Analysis of Oregon's cropland soil carbon: existing data sources and proposed accounting methodology *(draft document for discussion purposes)*

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Purpose

There is growing interest in the role agriculture in Oregon can play in mitigating greenhouse gas (ghg) emissions. While the agriculture sector in Oregon is estimated to contribute roughly 5-6 million metric tons (tonnes) of carbon dioxide equivalent (CO2e) annually (OGWC, 2018), this estimate does not include certain cropland management practices that could potentially offset emissions while also providing co-benefits related to soil health for Oregon's farmlands. In particular, current estimates do not account for the potential contribution of soil organic carbon (SOC) and only use gross estimates for the contribution of nitrous oxide (N2O).

In EO 20-04, Governor Brown directed the Oregon Global Warming Commission (OGWC) to submit a proposal regarding the adoption of state goals for carbon sequestration and storage in Oregon's natural and working lands (OGWC, 2020). A critical component of developing goals for agricultural lands is an understanding of the contribution cropland soils can have to mitigating climate change through sequestration of carbon dioxide (CO2) by increasing SOC and reducing N2O emissions through nutrient management. Accordingly, the development of an inventory process that includes estimates of a baseline and periodic conditions that account for soil carbon and N2O emissions is an essential starting point for developing reasonable net ghg emissions goals related to Oregon's agricultural lands and for understanding progress towards those goals.

The goals of this paper are to: 1) provide a brief overview of agricultural soil carbon cycle processes; 2) summarize what approaches and data exist for quantifying carbon stores and fluxes and N2O emissions within cropland soils that could be applied to developing an accounting procedure for the state of Oregon and; 3) provide a proposed methodology for a ghg accounting inventory for cropland soils. Additionally, we identify some challenges in developing a methodology, how to estimate uncertainties of results and provide recommendations for future investments in data and research. Finally, there does exist a growing body of research specific to the impact of agricultural practices on soil carbon sequestration and N2O emissions globally and here in the Pacific Northwest – however, it is outside the scope of this paper to review such efforts (for excellent overviews of the state of knowledge of the impact of agricultural practices on soil carbon and N2O emissions see Yorgey et al (2019) and Brown and Huggins (2012)).

Background

The carbon cycle is one of the most foundational systems on earth. As a gas, carbon mixes with oxygen to become CO2. Plants consume CO2 during photosynthesis, breaking down CO2 into carbon and oxygen—the latter of which animals, including humans, need to breathe. The air, soils, plants and animals all store carbon, and the natural carbon cycle moves this carbon from living systems (i.e., plants and animals) to CO2 in the air and back again.

Soils can act as either a sink or a source for CO2. Soils are in constant flux in the carbon cycle simultaneously releasing and absorbing carbon. When the net amount of carbon released from soil is greater than the amount of carbon absorbed, the soil becomes a source of CO2. On the other hand, if soil retains more carbon than it is releasing, the soil acts as a sink. In other words, carbon is being sequestered in the soil. (Smith et al., 2008)

Different methods of land management have varying impacts on soil's potential to be a carbon sink or source. The majority of soil carbon is derived from plants which, as they grow and die, leave behind organic, carbon-based compounds in the soil. Carbon is added to the soil when plants undergo photosynthesis, which is why agricultural activities can play a significant role in how much carbon is retained in or released from the soil. Intense or frequent tilling for example can cause carbon to be released from the soil into the atmosphere making agriculture in this case a carbon source. On the other hand, practices such as increasing crop residues by changing tillage dynamics and intensity have the potential to increase the net amount of carbon held within the soil, thereby sequestering more carbon than is being released into the atmosphere until the carbon soil flux reaches equilibrium.

There are four primary ways cropland managers can influence the quantity of soil organic carbon:

1.) Increasing crop residues and decreasing the level of soil disturbance through changing tillage practices.
2.) Improving soil microbial diversity and abundance and decreasing synthetic nutrient inputs through adding manure or other organic amendments (nutrient management).
3.) Maintaining continuous living plant cover on soils year-round through the use of cover crops.
4.) Field management dynamics such as intensifying production by eliminating fallow and replacing annual corps with perennial crops or converting cropland back to native grasses or forestland.

Research shows that managing croplands according to these principles can quickly lead to increases in soil carbon that may be highly useful in drawing CO2 out of the atmosphere and potentially reducing N2O emissions. These practices also increase soil health, which can increase the resilience of croplands to climate change by increasing soil water holding capacity, reducing susceptibility to impaction, moderating soil temperatures and increasing microbial activity (SARE, 2021).

A practice employed in one location however, will not always yield the same net ghg emissions outcomes as the same practice employed in another location. The amount of carbon that is stored, and the annual fluxes will vary dramatically from one location to another based on a wide array of geoclimatic variables and the practices that are employed (Ghimire et al., 2015; Luo et al., 2017). As such, which practices to use in different locations and for different crops can be confusing for policymakers and owners of working lands. While some efforts have been made that attempt to quantify at large scales climate benefits of adopting a suite of soil health practices, limited research exists that attempts to capture the variability of C sequestration rates across the landscape as they relate to the different geoclimatic constraints that affect these rates. This quantification is important to understand from an accounting standpoint because these geoclimatic variables can have huge impacts in how standard coefficients can be extrapolated.

The primary variables that affect C sequestration and N2O emissions regardless of crop and practice include[1]:

1. Soil temperature
2. Available water (either precipitation or irrigation)
3. Soil texture and structure;
4. topography and;
5. Percent soil organic matter.

The first four variables influence the rate at which carbon is stored or emitted from soils. The fifth variable constrains the total amount of additional carbon that can be added to soils. Gradients across these variables vary dramatically at different scales. That is, in some cases (e.g. temperature and precipitation) you see only incremental changes at small scales however available water is confounded by irrigation which can change dramatically over short distances. Likewise, soil properties can change dramatically at very small scales, meaning the capacity for soils to sequester carbon under similar crop/management practices can vary dramatically from one location to the next.

These factors are important to consider in the development of an accounting methodology as the level of data aggregation can obfuscate the variability of C sequestration and N2O emissions rates and therefore produce misleading or inaccurate results.

Nitrous oxide (N2O)

In addition to SOC storage and fluxes, changes in N_2O emissions also play a significant role in cropland soil's ability to mitigate climate change. Agriculture accounts for roughly 61% of total anthropogenic N_2O emissions worldwide (Montzka et al., 2011). The large N_2O emissions from agricultural lands are of concern because of its high global warming potential (GWP- N_2O =298) relative to CH4 (21) and CO2 (1) and its contribution to stratospheric ozone depletion (Li et al., 2014; Hou et al., 2016). Soil N_2O emission primarily results from nitrification and denitrification processes in soil. These processes are driven by the amount of nitrogen in the soil and often, a significant amount of excess nitrogen is related to the application of synthetic fertilizers.

There exists potential interaction between N2O and soil carbon as well and some practices that might have beneficial soil carbon outcomes might have adverse N2O outcomes. For example, reducing tillage intensity can result in C sequestration, but mitigation of GHG is limited unless it is coupled with nitrogen fertilizer management to also reduce N_2O emission (Post et al. 2012). As such, including a method for quantifying both baseline and future N_2O emissions and how these interact with the soil health building practices related to increasing SOC should be considered in any inventory approach.

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[1] This list was adapted from Yorgey et al (2019).

Soil carbon baseline and periodic accounting

Getting a snapshot of the total pool and annual fluxes of soil carbon across croplands in Oregon for any given time period can be extremely challenging. One of the primary challenges as compared to other natural and working lands is the complexity of both the environmental factors that affect C sequestration rates in soils and the wide variety of crops and practices that are employed throughout the State and during any given year. As such, standard emissions factors cannot be extrapolated on a one-to-one ratio across different geoclimatic zones. Reconstructing an estimate of past years can prove even more challenging as datasets required to do so are rarely consistent, or even exist over sufficient periods of time.

Regardless, it is important the State attempts the development of an accounting methodology as a starting point that can be improved over time as new data become available. We understand as well, given the limited resources to conduct periodic inventories that such an accounting methodology must be straightforward to execute, draw on widely available datasets and must have the spatial and temporal specificity to be able to capture variations in sequestration rates.

Without being able to monitor soil carbon at potentially tens of thousands of sites across the State, we must rely on existing data and modeling tools. The primary information required to construct an estimate of statewide soil carbon includes many of the factors we discussed above. Most notably, location specific information about the crop and practices employed over time and their location relative to the geoclimatic factors that influence sequestration rates. Utilizing a combination of empirical field data and modeling outputs, it is possible to derive a relationship between crops, practices, environmental variables, and output net soil carbon flux and N2O emissions rates. This relationship can then be extrapolated given the appropriate datasets exist with the required degree of spatial specificity (enough to capture the variability in the environmental variables). Unfortunately, relatively few datasets exist at adequate spatial scales and span time dating back to the desired baseline period.

We propose using a combination of existing datasets supplemented with additional survey data, field samples and modeling to estimate the baseline and periodic soil carbon flux and N2O emissions. In the next section we will briefly cover some of the more relevant datasets and modeling frameworks that can be used in the proposed methodology as well as some soil carbon accounting methods employed in other regions.

Relevant data

In this section we cover an array of publicly available data specific to agricultural activities and land use changes. These data represent some of the more common, readily available and standardized data that could be drawn on to estimate SOC stock and flux and N2O emissions across croplands in Oregon. Table 1 shows the different data that is summarized below along with the scale and thematic categories. A description of each dataset is provided below, paraphrased from the descriptions available on the corresponding webpages. The section is organized according to data relevant to crop management, land use change, and ancillary data.

Table 1 List of relevant, existing data sets for potential use in state soil carbon, carbon flux, and N2O emissions.

Data	**Source**	**Type**	**Spatial scale**	**Temporal scale**	**Time period**	**relevant information**
NASS Census of Agriculture	USDA-NASS	census	County	every 5 years	2012, 2017	harvested crops, tillage, cover crops, manure application
Crop residue management	CTIC	survey	County / crop	annual	1989-2012	Tillage practices by crop
Cover Crop Surveys	SARE / CTIC	survey	national	every 2 years	2012-2019	cover crops and associated costs
Conservation Reserve Program	USDA-NASS	enrolment data	County	annual		Data about cropland conversion to grasslands
Cropland Data Layer (CDL)	USDA-NASS	GIS data	30 meter	annual	2012-2018	Crop groups over time
National Resource Inventory	NRCS	GIS data	30 meter	annual	unknown	Land use
Irrigated lands (points of use)	Oregon Water Resources	GIS data	1:24,000	unknown		Water rights and use
SSURGO Soils	NRCS	GIS data	1:24,000	na	variable	Soils data

Cropland management data (practices)

USDA NASS Census of Agriculture (https://www.nass.usda.gov/AgCensus/)

The United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) conducts an Agricultural Census every five years. The Census provides a detailed picture of U.S. farms and ranches and the people who operate them. It is the only source of uniform, comprehensive agricultural data for every state and county in the United States.

The Census of Agriculture, taken only once every five years, looks at land use and ownership, operator characteristics, production practices, income and expenditures. Since 2012, the Census of has collected information on conservation practices related to tillage, cover cropping and manure application.

Crop Residue Management Survey (https://www.ctic.org/CRM)

The Conservation Technology Information Center's (CTIC) National Crop Residue Management Survey (CRM) is the only survey in the U.S. designed to measure and track the type of tillage used by crop at the county level through personal observation of field conditions at mile or half mile intervals. CRM data is available by county and crop however not all crops are surveyed for every year.

SARE/ASTA/CTIC Cover Crop Surveys (https://www.ctic.org/data/)

The cover crop surveys by the Sustainable Agriculture Research and Education (SARE) program and the Conservation Technology Information Center (CTIC) draw on the insights from roughly 2,000 producers nationwide, most of whom utilize cover SARE cover crop surveys go from 2012 to 2020 . The summary reports are available but source data would need to be requested.

Conservation reserve program (https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/)

CRP is a land conservation program administered by FSA. In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Contracts for land enrolled in CRP are 10-15 years in length. The long-term goal of the program is to re-establish valuable land cover to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat.

Land use change and crop diversity

Cropland Data Layer (CDL) (https://nassgeodata.gmu.edu/CropScape/)

The USDA-NASS Cropland Data Layer (CDL) is an annual raster, geo-referenced, crop-specific land cover data layer. The CDL Program began with one state in 1997 and expanded to cover the entire Continental United States in 2008.

In Oregon, the CDL has a ground resolution of 30 meters and covers years from 2008 to 2018. The data layer is aggregated to a possible 85 standardized categories, with the emphasis being agricultural land cover. Most data layers average about 10 to 20 categories out of the 85 possible categories.

The purpose of the Cropland Data Layer Program is to use satellite imagery on an annual basis to (1) provide supplemental acreage estimates for the state's major commodities and (2) produce digital, crop specific, categorized geo-referenced output products.

This program represents a cooperative venture between three USDA Agencies (headquarters units of NASS, the Foreign Agriculture Service, and the Farm Service Agency) plus in-state agreements among the Agricultural Statistics Service, the Department of Natural Resources and the Department of Agriculture.

National Resources Inventory (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/nri/?cid=nrcs143_014196)

The National Resources Inventory (NRI) provides a detailed record of land use and management activities and information on the status, condition, and trends of land, soil, water, and related resources on the Nation's non-federal lands in support of efforts to protect, restore, and enhance the lands and waters of the United States. The NRI database is a longitudinal dataset containing variables from 1982 through 2017 on a five year basis.

Ancillary data

OWRD water rights data (https://www.oregon.gov/OWRD/access_Data/Pages/Data.aspx)

The Water Rights Information System (WRIS) is a database housing water right information managed by the state. It includes information pertaining to water right applications, permits, certificates, transfers, leases, and related information. This tool contains information in tables, maps, and scanned historical documents. The wwris includes the places of use dataset which is an at-a-glance way to calculate how many places of use or acres are covered by water rights in a given area.

SSURGO soils (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627)

The SSURGO dataset is a compilation of soils information collected over the last century by the Natural Resources Conservation Service (NRCS). Mapunits delineate the extent of different soils. Data for each mapunit contains descriptions of the soil's components, productivity, unique properties, and suitability interpretations.

Soil carbon modeling frameworks

In the absence of time series field data, it is important to rely on modeling frameworks to fill in gaps of our understanding of soil carbon cycling processes and derive estimates for the relationship between practices, environmental variables, and soil carbon flux and N2O emissions rates. Soil carbon models are useful in capturing the dynamic nature of the carbon cycle as it interacts with cropland management and environmental variables.

Both empirical and process-based models are used to predict/estimate soil carbon flux and N2O emissions rates as a function of environmental and management variables (Stöckle et al. 2003). Process-based models have potential for a broader range of applicability across gradients of soil, climate and management conditions, but are more complex and difficult to use than empirically based models (Stöckle et al. 2003). We evaluated three different modeling frameworks including the IPCC empirical model, CropSyst, and DAYCENT. In addition, we describe three modeling tools that facilitate the use of more complex models: COMET-Farm, COMET-Planner CaRPE. Each is briefly described below.

IPCC

The Intergovernmental Panel on Climate Change (IPCC) developed the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories to provide methods by which signatory countries to the United Nations Framework Convention on Climate Change (UNFCC) could estimate 'emissions by sources and removals by sinks' of greenhouse gases. As part of the Land Use, Land Use Change and Forestry section of the guidelines, a method for estimating net C emissions from soils was developed. The method estimates average annual C emissions and/or sinks from land use and management changes, based on computed soil C stock changes over a 20-year inventory period. This empirical model includes coefficients that can be used to predict changes in C stock in soils using expansion factors.

CropSyst

CropSyst (Stöckle et al. 1994; Stöckle et al. 2003) is a multiyear, multicrop, daily time step cropping systems simulation model developed to study the effect of climate, soils, and management strategies on cropping systems productivity and the environment. The model has been evaluated and used extensively in the US Pacific Northwest (Pannkuk et al. 1998; Peralta and Stöckle 2002) and is particularly applicable for dryland crops in the inland Pacific Northwest.

CENTURY
The CENTURY model is a general FORTRAN process-based model of the plant-soil ecosystem that has been used to represent carbon and nutrient dynamics for different types of ecosystems (grasslands, forest, crops, and savannas) (Parton et al. 1987). CENTURY Agroecosystem module was developed to deal with a wide range of cropping system rotations and tillage practices for system analysis of the effects of management and global change on productivity and sustainability of agroecosystems. It integrates the effects of climate and soil driving variables and agricultural management to simulate carbon, nitrogen, and water dynamics in the soil-plant system.

All three models, and the latter two in particular, are highly complex and require a significant degree of knowledge of soil processes and technical acumen to execute effectively. However, tools exist that facilitate the use of some of these models. Below we briefly describe three tools that could have applicability to developing a ghg inventory for cropland soils.

COMET-Farm (https://comet-farm.com/)
COMET-Farm is a whole farm and ranch carbon and ghg accounting system that allows users to test the ghg outputs related to specific management activities on farm and ranch lands. The tool developed by NRCS and Colorado State University utilizes the DAYCENT model (a daily implementation of the CENTURY model described above) to estimate soil carbon and N2O emissions from a variety of pools over a 10 year period.

COMET-Farm api
The COMET-Farm api is an application programming interface (api) that provides back-end access to the COMET-Farm cropland sub-module. It facilitates the analysis of multiple locations and scenarios at a single time by providing a programable option for passing input files and returns results via email, rather than requiring users to develop scenarios for single locations at a time through the COMET-Farm interface.

COMET-Planner (http://comet-planner.com/)
COMET-Planner is an evaluation tool designed to provide generalized estimates of the greenhouse gas impacts of specific NRCS conservation practices and is intended for initial planning purposes. It differs from COMET-Farm in that it is not a site-specific planning tool but rather is based on an empirical model (and resulting coeficients) developed through multiple model simulations aggregated at the county scale.

CaRPE (https://farmland.org/project/the-carpe-tool/)
The Carbon Reduction Potential Evaluation Tool, is a web-based interactive tool developed by the American Farmland Trust to allow users to quickly visualize and quantify ghg emission reductions resulting from the implementation of a suite of cropland and grazing land conservation management practices. The CaRPE tool expands the utility of the data reported by COMET-Planner (described above) by layering cropland and grazing land acres data from the 2017 Census of Agriculture. Like COMET-

Planner, the CaRPE tool considers changes in soil carbon and N2O based on practices independent of location and cropping systems. Only the COMET-Farm tool and COMET-Farm api consider ghg emission impacts as a function of practice, cropping system and geoclimatic variables.

Existing approaches to soil carbon accounting

There are relatively few approaches that attempt to inventory soil carbon and N2O emissions in the U.S. This is due to the spatially explicit complexity of soil carbon processes outlined above and the relative lack of data at spatially disaggregated scales. This leaves researchers with no other choice than to make broad assumptions about the relationship between practices, geoclimatic variables and crops or draw on course coefficients developed at broad scales. We found only three approaches within the United States the are applicable to developing a soil carbon inventory for Oregon. These include a proposed framework by Sperrow et al. (2003), an analysis of the potential of conservation practices to reduce ghg emissions for Oregon's croplands and grazing lands (Moore et al 2021) and the USGS LandCarbon project (Schmidt et al. 2012). Each is briefly described below.

Using NRI data coupled with IPCC coeffients

Sperrow et al (2003) developed a framework that utilizes the Intergovernmental Panel on Climate Change (IPCC) soil organic C inventory method, together with the National Resources Inventory (NRI) and other data, to estimate agricultural soil C sequestration potential in the conterminous U.S. The IPCC method estimates soil C stock changes associated with changes in land use and/or land management practices. In the U.S., the NRI provides a detailed record of land use and management activities on agricultural land that can be used to implement the IPCC method.

Baseline and potential soil C stock changes were calculated using the IPCC inventory factors in conjunction with land use, management and soil information derived from the 1997 NRI data and a number of ancillary data sets.

Using the CaRPE tool to estimate the potential of conservation practices to reduce ghg emissions for Oregon's croplands and grazing lands.

Moore et al. (2021) utilized the CaRPE tool to estimate county-level ghg emissions for cropland and grazing land under current and projected conservation management practice scenarios in Oregon. The analysis focused 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. Results include estimated CO_2e reduction potential resulting from state-wide implementation, however, the CaRPE tool could potentially be used in a similar way to estimate periodic changes in management and resulting changes in SOC and N2O emissions.

LandCarbon

The LandCarbon project created spatially explicit maps of annual land cover and land-use change at the 250-meter pixel resolution for the great plains region of the U.S.. Management data were obtained from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) and USDA Economic Research Service (ERS) that provides information regarding crop type, crop harvesting, manure, fertilizer, tillage, and cover crop (U.S. Department of Agriculture, 2011a, b, c). These data were allocated to each 250 meter pixel. The derived gridded crop type, crop harvesting, manure, fertilizer, tillage, and cover crop products were then used as inputs to the LandCarbon models to represent the historic and the future scenario management data.

Proposed methods for soil carbon and N2O emissions accounting inventory

Following a combination of approaches outlined above, we recommend utilizing publicly available datasets to derive baseline and periodic estimates for soil carbon flux and changes in net N2O emissions. The recommended approach for each practice varies slightly drawing on different data and modeling techniques. Generally speaking, for each crop and different management practice the process is as follows:

- Utilize existing models to estimate the range of per acre carbon flux and N2O emissions on a county-by-county basis for each crop for different soil health practices.
- Estimate the total acres of each crop under different practices by county.
- Estimate the proportion of cropland under different environmental, soil and irrigation characteristics.
- Extrapolate the per acre carbon flux and N2O soil emissions by multiplying it with the total acres of each crop / practice in each county apportioned according to the environmental and soil characteristics.

Tillage, cover crops and manure applications

We recommend using a process similar to Schmidt et al, (2011) to allocate practices to crops within a given region (in this case for each county). In its publicly available form, crop data referenced above is aggregated at the county / crop level within most datasets. Practice data (tillage, manure application and cover crops) is also aggregated to the county scale within the 2012 and 2017 censes of Agriculture and is only associated with crops within the CRM data. For tillage, crop cover and manure applications, special requests can be made to USDA-NASS to obtain more spatially disaggregated information from the raw Census of Agriculture to associate crops with practices however, given privacy constraints, information at disaggregated scales may be limited in its utility because records may be omitted from the data. Alternatively, trend data from the CRM dataset can be extrapolated to estimate the relationship of crops and tillage practices to supplement the Census of Agriculture data but no ancillary dataset exists that would allow this same method to be applied for manure application and cover crops (the SARE cover crop surveys only date back to 2011 and are not disaggregated to the crop scale).

Without data to support relating crops to practices one is left with apportioning the acres of practices recorded in the Census of Agriculture to crops based on the proportion of total harvested cropland each crop represents in any given county. Once crop and associated practice are identified, coefficients that determine carbon stock changes as a function of climate, soil properties, disturbance history, tillage intensity, productivity, and residue management can be applied and extrapolated across each county based on the proportion of each crop under different environmental, soil and irrigation characteristics. These coefficients can be derived from existing literature (e.g. IPCC, 1997) or by using modeling approaches such as those described above or, in rare cases, by using field data where available.

Field management dynamics and land use change

For estimating effects of changing land use characteristics, we recommend utilizing a combination of the USDA-NASS Cropland Data Layer (CDL) and the National Resources Inventory (NRI) to estimate changes in SOC stock and flux and N2O emissions related to changes in the crop intensity, perennial crops and land use changes (i.e. cropland to native grasses or vice versa). This exercise is primarily geographic in nature and therefore relies on these spatial datasets. The CDL data can be used to assess over time the dynamics of crops and whether fallow is used in rotation by doing a time series analysis. This follows an approach conducted by Mueller-Warrant et al (2016) in which the authors modeled crop sequence history over an 11-year period in the Willamette Valley. The CDL data extends from 1997 to 2020 and therefore represents a reasonable time period to extrapolate trends in the use of fallowing in specific locations. For changes in crop intensity, standard coefficients may not be available, therefore we recommend the use of a modeling framework to then estimate the impact of changing crop production intensity by changing the use of fallow in rotations.

Likewise, the CDL dataset, used in conjunction with model estimates, can be used to evaluate changes between annual and perennial systems. Data should be cross-referenced with the NASS Census of Agriculture and supplemented with NRI data. We recommend the use of the CDL data compared to the NASS Census of Agriculture because of its geographic specificity (30 meter cell size) and because of its update frequency as compared to the Census of Agriculture that only represents a snapshot of cropping activity at the County scale once every 5 years and therefore is not resolved enough to capture the trends in semi-annual uses of fallowing.

Example of Morrow County

For demonstrative purposes, we modeled three different crop types in Morrow County to estimate the carbon sequestration and N2O emission rates for the year 2017. We used the process described above, where coefficients were derived from a sample of model runs using the COMET-Farm api. In this example, we only model the effects of management and have not considered crop intensity or land use change.

Morrow County is an arid county in the Columbia plateau dominated by grain production. According to the NASS 2017 Census Of Agriculture, there were just over 510,000 acres of cropland and just over 275,000 acres of harvested cropland. Of these, a little more than 1/3 (106,511) were irrigated. Winter wheat was the most common crop with 155,414 acres, followed by corn: 23,135, potatoes: 16,362, vegetables: 15,405 and spring wheat: 9,972. There were 124,732 acres left fallow (presumably as part of a wheat or barley rotation) and another 100,634 acres that were idle. In addition, there were just over 38,000 acres of hay or haylage, potentially also part of a wheat or barley rotation.

Conservation practices

According to the Census data, there was a significant increase in soil health related practices between 2012 and 2017 with the exception of cover crops. The data recorded in the Census related to these practices include: application of manure, use of cover crops, reduced tillage and no tillage. Table 2 shows the change in each practice between the Census years.

Table 2: Acres under different management practices in Morrow County in 2012 and 2017.

Practice	2012 (acres)	2017 (acres)	percent change
manure application	2,150	4,379	103.6744186
cover crops	9,796	0	-100
no till	150,723	191,730	27.20686292
reduced till	60,982	130,971	114.7699321
conventional till	71,595	38,402	-46.36217613

Both manure application and reduced tillage practices more than doubled between the two periods and no-till applications also saw an increase of 27% (harvested acres between 2012 and 2017 increased by just under 10%%). There were no cover crop acres reported in 2017 although there was a significant increase in the amount of haylage reported (9,607 acres). Often, farmers use haylage as a cover crop but do not necessarily report it accordingly. Cover crop data may also have been obfuscated due to privacy constraints. Regardless, given this data limitation, we were unable to estimate benefits related to changes in cover cropping.

Scenario development

Using the COMET-Farm api, we developed a set of scenarios for the three most commonly occurring crop / crop rotations: winter wheat, corn and potatoes. These scenarios included the use of the conservation practices defined above applied to each crop. A sample of 6 to 7 location specific “fields” were modeled across the County to capture the variability of environmental factors. Fields and associated crops were identified using the CDL dataset in combination with ancillary data. Historic practices assumed conventional approaches to these crops including conventional tilling, fertilizer, the use of fallow in wheat rotations and irrigation for corn and potatoes.

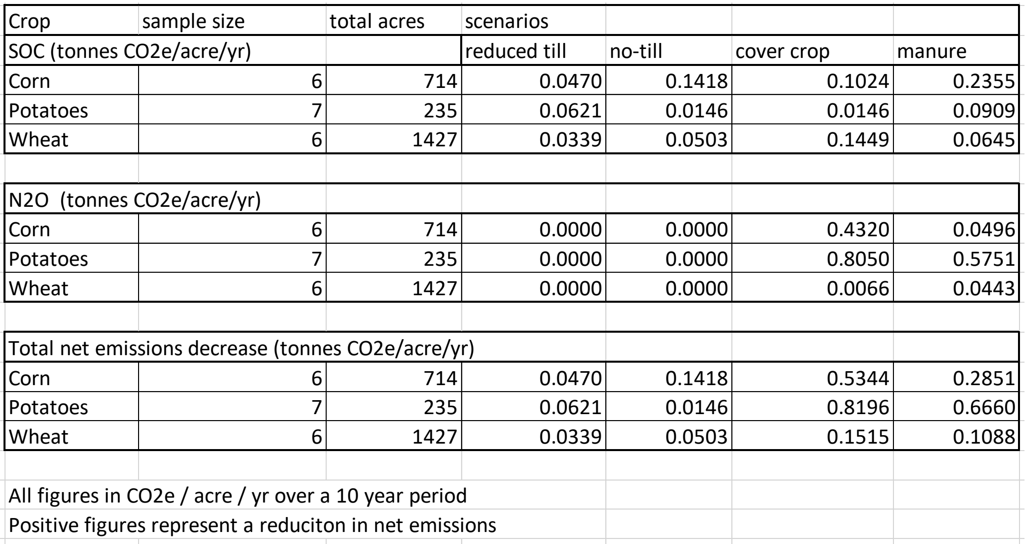
We developed separate scenarios for reduced tillage, no-till, cover crops and manure applications. For winter wheat, we specified a clover cover crop grown in the summer months, reduced fertilizer inputs by 30% and removed fallow from rotations as would be a common practice. For corn and potatoes, we specified an annual rye, legume, radish seed mixture cover crop and reduced fertilizer inputs by 50%. We specified a standard farmyard manure with a 1.2% nitrogen content and 45% moisture content and applied at 2 tonnes / acre for corn and potatoes and 1 tonne / acre for winter wheat. We subsequently reduced fertilizer application by 1/3rd for each crop.

Development of coefficients

Cover crops demonstrated the most beneficial ghg results for both SOC sequestration and N2O emissions reductions, with manure applications demonstrating the next greatest ghg reductions. Both

SOC increases and decreases in N2O were greater in corn and potatoes across all practices (with the exception of SOC related to cover crops), likely due to the effects of irrigation and the standard fertilizer application rates and corresponding reduction in fertilizers associated with cover-cropping. Table 3 shows the results from the modeling exercise for each crop. Values are consistent with the literature related to effects of crops, practices, and environmental conditions (in this case irrigation).

Table 3 – scenario results for Morrow County



Crop	sample size	total acres	scenarios			
SOC (tonnes CO2e/acre/yr)			reduced till	no-till	cover crop	manure
Corn	6	714	0.0470	0.1418	0.1024	0.2355
Potatoes	7	235	0.0621	0.0146	0.0146	0.0909
Wheat	6	1427	0.0339	0.0503	0.1449	0.0645
N2O (tonnes CO2e/acre/yr)						
Corn	6	714	0.0000	0.0000	0.4320	0.0496
Potatoes	7	235	0.0000	0.0000	0.8050	0.5751
Wheat	6	1427	0.0000	0.0000	0.0066	0.0443
Total net emissions decrease (tonnes CO2e/acre/yr)						
Corn	6	714	0.0470	0.1418	0.5344	0.2851
Potatoes	7	235	0.0621	0.0146	0.8196	0.6660
Wheat	6	1427	0.0339	0.0503	0.1515	0.1088
All figures in CO2e / acre / yr over a 10 year period						
Positive figures represent a reduciton in net emissions						

Extrapolating results to estimate baseline and periodic County-wide net emissions

Utilizing the modeling results of the scenarios (in this case, the mean per acre value across all locations) and the data from the Census of Agriculture, we apportioned practices across crop types based on the proportion of each crop within the County and extrapolated modeled results based on those proportions. For example, winter wheat represents over 155,000 of harvested acres, and given most if not all wheat production in the County utilizes fallowing as part of the wheat rotation, we can assume that the remainder of the fallow lands (124,732 acres) are also part of a wheat / fallow rotation for a total of 280,146 acres. We then extrapolated the per acre values associated with various practices apportioned to the proportion of wheat in the County. In this case, wheat represents over 56% of the harvested cropland landscape. We assume then that 56% of the conservation practices (no-till, reduced-till, cover cropping and application of manure) would be applied to the harvested wheat fields. The same logic was then applied to corn and potatoes, together with winter wheat, representing over 70% of the harvested croplands in the County. Table 4 shows the crop acres, associated apportioned practice acres and related ghg net emissions related to soil carbon and N2O.

Table 4: Extrapolated ghg emission results related to the three different crops and allocated practices

	Corn	Potatoes	Winter wheat
total acres (2017)	19338	16362	155414
proportion of harvested cropland	7.01%	5.93%	56.34%
allotted acres by practice			
reduced till	9,182	7,769	73,794
no till	13,442	11,373	108,027
cover crops	0	0	0
manure	307	260	2,467
Change in net emissions by practice*			
reduced till	432	483	2,502
no till	1,906	166	5,436
cover crops	0	0	0
manure	88	173	268
Total for all practices*	2,425	822	8,207
Total for all three crops*			11,454

*tonnes / CO2e / year

Identifying a baseline

The last step in the analysis requires identifying a baseline or starting point. The above figures are based on modeling results relative to conventional practices, therefore the extrapolation only reflects changes in net soil ghg emissions if the entire cropland landscape was managed conventionally in the past. However, we know this is not the case. Using the CRM dataset, we can back-cast tillage practices as far back as 1989 for certain crops. However, for other practices data does not readily exist for a similar exercise. The above analysis is only for example purposes and identification of baseline in this case is outside the scope of this paper.

It is important to consider however that results reflect changes in SOC over a 10-year period and it is likely that C sequestration rates will flatten over a period of time. This is because there is an upper limit to the amount of carbon that can be sequestered in soils. When a change in management increases carbon in soils, this will ultimately lead to higher rates of CO2 being emitted from the soil and these will eventually balance out and the system may approach a new steady state over time (Yogler, 2020). How much time depends on a wide variety of factors but if a baseline year is defined too far in the past, new ghg reductions would have already been realized and as the soil carbon reaches its upper limit the additional CO2e being sequestered currently would be nominal at best. This is not to say that soil health practices should not be pursued, but rather it is important how one frames the conversation around additionality in that after a certain period of time, additional ghg reductions are only possible through converting more acres to soil health building practices. Once this equilibrium state has been met however, the amount of additional carbon in the soils will remain sequestered until another shift in management occurs.

Uncertainty, needs for future exploration and investment in future data gaps.

Given potential issues with limitations of scale of the data, the accuracy of any estimates (baseline or future years) is dependent on the answer to three primary questions:

1. What is the variation of net emissions (both C and N_2O) across a county for any given crop?
2. What are the interaction effects of combining a suite of conservation practices (e.g. cover crops and reduced tillage practices)?
3. What are the different rates of net emissions (both C and N_2O) across different crops utilizing similar cover cropping, tillage and manure application strategies?

Using the above analysis, looking at the three different crops in Morrow County, we attempted to answer the above questions. To more accurately answer the questions would require additional sample locations, additional crops and to perform the analysis in a variety of counties – something that is outside the scope of this paper. Regardless, even evaluating results from the above example provides some insights.

1) *What is the variation of net emissions (both C and N_2O) across a county for any given crop?*

Modeled results for winter wheat showed that employing the same practices across all wheat fields in the sample yielded increases in soil carbon (except for one location that resulted in a slight decrease in SOC) and decreases in net emissions of N2O across all locations in the case of cover crops and manure applications. These changes however varied dramatically - ranging from 0.011 to 0.075 tCO2e / acre / yr, related to increased SOC for reduced tillage, -0.003 to 0.095 tCO2e / acre / yr for no-till, 0.040 to 0.273tCO2e / acre / yr for cover crops and 0.046 to 0.075 tCO2e / acre / yr for manure applications.

Corn exhibited similar characteristics with relatively large fluctuations of soil carbon flux from one location to the next. Only potatoes exhibited small variations across all locations for all practices. This suggests that the variation of net emissions across a county for many crops will be so great that generalized expansion factors (to the county scale) are most likely inappropriate.

2. *What are the interaction effects of combining a suite of conservation practices (e.g. cover crops and reduced tillage practices)?*

To test this question, we modeled additional scenarios that included multiple practices (reduced till with cover crops and no-till with manure). We found outputs were basically additive suggesting that minimal interaction effects exist (or at least are captured using the COMET-Farm api). In this case, the lack of information about what practices are employed to what crops is less important than where the crops are distributed throughout any given county.

3. *What are the different rates of net emissions (both C and N_2O) across different crops utilizing similar cover cropping, tillage and manure application strategies?*

Evaluating the results in table 3 above clearly shows that there are significant differences between the ghg impacts relating to similar practices across different crops. These differences are most pronounced in cases of N2O emissions, most likely not due to the crop itself but rather because differences in standard N application rates applied to different crops and corresponding changes in these rates that are a primary driver in N2O emissions. Regardless, these results point to the importance of having data that defines the relationship between crops and practices.

As mentioned above, this analysis is for demonstration purposes only: a more rigorous sensitivity analysis should be conducted to estimate uncertainty of any estimates. This would include increasing the sample size of locations that are modeled, including additional counties with different cropping systems and geoclimatic conditions, and increasing the number of crops modeled. In the next section we identify some datasets that could be expanded to reduce uncertainties in estimations.

Next steps

Given the variability of ghg impacts across crops and across geographic space at scales smaller than the county, estimation would be greatly enhanced with spatially explicit datasets related to both crop and practice activities. Currently, the CDL data represents a generalized overview of crops on an annual basis but no such data exists that describes practices for the entire state of Oregon. Any investments in an accounting methodology for croplands that include soil carbon and N2O should be focused on filling the data gaps associated with temporal, spatially explicit management data.

One such dataset that does show promise is the Operational Tillage Information System (OpTIS). OpTIS represents a partnership between the Conservation Technology Information Center, Regrow and The Nature Conservancy to develop an automated system to map tillage, residue cover, winter cover, and soil health practices using remote sensing data. OpTIS-based data are currently available for the years 2005 through 2018 for the US Corn Belt, including all of Illinois, Indiana, and Iowa, as well as parts of: Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, Oklahoma, South Dakota, and Wisconsin. If this data were expanded to include Oregon, it would prove invaluable in reducing some of the uncertainties identified above.

Finally, we recommend conducting a more rigorous sensitivity analysis to ensure the proposed methodology can provide reasonable estimates and that any uncertainties do not outweigh expected impacts. As mentioned above, this analysis should include additional sample locations, crops and counties. Furthermore, we used the COMET-Farm api in the above analysis. While COMET-Farm (and the underlying Daycent model) have been in production for a number of years, it is poorly calibrated for Oregon with minimal empirical data to drive the model. Investments in additional field monitoring for model calibration and additional crops (specific to Oregon), whether for COMET-Farm or other models, could greatly improve estimates.

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