.86
	Windbreak/Shelterbelt Establishment (CPS 380)	8.06
Restoration of Disturbed Lands	Critical Area Planting (CPS 342)	1.50
	Riparian Restoration	1.62

[1] 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 the ability to estimate the CO_2e reduction potential based on these practices. Estimates of the remaining potential and where efforts could be prioritized can be coupled with current estimates to develop course of action for additional implementation.

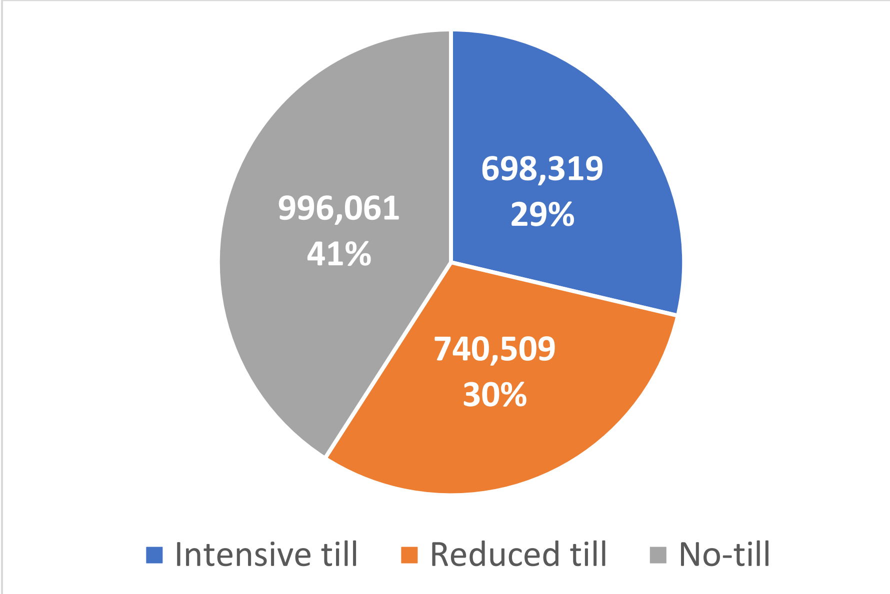
In Oregon, cover cropping was practiced on 100,908 acres (or 2.8% of the estimated 3.6 M acres available cropland for cover cropping). Percent adoption was calculated with hay and haylage acres excluded since it is not practical to apply a cover crop to these perennial acres.

Among the eleven western states, Oregon ranked 8th for cover crop adoption and had a lower percent of cover crop acres than the national average at 4.5%. The regional average was 2.4% and included Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. Nevada had the greatest percent adoption at 5.2%.

In Oregon, no-tillage was practiced on 40.9% and reduced tillage was practiced on 30.4% of the 2.4 M acres with tillage practices reported (ERROR! REFERENCE SOURCE NOT FOUND.). Percent no-tillage adoption was lower than the regional average of 41.4% and higher than the national average of 37%.

Among the western states, Montana had the greatest percent no-till adoption at 73%. Oregon had the third greatest percent reduced tillage adoption, which was greater than the regional but lower than the national averages of 28% and 35%, respectively.

Figure 5. Acres of intensive tillage, reduced tillage, and no-tillage practices for Oregon based on 2017 AgCensus data.



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 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?

Percent cover crop adoption ranged from 0 to 35%, with greater levels in the western portion of the state (FIGURE 6). It is important, however, to consider the actual number of available acres in addition to percent of adoption to avoid possible overinterpretations. For example, Tillamook county is an anomaly where high percent adoption (35%) is largely driven by the very low cropland acres available for cover cropping (i.e., 3,294 acres available with 1,145 acres in cover crop). The five counties with the greatest percent cover crop adoption, excluding counties with low acreage, had a total of 25,271 acres in cover crops and ranged between 7.8 and 15.1% of adoption (TABLE 6).

Figure 6. Adoption of cover crops as (top) percent of cover crops and (bottom) acreage of cover crops.

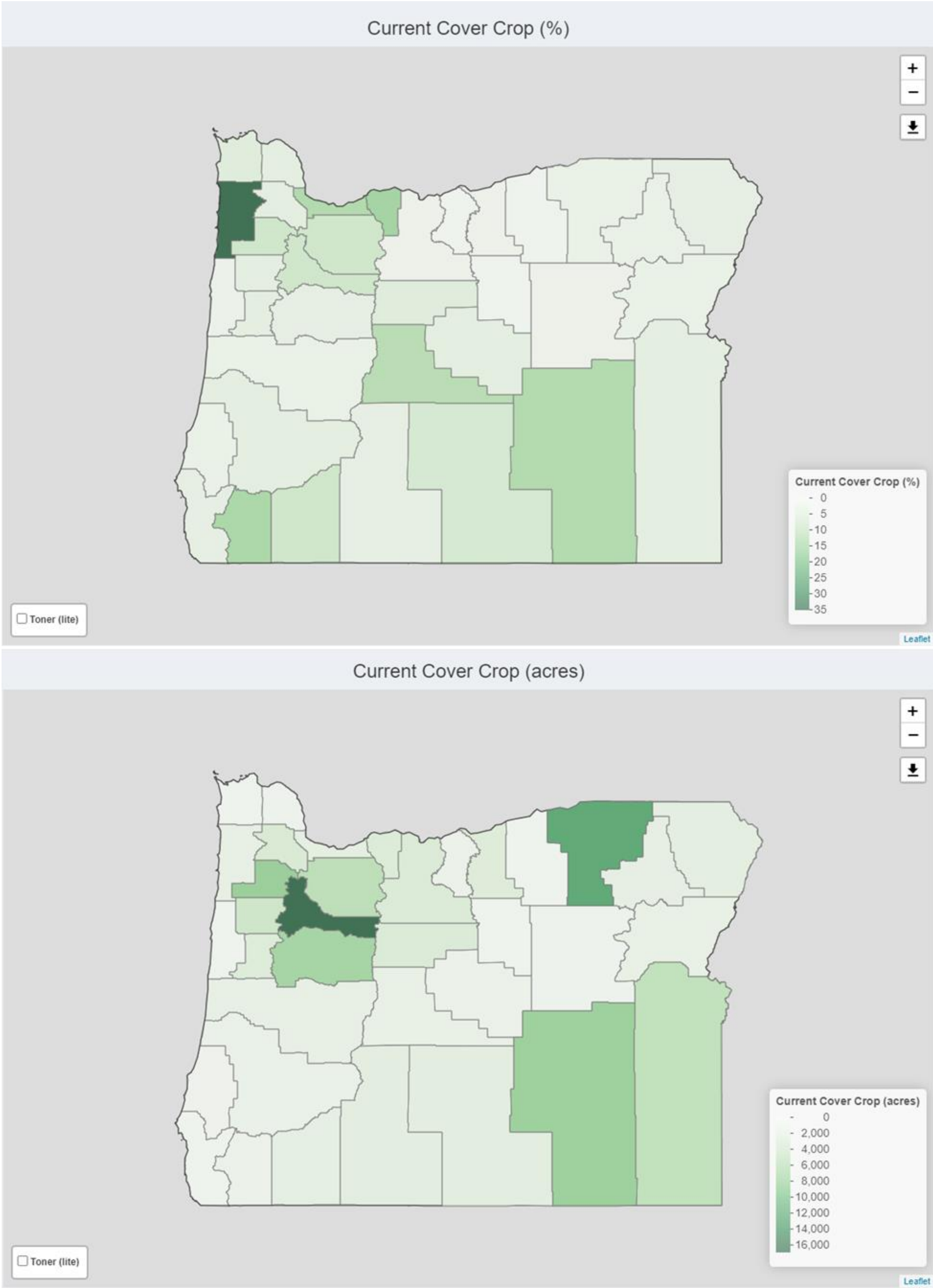


Table 6. Top five counties in Oregon as percent of adoption for cover cropping, no-tillage, and reduced tillage[1].

County	Total Cropland Acres	Available Acres for Practice	Current Acres in Practice	% Adoption
		Cover Crop		
Hood River	19,288	17,875	2,692	15.1
Harney	233,480	60,838	7,647	12.6
Clackamas	83,738	64,498	5,466	8.5
Yamhill	113,373	93,611	7,894	8.4
Jackson	40,667	20,073	1,572	7.8
		No-Tillage		
Wasco	237,719	149,192	125,402	84.1
Sherman	340,948	253,880	188,323	74.2
Columbia	12,646	2,434	1,442	59.2
Morrow	511,874	361,103	191,730	53.1
Gilliam	249,673	155,335	71,652	46.1
		Reduced-Tillage		
Gilliam	249,673	155,335	74,201	47.8
Washington	75,670	43,384	20,517	47.3
Umatilla	815,962	596,978	257,761	43.2
Union	121,085	59,042	23,500	39.8
Deschutes	30,997	5,204	1,923	37.0

[1]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.

Similar to cover crop adoption, adoption of no-tillage (FIGURE 7) and reduced tillage (FIGURE 8) varied considerably at the county level. Counties in the north central portion of the state tended to have the greatest number of acres in no-tillage and reduced tillage. Excluding counties such as Coos and Clatsop due to relatively low acreage, the top five counties for percent no-tillage adoption had a range of 46.1 to 84.1% adoption and collectively about 578,549 acres in no-tillage (TABLE 6). The range was 37 to 47.8% for reduced tillage with about 377,902 acres that implemented this practice.

Figure 7. Adoption of no-tillage expressed as (top) percent of tillable acres and (bottom) acreage of no-tillage.

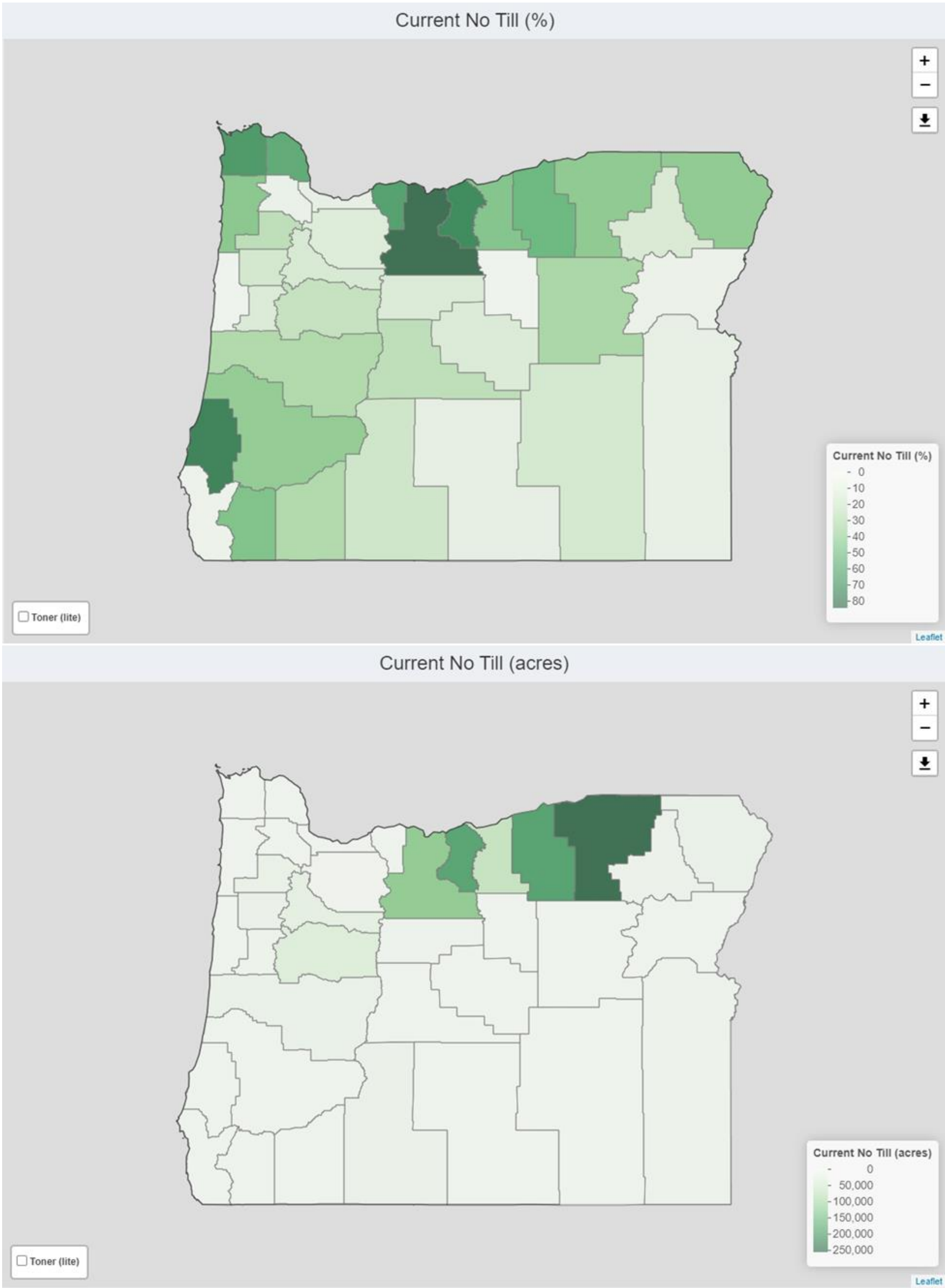
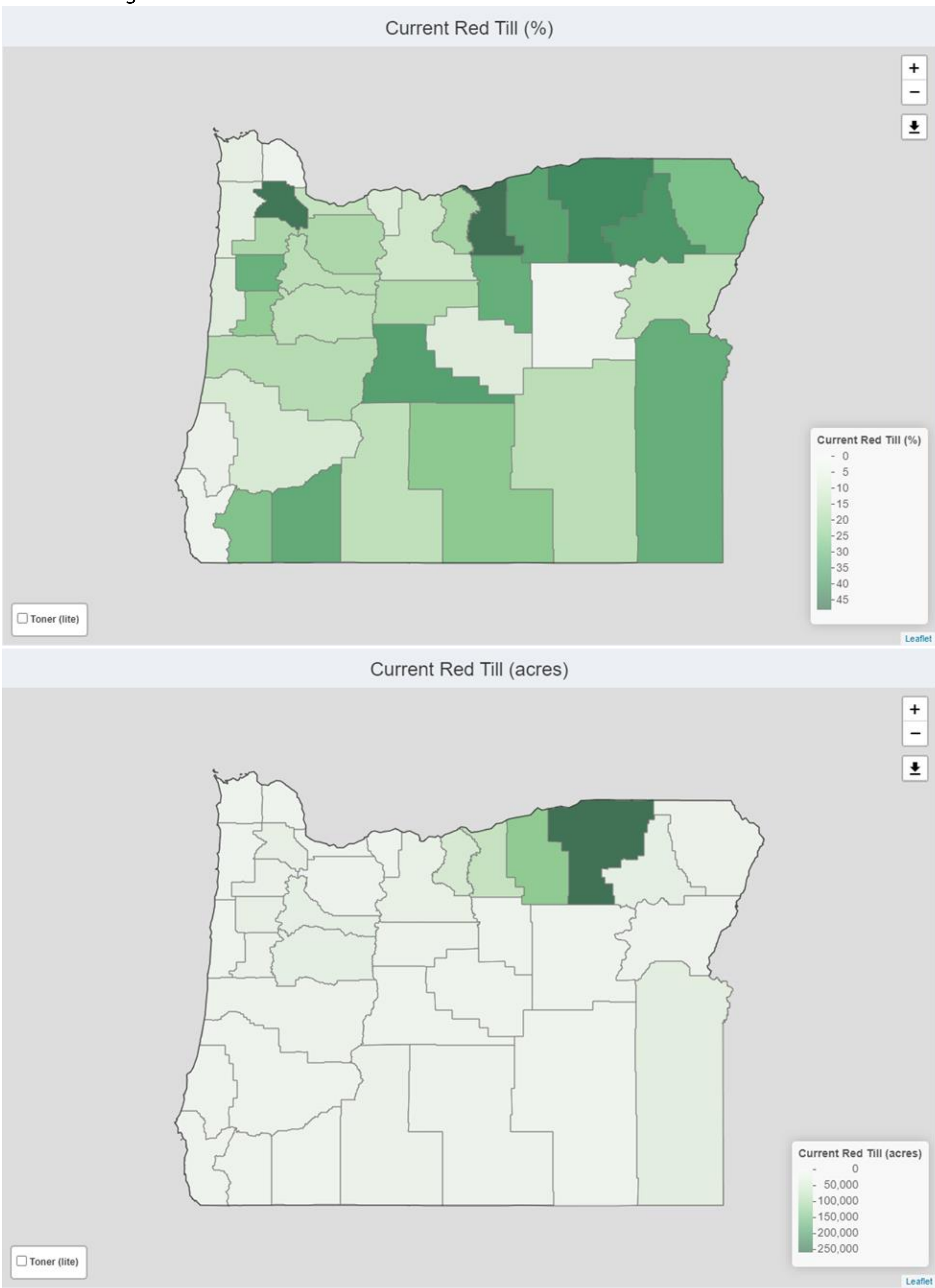
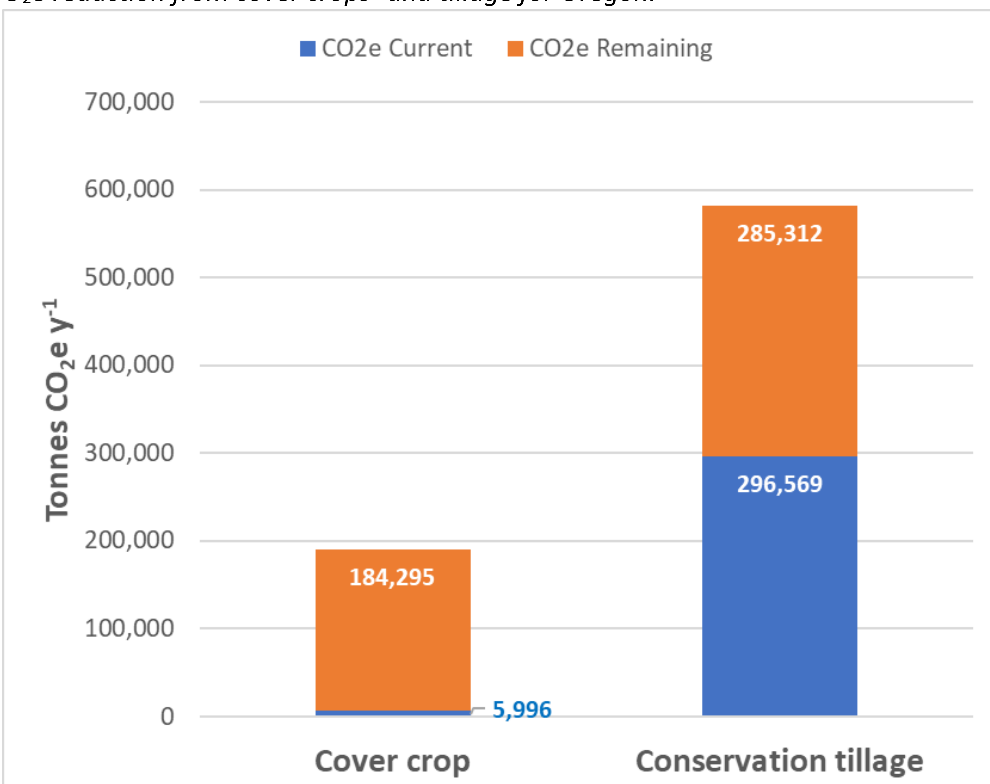


Figure 8. Adoption of reduced tillage expressed as (top) percent of tillable acres and (bottom) acreage of reduced tillage.



Relative to fields without cover crops and under intensive tillage, the 100,908 acres currently in cover crops[7] and 1.7 M acres in reduced or no-till[8] are estimated to reduce CO_2e by approximately 251,000 to 305,000 tonnes annually. The 2017 adoption of cover crops on the 100,908 acres was estimated to reduce CO_2e between 5,252 and 8,227 tonnes CO_2e yr^{-1}, depending upon the proportion of legume: non-legume cover crop. Assuming 25% of current cover crop acres were planted to a legume cover and 75% to a non-legume cover, approximately 5,996 tonnes CO_2e y^{-1} were potentially lowered (**ERROR! REFERENCE SOURCE NOT FOUND.**). With up to 3.6 M more acres that could implement cover crops, there is great potential for additional CO_2e reductions across the state (up to 184,295 additional tonnes each year). Under this scenario, current cover cropping constitutes about 3% of total theoretical maximum reduction potential of 190,291 tonnes CO_2e y^{-1}.

Figure 9. CO_2e reduction from cover crops[1] and tillage for Oregon.



[1] Please note that altering the proportion of legume:non-legume acres will alter these values.

Current adoption of no-tillage and reduced tillage on approximately 1.7 M acres combined has potentially reduced CO_2e by over 296,000 tonnes per year (**ERROR! REFERENCE SOURCE NOT FOUND.**). Converting all remaining intensively till acres (nearly 699,000) and all acres under reduced tillage (nearly 741,000) to no-till could reduce an additional 285,312 tonnes CO_2e yr^{-1}. Current no-till and reduced till practices combined constitute approximately 51% of the total theoretical maximum potential of 581,000 tonnes CO_2e y^{-1}. Summing current and remaining cover cropping and no-till, the total 722,172 tonnes CO_2e yr^{-1} reduction potential is equivalent to the amount of carbon that is sequestered by planting over

[7] US Department of Agriculture NRCS Conservation Practice Standard #340
[8] US Department of Agriculture NRCS Conservation Practice Standard #345

11.9 million tree seedlings grown for 10 years or the equivalent amount of GHG emissions by removing more than 156,000 vehicles from the road for one year.

Summary

The analysis presented here showcases that Oregon cropland management has 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 achieve 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 6.1 M tonnes CO_2e that are roughly estimated using default values in the EPA State Inventory Tool.

References

Ball, B. C., Griffiths, B. S., Topp, C. F., Wheatley, R., Walker, R. L., Rees, R. M., ... & Nevison, I. M. (2014). Seasonal nitrous oxide emissions from field soils under reduced tillage, compost application or organic farming. Agriculture, Ecosystems & Environment, 189, 171-180.

Basche, A. D., & DeLonge, M. S. (2019). Comparing infiltration rates in soils managed with conventional and alternative farming methods: A meta-analysis. PloS one, 14(9), e0215702.

COMET-Planner. 2019. http://comet-planner.com. Emission reduction coefficients for each county were downloaded between July and September 2019.

EPA. 2019. Annexes to the Inventory of US GHG Emissions and Sinks. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2017.

EPA. 2019. Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2017. EPA 430-R-19-001. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2017.

EPA. 2020. Greenhouse gas equivalency calculator. Available online at: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator. Accessed 7/2/2020.

EPA. 2020. State Inventory and Projection Tool. Available online at: https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool.

Fargione et al. 2018. Natural climate solutions for the United States. Science Advances; Vol. 4, no. 11, eaat1869. https://advances.sciencemag.org/content/4/11/eaat1869/tab-article-info.

Follett, R.F. 2001. Soil management concepts and carbon sequestration in cropland soils. Soil Tillage Res. 61: 77-92.

Guenet, B., Gabrielle, B., Chenu, C., Arrouays, D., Balesdent, J., Bernoux, M., ... & Zhou, F. (2021). Can N2O emissions offset the benefits from soil organic carbon storage? Global Change Biology, 27(2), 237-256.

Hartwig, N., and H.U. Ammon. 2002. Cover Crops and Living Mulches. Weed Science 50(6):688-600.

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Kladivko, E. J. (2001). Tillage systems and soil ecology. Soil and Tillage Research, 61(1-2), 61-76.

Lal, R., J.M. Kimble, R.F. Follett, and C.V. Cole. 1998. The potential of US cropland to sequester carbon and mitigate the greenhouse effect. Sleeping Bear press, Inc., Chelsea.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science, 304(5677), 1623-1627.

LaRose, J. and R. Myers. 2019. Progress Report: adoption of soil health systems based on data from the 2017 U.S. Census of Agriculture. Available at: https://soilhealthinstitute.org/wp-content/uploads/2019/07/Soil-Health-Census-Report.pdf. Accessed 7/2/2020.

Lehman, R. M., et al. 2015. Soil biology for resilient, healthy soil. Journal of Soil and Water Conservation 70(1): 12a-18a.

Linton, N. F., Machado, P. V. F., Deen, B., Wagner-Riddle, C., & Dunfield, K. E. (2020). Long-term diverse rotation alters nitrogen cycling bacterial groups and nitrous oxide emissions after nitrogen fertilization. Soil Biology and Biochemistry, 149, 107917.

Mallinger, R. E., Franco, J. G., Prischmann-Voldseth, D. A., & Prasifka, J. R. (2019). Annual cover crops for managed and wild bees: Optimal plant mixtures depend on pollinator enhancement goals. Agriculture, Ecosystems & Environment, 273, 107-116.

Paustian, K., G. Bluhm, J.L. Smith, and E.T. Elliott. 2001. Modeling and regional assessment of soil carbon: a case study of the Conservation Reserve Program. *In* R. Lal and K. McSweeney (eds) Soil Management for Enhancing Carbon Sequestration. Pp. 207-225. SSSA Special Publ., Madison, WI.

Post, W.M., R.C. Izaurralde, L.K. Mann, and N. Bliss. 2001. Monitoring and verifying changes of organic carbon in soil. Climate Change 51:73-99.

Rippey, 2019. Nations wettest 12-month period on record slows down 2019 planting season. Available at: https://www.usda.gov/media/blog/2019/06/14/nations-wettest-12-month-period-record-slows-down-2019-planting-season. Accessed 7/2/2020.

Roesch-McNally, G.E., Basche, A.D., Arbuckle, J.G., Tyndall, J.C., Miguez, F.E., Bowman, T., and R. Clay. 2018. The trouble with cover crops: Farmers' experiences with overcoming barriers to adoption. Renewable Agriculture and Food Systems, 33(4), 322-333. doi:10.1017/S1742170517000096.

Roesch-McNally, G.E., Moore-Kucera, J. Owens, C. 2019. Applying Soil Health Management Systems to Reduce Climate and Weather Risks in the Northwest. USDA-NRCS Factsheet. Available here: https://www.climatehubs.oce.usda.gov/hubs/northwest/topic/soil-health-management-reduce-climate-and-weather-risks-northwest. Accessed 8/3/2019.

Sanderman, J., Hengl, T., & Fiske, G. J. 2017. Soil carbon debt of 12,000 years of human land use. Proceedings of the National Academy of Sciences, 114(36), 9575-9580.

Sperow, M., M. Eve, and K. Paustian. 2003. Potential Soil C Sequestration on US agricultural soils. Climate Change 57:319-339.

Swan, A., Easter, M., Chambers, A., Brown, K., Williams, S.A., Creque, J., Wick, J., and K. Paustian. 2019. COMET-Planner Carbon and Greenhouse Gas Evaluation for NRCS Conservation Practice Planning. A companion report to www.comet-planner.com. Available at: https://planner-prod-dot-comet-201514.appspot.com/static/media/COMET-Planner_Report_Final.3de20776.pdf.

USDA-NASS, 2017a. United States Department of Agriculture, National Agricultural Statistics Service. 2017 Census of Agriculture. https://www.nass.usda.gov/Publications/AgCensus/2017/index.php. Accessed 10.20.2019.

USDA-NASS, 2017b. United States Department of Agriculture, National Agricultural Statistics Service. 2017 Census Report Form Guide. Available at: https://www.nass.usda.gov/AgCensus/Report_Form_and_Instructions/2017_Report_Form/index.php.

USDA-NASS, 2017c. Oregon State Profile. Retrieved from, accessed 12/19/2019.

USDA-NASS, 2017d. United States Department of Agriculture, National Agricultural Statistics Service. 2017 Census of Agriculture. From 2017 Census Volume 1, Chapter 1: U.S. National Level Data. Table 52. Available online at https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US.

USDA-NRCS. 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296.

USDA-NRCS. 2020. National Conservation Practice Standards. Available online at: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/ncps.

USDA-NRCS. 2018. Principles For High Functioning Soils: a Factsheet. Available online at: https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcseprd1388460&ext=pdf.

West, T.O. and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Sci. Soc. Am. J. 66:1930-1946.

WMO. 2019. World Meteorological Organization. "WMO confirms past 4 years were warmest on record World Meteorological Organization." February 6, 2019. Available online at: https://public.wmo.int/en/media/press-release/wmo-confirms-past-4-years-were-warmest-record. Accessed October 27, 2019.

Ziska, L. H. 2003. Evaluation of yield loss in field sorghum from a C 3 and C 4 weed with increasing CO2. Weed Science, 51(6), 914-918.

Zomer, R. J., Bossio, D.A., Sommer, R., Verchot, L.V. 2017. Global Sequestration Potential of Increased Organic Carbon in Cropland Soils. Scientific Reports 7(1): 15554-15554.

Acronym List

AFT	American Farmland Trust
CaRPE	Carbon Reduction Potential Evaluation Tool
CH_4	Methane
CO_2	Carbon dioxide
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CPS	Conservation Practice Standard
EPA	US Environmental Protection Agency
ERC	Emission Reduction Coefficient
FWP	Farmable Wetlands Program
GHG	Greenhouse Gas
MLRA	Major Land Resource Area
N_2O	Nitrous oxide
NRCS	Natural Resources Conservation Service
SIT	EPA State Inventory Tool
USDA	US Department of Agriculture
WRP	Wetlands Reserve Program

Appendix A: Conservation Practices & Glossary

The 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.[9] and follow the NRCS CPS definitions.

Combustion System Improvement (CPS 372) - Improved Farm Equipment Fuel Efficiency. Installing, replacing, or retrofitting agricultural combustion systems and/or related components or devices for air quality and energy efficiency improvement.

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.

[9] Swan, A., Easter, M., Chambers, A., Brown, K., Williams, S.A., Creque, J., Wick, J., and K. Paustian. 2019. COMET-Planner Carbon and Greenhouse Gas Evaluation for NRCS Conservation Practice Planning. A companion report to www.comet-planner.com. Available at: https://planner-prod-dot-comet-201514.appspot.com/static/media/COMET-Planner_Report_Final.3de20776.pdf.

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 and 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 and 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.

Appendix B: Methods, Visualization & Quantification, and Equations

Methods

To evaluate the current and projected GHG mitigation potential across the US, the authors developed the CaRPE Tool that 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., 2019*) and state programs (e.g., Oregon Global Warming Commission); for detailed information on these programs, see the USCA Agriculture Policy Toolkit. 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 was used to combine the Ag Census and COMET-Planner emission reduction coefficients. County coefficients were extracted from COMET-Planner in August 2020, following a recent update by the COMET team.

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

Cover Crops

For the 2017 AgCensus, 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 management 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 grain. 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, cover crop adoption was calculated without hay and haylage acreage in the total cropland acres. 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 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).

Defining Irrigated 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 management 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 (tonnes of $CO_2e\ yr^{-1}$) scaled at the county level.

Equations

Current percent cover crop adoption (Equation 1) was calculated by subtracting hayland 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:

$$\frac{acres\ of\ cropland\ in\ a\ cover\ crop}{(total\ cropland\ acres - hayland\ acres)} \times 100\%$$

Percent no-tillage, reduced tillage, and intensive tillage adoption (Equation 2) 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:

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

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.

Estimating GHG reduction potential on cropland using cover cropping & conservation tillage

For cover crop practices, the COMET-Planner tool has a different ERC depending on irrigation status and whether a legume or non-legume species was planted. The CaRPE Tool does not account 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 (tonnes CO_2e yr^{-1}). 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 (ii) intensive tillage to reduced tillage.

GHG reduction potential: current cover crop adoption (Equation 3)

$$acres\ of\ cropland\ in\ cover\ crop\ \times cover\ crop\ emission\ reduction\ coefficient$$

GHG reduction potential: current no-tillage & reduced tillage adoption (Equation 4)

$$acres\ of\ cropland\ in\ reduced\ or\ no-tillage\ \times emission\ reduction\ coefficient$$

GHG reduction potential: remaining cropland adopting cover crops (Equation 5)

$$(acres\ of\ cropland\ NOT\ in\ cover\ crop - hayland\ acres)\ \times cover\ crop\ emission\ reduction\ coefficient$$

GHG reduction potential: remaining intensive tillage acres adopting no-tillage (Equation 6)

$$(acres\ of\ cropland\ in\ intensive\ tillage\ \times no-tillage\ emission\ reduction\ coefficient)$$

GHG reduction potential: remaining intensive tillage acres adopting reduced tillage (Equation 7)

$$(acres\ of\ cropland\ in\ intensive\ tillage\ \times reduced\ tillage\ emission\ reduction\ coefficient)$$

GHG reduction potential: remaining reduced tillage acres adopting no-tillage (Equation 8)

$$(acres\ of\ cropland\ in\ reduced\ tillage\ \times no-tillage\ emission\ reduction\ coefficient)$$