

Organic and climate-smart agriculture

Contribution towards Washington State climate response goals



Riparian planting along Kamm Creek in Lynden (photo by Tristan Simons)

A report to the Washington Legislature

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Cover crops in Douglas County (photo by Leslie Michel)

Executive Summary

Washington State's diverse and productive agricultural sector has great potential to contribute to the state's climate goals and create other immediate and long-term public benefits through voluntary greenhouse gas emissions reductions. To this end, the Washington State Legislature requested that the Washington State Conservation Commission conduct an evaluation of "the current contribution that organic and climate-smart agriculture makes towards Washington's climate response goals, the potential there is for increasing this contribution, and how additional investments will help realize this potential, while supporting resiliency."

This report fulfills that request and has been produced through a partnership between Washington State University and the Washington State Conservation Commission, with support from KR Creative Strategies (KRCS). WSU partners carried out an extensive review of scientific literature, while KRCS engaged with producers and agriculture-allied entities across the state to better understand their perspectives. These viewpoints are an important foundation and are incorporated throughout the report, summarized in [Box 1](#) of this executive summary, and detailed in [Appendix A](#).

Box 1. Producers and agricultural stakeholders in Washington had four main messages relating to climate-smart agriculture:

1) To navigate changes and adopt climate-smart practices, agricultural producers need flexible, grant-driven funding and expert assistance. Conservation technical assistance is vital to guide farmers in adopting new practices and identifying and securing suitable funding opportunities. Long-term financial support beyond the early phase of adopting climate-smart techniques would ensure practices can remain in effect for a decade or more.

2) There is a need for on-farm research on climate-smart practices and better baseline data. On-farm research across the range of environmental conditions and diverse production systems reduces the risks producers face in implementing new practices. Baseline data is important for understanding the current status and progress over time.

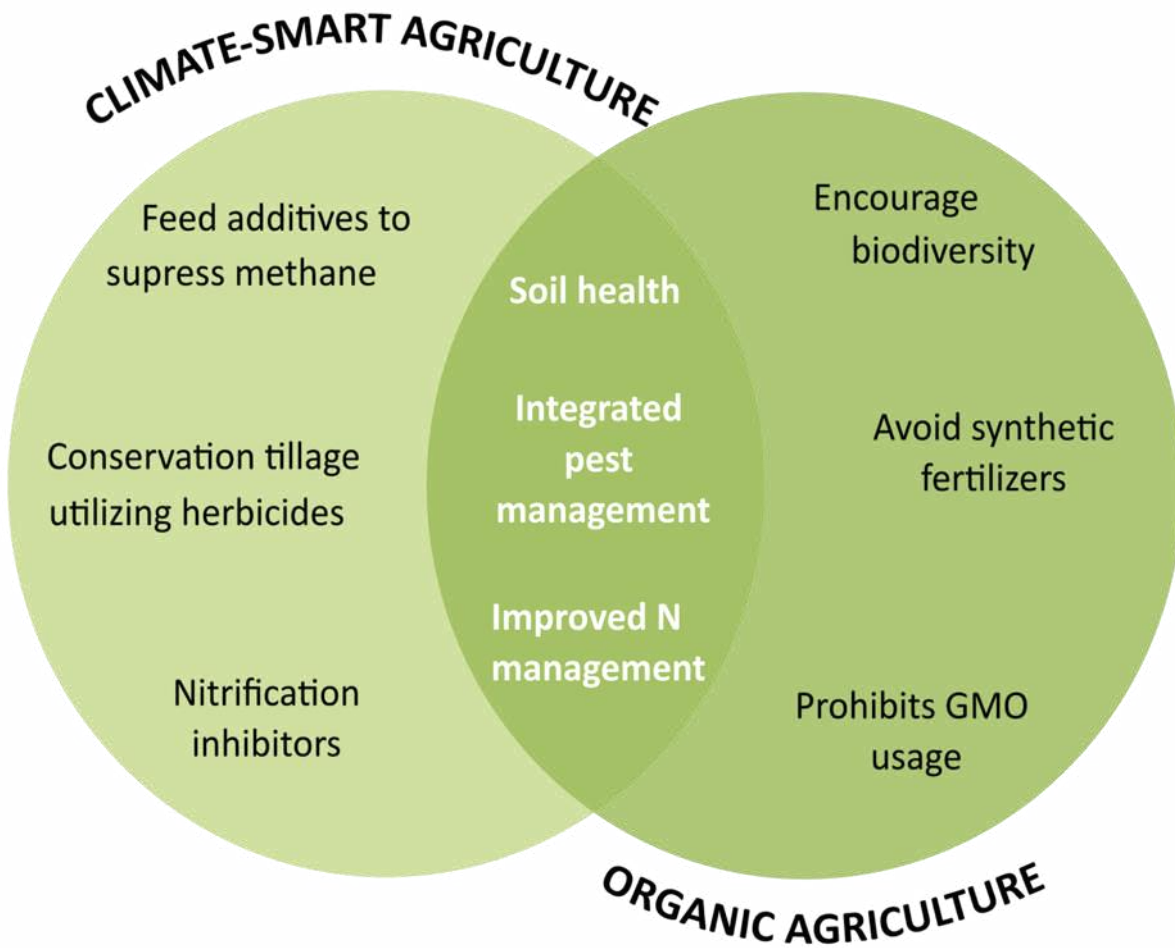
3) Climate-smart policies in Washington should support agriculture and keep farmland in production. It is important for the state to work with farmers and the agriculture industry and not jeopardize the system that our region, and the world, relies on for producing nutritious food.

4) Approaches to climate-smart agriculture should be built from the farm up, utilizing a farmer-centric perspective. For example, although current funding through the Sustainable Farms and Fields Program at Washington State Conservation Commission is extremely helpful in supporting adoption of new practices, grant funding cycles for this and other opportunities are misaligned with the growing season, making participation impractical for many. The term “climate-smart agriculture” could also be referred to as “conservation practices” for wider farmer buy-in.

Climate-smart agriculture seeks to sustainably increase productivity, adapt agricultural systems to climate change, and reduce greenhouse gas emissions. Many, but not all, approaches used in climate-smart agriculture align with those used in organic agriculture. Organic production is a longer-established system that holistically integrates cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity. Organic production practices are regulated by the U.S. Department of Agriculture, while the term “climate-smart agriculture” is not regulated.

Many climate-smart agricultural practices can be used in both organic and conventional systems, sometimes with adaptations: this includes reduced or no tillage, promoting nutrient cycling, and building soil health ([Figure E1](#)). Many organic practices reduce reliance on fossil-fuel inputs and build soil organic carbon through actions that include cover cropping, crop rotations, and the use of organic amendments. Unlike organic agriculture, climate-smart agriculture does not prohibit the use of synthetic pesticides, fertilizers, or herbicides. Climate-smart agriculture also focuses specifically on reducing emissions of climate-warming greenhouse gases, and therefore can include some practices not common, or not allowed, in organic systems, such as feed additives to reduce the impact from ruminant animals, or practices that utilize herbicides to manage weeds in order to omit soil tillage.

Figure E1: Not all climate-smart practices are organic, and not all organic practices are considered climate-smart, but there are many areas of overlap.



Note: The practices in this figure are illustrative examples rather than a comprehensive list.

Agriculture is responsible for 6.9% of the 96.1 MMT CO₂e of emissions reported in Washington in 2021 according to the most recent statewide greenhouse gas inventory (Department of Ecology, 2025). These emissions account for three agricultural activities: digestion of ruminant livestock (3.1% of all emissions), fertilization and management of agricultural soils (2.0%), and manure management (1.7%). Activities under these broad categories release two primary greenhouse gases: methane (CH₄) and nitrous oxide (N₂O), both of which are much more potent than carbon dioxide (CO₂) by weight. Long-term carbon gains and losses from croplands and rangelands generally fall under the natural and working lands appendix to the greenhouse gas inventory and are accounted for separately but are also important. The ability to “draw down” carbon from the atmosphere (or alternatively, to release it into the atmosphere) is a unique attribute of agriculture and other working lands.

There are important nuances to emissions accounting that result in the state inventory not capturing all emission dynamics associated with food production in the state – and certainly not all

of those related to food consumption. For example, production of fertilizers and other farm inputs, fuel use, transportation of agricultural goods, and emissions from food waste are not accounted for under agricultural emissions. Furthermore, the current inventory relies on many national level inputs and assumptions, meaning that changes to agricultural management in the state that impact greenhouse gas emissions would not necessarily be reflected in the inventory with current methodologies.

Voluntary climate mitigation practices in agriculture are achievable using current technologies and knowledge. These practices can reduce emissions and sequester carbon, which contribute to achieving the state's climate goals. In some cases, these practices have long been used, but in others they still need to be tested and adapted to fit within the diverse cropping systems in Washington. On-farm research can help explore these and reduce the risks that producers face when adopting new practices.

Many climate-smart and organic practices, especially those that preserve carbon and reduce nitrogen losses, have substantial other benefits to agriculture and to the public. For farmers, these practices can reduce erosion, improve soil water retention, improve nutrient cycling, enhance productivity and food production, and improve resilience to weather shocks. These benefits should be highlighted to motivate farmers and other stakeholders in support of climate-friendly practices. The public can also benefit from climate-smart and organic practices through reduced climate risks, cleaner air and water, soil conservation and the scenic and wildlife benefits of natural working lands. These co-benefits are particularly strong for practices that build soil health and improve the management of fertilizers.



Chase O'Neil (left) and Louise Margaret pull soil samples in Snohomish County (photo by Kathryn Wells)



Sustainable rangeland management practices used on Puget Sound Energy-owned rangeland in Kittitas County (photo by Tipton Hudson)

Preserving and Storing Carbon in Agricultural Landscapes

Management can be used to preserve and store carbon in cropland, rangeland, woodlands and forests, providing carbon dioxide removals, while also producing food, fuel, fiber and other fossil fuel substitutes. Thus, Washington would benefit from a comprehensive strategy to both preserve existing carbon in agricultural landscapes, and to take advantage of opportunities to build it. Preservation is at least as important as building soil carbon. Recent wildland fires have shown that large amounts of carbon can quickly be lost from rangelands and other working lands, and not easily restored. Likewise, such a strategy would lead with keeping farmland in production and keeping farm enterprises viable, as noted by stakeholders and supported by the literature.

The benefits associated with climate-smart and organic practices are provided over medium- or long-term time horizons. If agricultural land is converted to other purposes, its stored carbon will most likely be re-released and additional carbon will not be sequestered. Conserving farmland can go hand-in-hand with limiting urban sprawl, a strategy that limits greenhouse gas emissions from transportation and development of infrastructure and housing. While distributed renewable energy installations (e.g. wind and solar) are needed, without proper planning they can result in permanent farmland loss or damage.

Tools for conserving farmland include conservation easements and land preservation programs. For example, in California, land preservation programs have benefitted from cap-and-trade funding with a methodology to calculate the climate benefits associated with farmland protection. Other important strategies include strong agricultural zoning laws, land use policies that incentivize and encourage retention of agricultural lands and promote agricultural viability, support for farmland succession and transition, including affordable access for new farmers, well-defined urban growth

and urban service boundaries, and municipal policies emphasizing infill development. The Washington Food Policy Forum recommends that government land use actions resulting in the loss of agricultural land be mitigated by conserving adjacent farmland that is comparable in size, soil quality, and agricultural value, as well as substantial increases to funding for permanent farmland protection.

Strategies to enhance agricultural carbon storage increase climate change resilience. Rangelands science emphasizes avoiding degradation or conversion of rangelands should be the dominant approach, as possible loss of sequestered carbon from these ecosystems is orders of magnitude greater than the slow changes that grazing management can achieve. Meanwhile, within cropping systems, existing Pacific Northwest data suggest soil health practices can provide modest, but real, contributions to carbon sequestration. Practices for which we have the most regionally relevant long-term data are largely for dryland grain-based systems and irrigated cropping systems in the inland, eastern portions of the state. In these areas, existing data explore the impacts of intensifying crop production (through cover cropping, double cropping, eliminating fallow, crop rotation or other strategies), reducing or eliminating tillage, perennial crops, soil amendments, and reduced burning. In general, opportunities to build soil organic carbon are greater on a per acre basis in annually cropped systems with higher rainfall or irrigation and therefore higher productivity. However, dryland grain systems and rangeland systems should not be ignored given their large extent in the state.

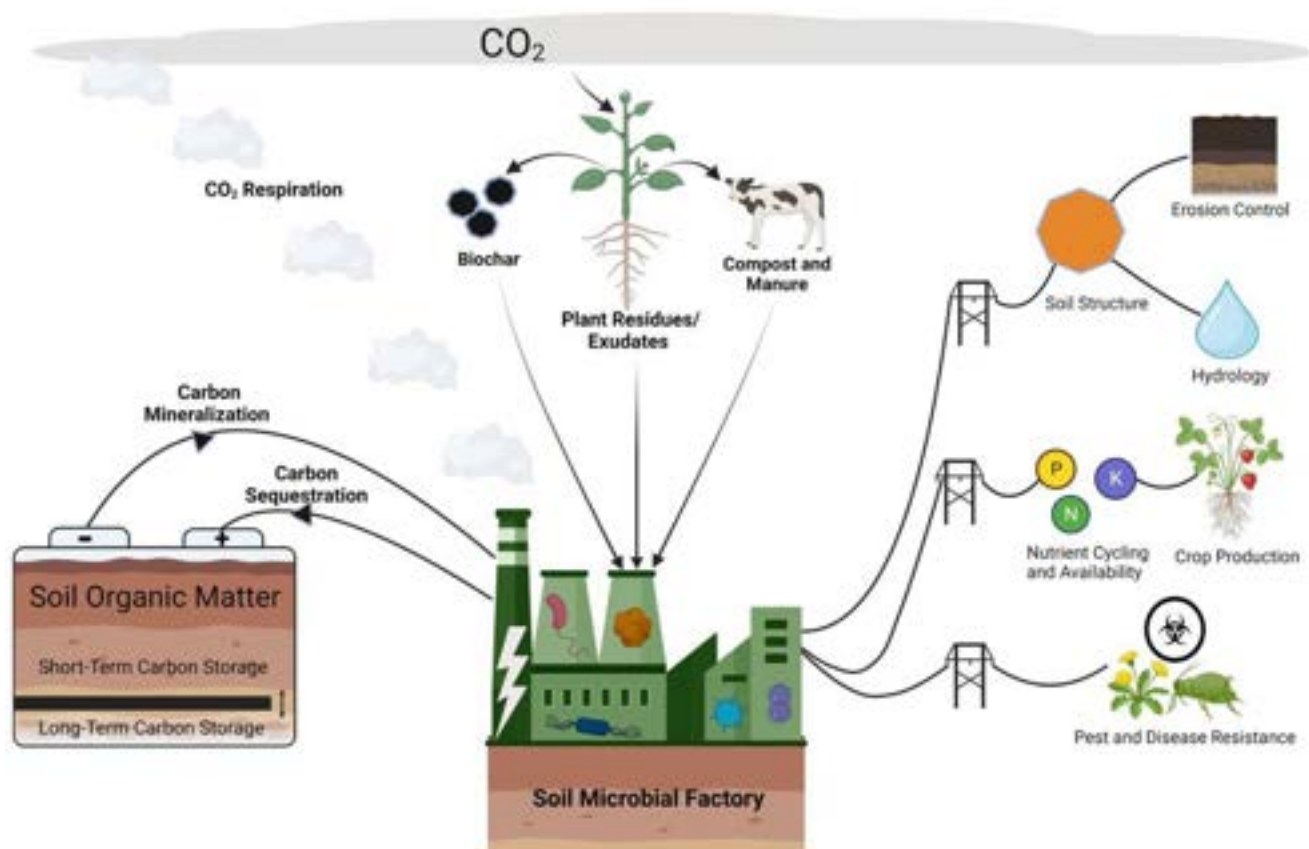


A wheat field in Washington (photo from Natural Resources Conservation Service)

Supporting organic farming across the state could also be an important part of a comprehensive strategy to retain and build soil carbon. Organic systems tend to have a smaller impact on the climate per unit area (though not always per unit of output) than conventional systems. This is often because organic systems produce less methane and nitrous oxide per unit area than conventional systems. By addressing current barriers to organic conversion, such as the cost of certification, or supporting demand for organic food purchasing, the state could encourage broader adoption. One potential upside of such a strategy is that acreages are already regularly reported through the certification process, and standards are well defined. In addition, identifying crops and production systems where there are yield gaps compared to conventional systems, and supporting research, extension, and implementation to close those yield gaps, is likely to be important.

While available data show potential for soil health practices to store additional carbon in agricultural systems, it is important to realize that most of the carbon added to agricultural systems is eventually re-released into the atmosphere, while some is retained. However, this does not mean that carbon returned to the atmosphere is a “loss;” agricultural systems need to utilize carbon to support soil microbial life and crop production (Figure 2E). Ongoing utilization of climate-smart practices will be needed to retain soil carbon in soils over time.

Figure 2E: Conceptual diagram of how soil organic carbon is both accumulated and utilized by soil microbes to power a broad suite of ecosystem services.



From Gelardi et al., (2023).

Beyond these well-researched practices, interest in the addition of biochar or basalt to agricultural soils has increased, as potential methods for storing carbon over even longer timeframes: hundreds to thousands of years (for biochar) or longer (for basalt). Technical analysis in our region suggests that biochar applied to agricultural lands from waste wood materials could offset a substantial amount of the state's greenhouse gas emissions (8-20%), although actual offsets would be substantially less. For example, economic barriers relating to gathering and transporting biochar across the landscape, as well as the potential cost burden to agricultural producers need to be considered. However, the greenhouse gas reduction potential is significant enough to warrant further work to identify and address these barriers. Work to explore whether a biochar strategy could also simultaneously improve pH in some agricultural soils and help reduce fuels loads in forests is also ongoing if practical, such strategies could increase benefits to the state.



Biochar being applied to a field in Stevens County (photo by Pauline Hagen)

Meanwhile, ongoing research on spreading crushed up basalt onto agricultural land to enhance weathering and store carbon (known as enhanced rock weathering) is underway in other areas of the U.S. and the world. Initial findings have demonstrated benefits to agriculture such as improving soil pH, providing important nutrients to plants, and improving crop yields. Washington can take advantage of its large expanse of basalt (i.e., Columbia River Basalt flows), sourcing from existing mining operations. Field studies are lacking in the Pacific Northwest and are needed to better understand the actual carbon sequestration potential while simultaneously addressing the potential risks to the environment and people.

Non-cultivated lands managed by agricultural producers also play a vital role in supporting carbon sequestration, as well as reducing reactive nitrogen losses, and supporting biodiversity and wildlife habitat. This can include wetlands, forested areas, and riparian areas. Practices that can be incorporated into the farm landscape include windbreaks and/or hedgerows and vegetated riparian buffers. These practices can help with wind reduction, soil erosion control, providing shade to

livestock, filtering out pollutants, and moderating water temperatures. Appropriate practices depend on context and no one practice is ideal for all farm types, sizes and locations.

Overall, there are relatively few long-term datasets relating specific agricultural management practices in Washington's diverse production systems to changes in greenhouse gas emissions and carbon storage. This, plus the fact that agricultural production occurs in complex and open biological systems, makes it impossible with current tools and methodologies to precisely estimate the benefits that could be provided by the implementation of these practices across the state. Ongoing scientific work is providing a foundation that could close this gap over time. The Washington Soil Health Initiative (WaSHI), funded by the Washington Legislature, established long-term agroecological research sites across the state's diverse production systems between 2020 and 2023. In the years to come, data from these sites will be a critical resource for estimating mitigation impacts, though sites are currently focusing on carbon dynamics and other soil health related measurements and are seeking additional funding for instrumentation to measure nitrous oxide fluxes. Meanwhile, modeling approaches are also in development but depend on existing experimental measurements to evaluate their ability to represent real-life conditions. Continued scientific work towards more realistic estimates of the climate impact from particular management practices will help support stakeholders' desire to define baselines and evaluate the effectiveness of climate-smart practices over the long term.



A newly planted riparian buffer near the mouth of Drayton Harbor (photo by Tristan Simons)



Reducing Agricultural Emissions

Efforts to reduce on-farm greenhouse gas emissions can complement efforts to preserve and enhance soil carbon and may result in immediate and ongoing contributions to the state's climate goals. Manure management and storage strategies that produce both methane and nitrous oxide offer immediate and impactful opportunities for climate mitigation. When appropriate for the farm, anaerobic digestion systems provide very substantial greenhouse gas reductions of 60-70% in manure management emissions plus additional climate benefits resulting from the production and use of renewable electricity or fuels. However, under current incentive structures these systems are only viable for larger dairies with more than about 3000 cows, and systems may not be a fit with all production systems or marketing strategies. For smaller dairies, cap and flare lagoon covers (that capture methane and destroy it) could reduce greenhouse gas emissions by almost the same magnitude but are more expensive than simpler solids separation systems. Solids separators provide much smaller, but still meaningful reductions of around a quarter or perhaps less of manure management emissions – and are a needed precursor to cap and flare.

Meanwhile, strategies to reduce emissions from the digestive processes of cows and sheep include diet manipulation and feed additives. The approved feed additive nitro-oxypropanol (3-NOP; commercially known as Bovaer) reduces emissions by roughly a third has been recently approved in the US, but it is quite expensive (~\$0.50 per cow per day). Inclusion of certain unsaturated lipids in the diet can also reduce emissions by roughly 15%. Monensin, already fed to some livestock to support productivity, reduces emissions by a small amount, often considered to be less than 10%, but is much more economical (\$0.02-\$0.04 per cow per day). Feed additives are relevant at all farm scales but currently challenging to use on rangelands (where animals are dispersed), although strategies are in development.

Nitrous oxide emissions are generated as a byproduct by naturally occurring bacteria in soils that transform nitrogen from fertilizers and manure. Nitrogen is vital to growing crops, and if nitrogen is not available to plants in adequate supply, yields suffer. However, if nitrogen is overapplied, the proportion of applied nitrogen emitted as nitrous oxide increases as application rates increase above what is needed. The most straightforward way to reduce nitrous oxide emissions is to utilize the four principles of fertilizer management: right rate, right time, right place, and right source. Opportunities to reduce application rate exist only on acreage that is currently receiving more than the needed fertilizer, but in these cases, working to ensure that the right rate will provide strong climate and other benefits, and will result in cost savings to producers. Other strategies that can reduce nitrous oxide emissions include better matching fertilizer timing with plant needs, using (more expensive) slow-release or inhibitor-treated fertilizers that enhance efficiency, irrigation management to avoid anaerobic soil conditions, and biochar application. Reductions by 20-30% in nitrous oxide emissions are sometimes estimated as achievable, but this is in the absence of state-specific evaluations to identify what opportunities exist for ongoing improvements. Analyses from across temperate portions of the northern hemisphere also indicate nitrous oxide emissions from organic systems are generally lower than in conventional systems.

Last but not least, considerations relating to energy use on farms is important. There are relatively few detailed analyses of the “carbon footprint” of Washington farms. Existing analyses suggest that energy use does not dominate the footprint but still plays an important role (e.g. nation-wide figures of energy use suggest this accounts for ~7% of the total agricultural production footprint). Liquid fuels are prevalent on farms, but conversion to electric is becoming more viable for smaller-scale mobile equipment (<70 horsepower) and larger-scale fixed equipment (pumps, wind machines). Another significant source of (indirect) emissions is the production of fertilizers, while manufacturing of pesticides and other inputs likely has a small footprint. Opportunities for energy



Digested fiber solids are used to replace bedding material at a northwest dairy (photo by Andgar)

efficiency can require up-front investments that are challenging for some producers, but can reduce costs and energy demand, though emissions impacts depend on the footprint of the farm's current energy mix. Current frontiers of development in terms of energy use and farm inputs include low-carbon fertilizers, agrivoltaic systems (especially in specific applications such as orchards, rangelands, and dairy where shade can benefit production), and electrification of various equipment.

Contributions to Bioenergy Production

The third mitigation approach in which agriculture is often a participant is bioenergy production. This can include electricity, fuels, or heat created from organic materials. Under the right circumstances, these products have the potential to produce energy with a lower climate footprint than energy from fossil fuels. In the Pacific Northwest, and given current economics, bioenergy strategies that are currently implemented at scale to some extent include utilization of waste biomass to produce renewable electricity or renewable natural gas through anaerobic digestion on dairies, and use of oilseed bioenergy crops in rotation with other crops. These strategies are both economically viable in some (though not all) contexts. Ongoing research and technical assistance have supported the adoption and continue with a focus on reducing costs and other barriers, and maximizing benefits to producers. This can include benefits to stabilizing waste (for anaerobic digesters) and benefits to disease management and yields of following grain crops (for oilseeds).



Pear orchards and pastures in Wenatchee Valley (photo by Louis Nottingham)

Broader Context

Given that agriculture is deeply interlinked with local and global economies, food security and diets, and sectors like energy and waste, this report also discusses important contextual factors that must be part of any discussion of mitigation efforts through agriculture. To successfully address the

climate crisis, reductions in emissions within our state's boundaries need to contribute to global reductions in climate emissions, rather than creating compensatory increases in emissions elsewhere.

To achieve this, successful implementation of climate-smart practices should retain agricultural production within the state and avoid pushing it elsewhere. This is a central message from stakeholders that is also supported by some key facts. Agriculture is a cornerstone of Washington's economy, adding more than 150,000 jobs and \$14 billion in value. The state is a leading producer of many nutritionally dense foods, including apples, pears, hops, cherries, dry onions, a wide variety of organic fruits and vegetables, meat, and dairy products. There are also important environmental reasons why it makes sense to retain food production within the state's boundaries. Washington is a responsible producer of food, and similar to many other industrialized regions, its agricultural production also has a relatively low emissions intensity. This means that production moving elsewhere would likely result in higher net emissions globally, both due to land clearance and the higher emissions per unit of food production. For these same reasons, climate-smart practices also need to be implemented without resulting decreases in productivity, although there is currently little evidence to suggest that specific climate-smart or organic practices negatively affect productivity within Washington's production systems.



A mixed mustard-arugula cover crop is chopped and incorporated into the soil prior to planting potatoes in Grant County (photo by Dale Gies)

Broader analyses of the climate impacts of the food system as a whole also illustrate the role of three aspects of the food system that do not pertain to agricultural practices but have large greenhouse gas mitigation potential: reducing food loss and waste, dietary choices, and reducing emissions from processing and transportation. National estimates suggest that somewhere between one and two percent of *all* emissions could be mitigated via actions in each of these areas, which likely adds up to more than the total achieved by large-scale adoption of feasible on-farm practices – although each of these actions is likely to face their own challenges in implementation.

Finally, to better understand how changes in agricultural practices can be sustainably supported and maintained within the state's agricultural enterprises, it is helpful to follow the recent development of agricultural carbon markets. This is especially true given the economic reality that agricultural profit margins are thin, and many climate-smart practices also result in added costs, either up-front or ongoing. And yet, to experience climate benefits, practices need to be maintained over the long run. International and domestic corporations have engaged in supporting adoption of climate-smart agricultural practices via voluntary purchases of offsets (meaning emission reductions credits are purchased by entities outside of food and beverage supply chains) and insets (credits are purchased by food and beverage companies within their own supply chains).

As further discussed in the report, carbon markets are in their infancy in Washington. In the U.S., the understanding of quantifiable carbon benefits associated with various practices is still very limited outside of main row crop systems and more homogenous conditions of the Midwest. From a grower perspective, these carbon programs have important limitations, including that many only support newly adopted practices. They thus exclude farms who have implemented certain practices previously, including many organic farmers and others who are leading in producing products with a smaller than average climate footprint. The programs also may not pay enough to cover all ongoing costs, often exclude farms that are small in size or operate on rented land and require a high degree of administrative and record-keeping capacity. There is an opportunity for state programs to complement these market-based programs where possible (e.g., to support upfront investments where carbon market programs would support ongoing costs), to support farm types and farmer groups who are underserved by carbon markets, and to provide educational and training opportunities to build farmers' capacity to engage in these programs.

Conclusion

Any strategy implemented to reduce emissions and enhance carbon sequestration in agriculture needs to think holistically about both the initial upfront costs and the private and public financial mechanisms that are going to support ongoing costs of operating and maintaining the use of these technologies and practices over time. Agricultural stakeholders in Washington have emphasized the need for flexible grant funding, continued financial support, and expanding eligibility and timing for grants. Overcoming operational or technical constraints is also important, and in some cases long-term investments may be needed to drive technological development that addresses cost and scale barriers, and that develops new strategies for hard to abate emissions.

Without measured baselines, it is difficult to track progress. Washington State's current greenhouse gas inventory largely relies on national data and assumptions which do not reflect many changes in local management. Collaborations to improve the statewide greenhouse gas

inventory in ways that do not put additional administrative burden on farmers can help ensure that any progress by farmers is evident at the state level.

Meanwhile, improving the estimates of mitigation potential and assessing cost-effectiveness for key climate-smart practices could help refine prioritization of state actions. This could build on existing strong linkages between industry groups (who have insights into the practice(s) that may be most appealing and realistic within their agricultural systems as well as costs), the scientific community (who have insights into the climate mitigation benefits that can be expected, and can implement longer-term research to overcome remaining barriers), and agencies (who have insight into the most effective state strategies for support).

This work will likely also require ongoing scientific development, including the collection of additional data from both organic and conventional long-term experiments linking management practices to primary long-term data on soil carbon sequestration and methane and nitrous oxide fluxes, meta-analysis across long-term datasets, and modeling approaches. By supporting investments in climate-smart and organic practices, Washington has the potential to drive innovation and agricultural competitiveness. These investments will benefit the whole sector, while producing nutrient-dense food, supporting rural livelihoods, and positioning the state as a leader in climate-smart agriculture.



Sustainable grazing management in Kittitas County (photo by Darrell Kilgore)

Definitions

Anaerobic digestion: A process in manure management where microorganisms break down organic waste in the absence of oxygen.

Biochar amendments: Made from organic waste material or biomass that is partially combusted in the presence of limited oxygen.

Bioenergy: Energy products that can be made from organic materials like fuels or heat.

Carbon dioxide equivalent (CO₂e): A metric to compare the climate impact of different greenhouse gasses. It is calculated by multiplying the amount of greenhouse gas by its global warming potential (GWP).

Carbon insets: Emissions reductions or removals within the value chain of a company.

Carbon offsets: A reduction in greenhouse gas emissions or an increase in carbon storage in one place to compensate for emissions that occur elsewhere.

Carbon sequestration: Removing meaningful quantities of carbon from the atmosphere and storing it in soils and vegetation.

Climate-smart agriculture: An approach to sustainability increase productivity, adapt agricultural systems to climate change, and reduce greenhouse gas emissions (mitigation). See [Table 1](#) for a list of practices.

Cover and flare: A process in manure management where storage lagoons are covered and the trapped methane is converted to carbon dioxide and combusted.

Denitrification: The final step in the nitrogen cycle where bacteria convert nitrate back into gaseous nitrogen. This process occurs under anaerobic conditions (without oxygen) by specialized bacteria.

Enhanced rock weathering: A carbon sequestration technique that draws down atmospheric carbon through weathering of rocks like basalt on croplands.

Enteric fermentation: Digestion of ruminant livestock (i.e., sheep and cattle). Bacteria in the animal's gut work to process grass and other plant materials and release methane.

Global warming potential (GWP): Multipliers that estimate the warming impact based on carbon dioxide. For example, methane has a GWP of 28, meaning that methane is 28 times more potent than carbon dioxide.

Greenhouse gas (GHG): Gases in the atmosphere that trap heat and warm the earth. These gases include carbon dioxide, methane, nitrous oxide, and water vapor.

Integrated pest management (IPM): A management approach that shares fundamental goals with organic farming to reduce pesticide use and instead use biological controls such as natural enemies (parasitoids and predators), crop rotation, and habitat management to promote biodiversity and a focus on non-chemical tools like pheromones, traps, and resistant crop varieties.

Intergovernmental Panel on Climate Change (IPCC): A United Nations body of scientists who evaluate the state of scientific knowledge related to climate change and provide policymakers with comprehensive assessments.

Land use, land use change and forestry (LULUCF): Category used by the IPCC that includes agricultural land, forestry, and any land use changes.

Life cycle analysis (LCA): A systematic method for assessing the environmental impact (typically greenhouse gas impacts) of a product through its entire life cycle.

National Resources Conservation Service (NRCS): A USDA agency that provides financial and technical assistance to help conserve agricultural lands and limit non-agricultural uses of land.

Nitrification: A step in the nitrogen cycle where a microbial process converts ammonia into nitrate.

Nitro-oxypropanol (3-NOP): A feed additive that can decrease methane production in lactating cows between 8% and 60%. Commercially known as Bovaer.

Organic agriculture: A holistic production system that integrates cultural, biological, and mechanical practices that foster the cycling of resources and promote ecological balance, and conserve biodiversity. Strives to foster a resilient and regenerative approach to food production.

Regenerative agriculture: Agriculture that prioritizes restoring soil health and biodiversity, focusing on holistic practices that improve ecosystem functions and sequester carbon.

Soil organic carbon (SOC): Carbon stored in soil that comes from plants, animals, and microbes.

Soil organic matter (SOM): The organic material in soil which is derived from living and dead organisms (plant roots, microbes, compost, organic fertilizers).

Solid liquid separation: A process in manure management that separates out the solids from the liquids. Methods to separate include gravity settling, in-channel flighted conveyor screens, rotating screens, screw presses, belt presses, rotary presses, centrifuges, and hydrocyclones.

Urease inhibitors: Chemicals that reduce nitrogen loss from fertilizers by slowing the breakdown of urea into ammonia gas.

Vegetated riparian buffers: Strips of riparian vegetation between farmland and waterways that can filter agricultural nutrients and pollutants, reduce erosion, moderate water temperatures, improve water quality, and provide wildlife habitat.

Windbreaks: Linear planting of trees and shrubs into an agricultural landscape designed for wind reduction, soil erosion control, or providing shade for livestock.

Section I. Introduction & Overview

In 2024, the Washington State Legislature provided a one-time funding for the Washington State Conservation Commission to evaluate “the current contribution that organic and climate-smart agriculture makes towards Washington’s climate response goals, the potential there is for increasing this contribution, and how additional investments will help realize this potential, while supporting resiliency.”

In response, this report has been produced through a partnership between Washington State University’s Center for Sustaining Agriculture & Natural Resources (CSANR) and the Washington State Conservation Commission, with support from KR Creative Strategies (KRCS).

I. Agriculture in Washington

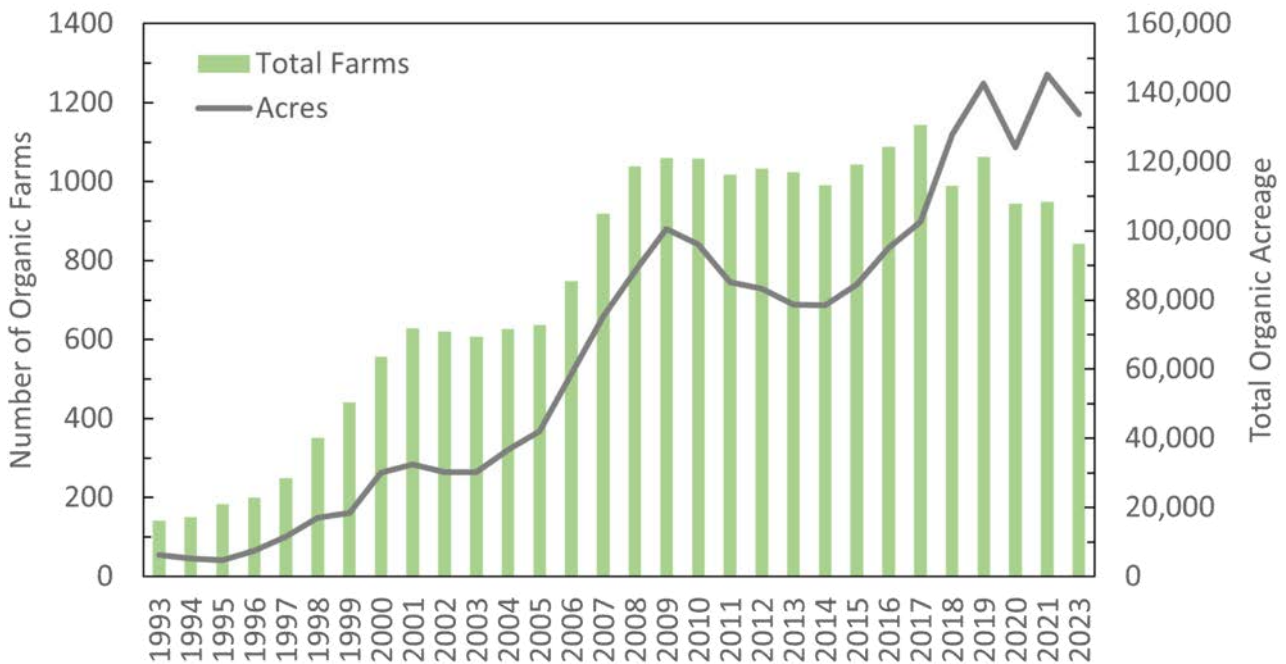
Washington State is home to a broad and varied agricultural landscape that contributes significantly to the state’s economy. With approximately 13.9 million acres of farmland and over 32,000 farms, Washington supports a diverse array of crops and livestock. Crops of note include wheat, potatoes, and specialty crops like apples, cherries, vegetables, wine grapes, and small fruits. Washington also has large numbers of cattle, cows and beef (223,000 head in 2023), important shellfish and finfish production areas, and significant numbers of poultry, as well as smaller numbers of other livestock. Washington’s agricultural lands span a number of diverse ecosystems and climatic zones, though most are characterized by relatively mild winters, with rainfall concentrated during the winter months. A strong rain shadow effect between the eastern and western sides of the state means that precipitation varies from as little as 6-8 inches per year in some dryland grain growing areas east of the Cascade crest, to more than 60 inches per year in areas along the coast where cranberries are grown.

Washington is a national leader in agriculture, ranking first in 2023 for production of apples, pears, hops, cherries, dry onions, and spearmint oil. Among these, the state accounted for 73.6% of the nation’s hop production and 67% of its apple production. However, between 2020 and 2023, Washington’s net farm income experienced a significant decline, falling from \$3.23 billion to \$1.53 billion, a contraction of 52.5%. This downturn had strong negative impacts on profitability, and was primarily due to escalating intermediate product expenses that surged from \$5.18 billion in 2020 to \$7.84 billion in 2023. These increases were driven by sharp rises in the costs of fertilizer, fuel, and feed purchases, as well as cost of labor and reduced governmental support, mirroring a nationwide drop in farm income (USDA ERS, March 2024). Nevertheless from 2022 to 2023, Washington’s total agricultural output grew by 5.5%, reflecting its critical role in the state and national economy (NASS, October 2024).

Organic farming generated \$870 million in certified sales in Washington in 2022 – 7% of agricultural sales in the state, and 10% of all certified organic sales nationwide (NASS, September 2024; NASS, October 2024). This highlights the state’s success in integrating high-value organic crops like apples, vegetables and specialty grains into its agricultural systems. In 2019, the state produced 93% of the nation’s fresh organic apples, 92% of sweet organic cherries, 74% of organic pears, and roughly half of the nation’s organic onions, peas and sweet corn (NASS, 2019). Organic milk products, livestock, poultry and eggs are also economically important products. Organic agriculture has also experienced significant volatility over recent years, driven primarily by the

entry, exit, and growth decisions of medium and large farms (Brady et al., 2023; Figure 1). These patterns likely reflect broader economic trends among consumers whose demand for organic products is more elastic with respect to their economic well-being than their demand for conventional products. Organic farm expansions hence often occur during periods of economic growth and contractions during downturns (Brady et al., 2023).

Figure 1: Number of organic farms and total organic acreage in Washington state.



The data was compiled following the methodology in Brady, et al. (2023).

Any attempt to support climate-smart practices amongst Washington’s agricultural producers needs to be aware of these economic realities, and ensure that efforts first and foremost support the long-term economic viability of agriculture across the state. If climate-smart practices are implemented in a way that negatively impacts farm productivity or economic health, the likely outcome will be expanded emissions elsewhere as farm businesses outside the state expand to make up for lost production. Meanwhile, if such efforts reinforce economic viability of agriculture in the state, Washington’s agriculture can enhance resilience, contribute to the state’s climate mitigation goals, and generate other benefits that accrue not only to farmers but also to the public at large, whether they live in rural or urban areas. These benefits include improved air and water quality, increased soil water retention, reduced erosion, improved biodiversity, and enhanced plant productivity. Targeted investments in these practices could also help position Washington as a leader in promoting economic growth via environmental stewardship.

II. Organic and Climate-Smart Agriculture



Sunflowers as cover crops on a wheat field in Douglas County
(photo by Chelsea Trout)

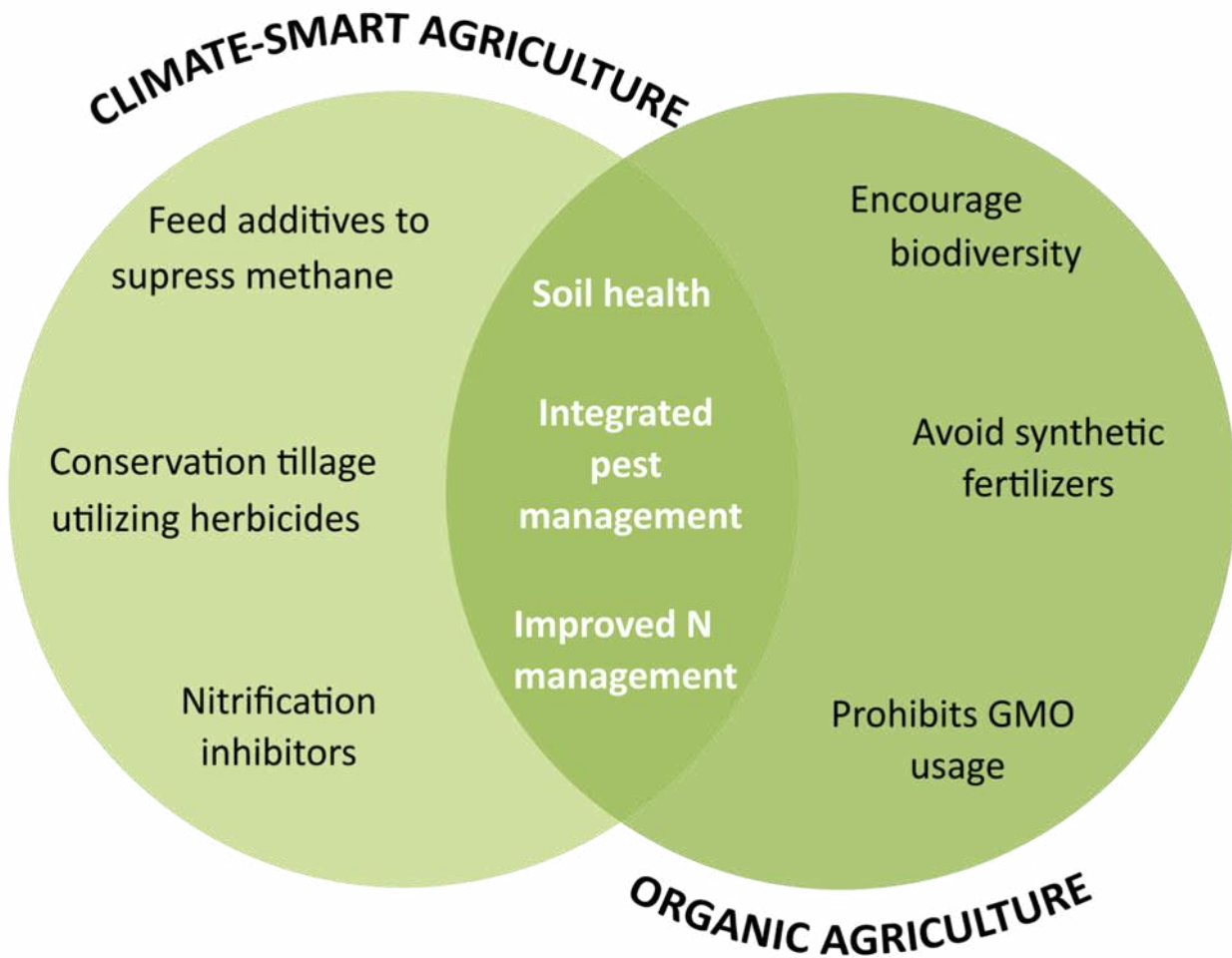
Organic agriculture, as defined under the National Organic Program (NOP) standards, is a holistic production system that integrates cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity. The USDA oversees the National Organic Program, providing the regulatory structure and guidance that defines organic agriculture in the United States. By prioritizing sustainability and environmental health, organic agriculture strives to foster a resilient and regenerative approach to food production.

Climate-smart agriculture is “an integrated approach that enables farmers, ranchers,

and forest landowners to respond to climate change by reducing or removing greenhouse gas emissions (mitigation) and adapting and building resilience (adaptation), while sustainably increasing agricultural productivity and incomes” (USDA, 2023). This concept, first defined by the United Nations Food and Agriculture Organization around the three pillars of adaptation, mitigation and productivity (FAO, 2013; Lipper et al., 2014), has garnered increasing attention in the United States as a way of addressing the climate challenge while building resilience and providing strong co-benefits to both agriculture and the public.

Many organic practices, including cover cropping, crop rotations, and organic amendments, are also key climate-smart agricultural practices in that they reduce reliance on fossil-fuel intensive inputs, and build soil organic carbon. However, there is ongoing discussion about whether all organic practices are climate-smart, and it is known that not all climate-smart practices are organic ([Figure 2](#)). There is significant overlap, but organic systems avoid some methods and materials that may be used in climate-smart agriculture, and some climate-smart practices, such as feed additives, are not a particular focus of organic systems. Important areas of overlap include emphasizing practices that build soil health, promote nutrient cycling and non-chemical nitrogen sources, and integrated pest management.

Figure 2: Not all climate-smart practices are organic, and there are organic practices that are not specifically climate-smart, though there are many areas of overlap.



Note: The practices in this figure are illustrative examples rather than a comprehensive list.

Most climate-smart practices have already been recognized by Natural Resources Conservation Service (NRCS) or others as aligning with previously defined conservation practice standards ([Table 1](#)) that achieve a variety of beneficial outcomes for soil health and nutrient management.

Unlike organic agriculture, climate-smart agriculture is not regulated by a governing body, nor does it prescribe what materials and inputs can be used. Instead, it provides a framework that farmers can use as a flexible guide toward climate-resilient practices. According to agriculture stakeholders in Washington, the most widely adopted climate-smart practices in the state are no-till and direct seed/reduced till, waste management and storage, cover crops, precision agriculture, and on-farm energy efficiency ([Appendix A](#)). However, the term “climate-smart agriculture” is not a common phrase among farmers who instead tend to use the term “conservation practices.”

Both organic and climate-smart agriculture also share some common goals with regenerative agriculture but emphasize slightly different aspects. Regenerative agriculture prioritizes restoring soil health and biodiversity, focusing on holistic practices that improve ecosystem functions and sequester carbon.

Table 1: List of NRCS climate-smart agricultural practices

Adapted from Perez et al. (2023) and updated with NRCS (2024)¹.

Management Areas	Description	NRCS Practices
Soil Health	Reducing carbon dioxide and nitrous oxide emissions from soils and enhancing soil carbon sequestration	Conservation cover (327), Conservation crop rotation (328), Residue and tillage management, No till and reduced till (329 and 345), Contour buffer strips (332), Soil carbon amendment (336), Cover crop (340), Field border (386), Filter strips (393), Grassed waterways (412), Mulching (484), Strip-cropping (585), Vegetative barriers (601), Herbaceous wind barriers (603), Saturated buffer (604)
Nitrogen Management	Reduce nitrous oxide emissions through the 4Rs of nitrogen management: Right source, Right rate, Rate time, Right place	Nutrient management (590)
Livestock	Reducing methane emissions from enteric emissions, and methane and/or nitrous oxide from manure	Composting facility (317), Waste storage facility (313), Anaerobic digester (366), Roofs and covers (367), Feed management (592), Waste separation facility (632)
Grazing and Pasture	Building soil carbon stocks in grazing systems	Brush management (314), Herbaceous weed treatment (315), Prescribed burning (338), Pasture and hay planting (512), Prescribed grazing (528), Range planting (550)
Agroforestry	Building carbon stocks in perennial biomass and soils	Alley cropping (311), Critical area planting (342), Forest farming (379), Windbreaks/shelterbelt establishment & removal (380), Silvopasture (381), Fuel break (383), Woody residue treatment (384), Riparian herbaceous cover (390), Riparian forest buffer (391), Wildlife habitat planting (420), Hedgerow planting (422), Tree/shrub establishment (612), Restoration of rare or declining natural communities (643), Forest stand improvement (666)

¹ <https://www.nrcs.usda.gov/sites/default/files/2023-10/NRCS-CSAF-Mitigation-Activities-List.pdf>

Restoration of disturbed lands	Increase soil and perennial biomass carbon stocks in previously mined or degraded lands.	Land reclamation, Landslide treatment (453), Land reclamation, abandoned mined land (543)
Energy, combustion and electricity efficiency	Reducing emissions from agricultural operations and infrastructure through energy and fuel efficiency and system and operational improvements	Combustion system improvement (372), Energy efficient agricultural operation (374), Irrigation pipeline (430), Irrigation system, micro irrigation (441), Sprinkler system (442), Pumping plant (533), Energy efficient building envelope (672), Energy efficient lighting systems (670)
Wetlands	Enhance carbon storage in soils and vegetation through wetland restoration.	Wetland restoration (657)

Each of these terms not only serves to describe the motivation behind particular practices, they are also meaningful to food purchasers and consumers. As such, they have played a role in catalyzing innovation to meet consumer preferences for certain attributes related to agricultural practices. Given that agricultural producers lack pricing power in conventional agricultural systems, they have a strong financial incentive to reduce costs. Minimizing costs has been one driver of farm consolidation over the last several decades, and often results in growers adopting the same, or very similar, production practices. This efficiency usually comes at the expense of resilience to external shocks, leaving farm businesses with little financial room to change directions or invest when conditions change.

In the midst of these economic forces that have tended to make farms larger and more similar to each other, organic agriculture has introduced or revitalized several production practices to build soil health, reduce reliance on fossil-fuel derived inputs, and encourage natural control of pests. The incentives for this arose from needing to meet organic standards, and from higher prices that consumers have been willing to pay. However, these practices have been available for all farmers, and can be seen as diversifying the toolbox of potential practices for all agricultural producers. Thus, among the benefits of organic systems is that they have served as an impetus for the development or re-development of management practices that are now being valued for their climate friendly attributes.

Integrated Pest Management (IPM) serves as one example in which iterative interactions and feedback between organic and conventional agricultural systems have benefitted both. Organic pest management systems and IPM use some of the same practices, as both emphasize the use of biological control, including natural enemies like parasitoids and predators, cultural practices such as crop rotation and habitat management to promote biodiversity, and a focus on non-chemical tools like pheromones, traps, and resistant crop varieties. And yet there are some distinctions; while organic farming strictly prohibits synthetic pesticides, IPM integrates limited chemical solutions while ensuring that pest control aligns with ecological principles (Baker et al., 2020). Both IPM and organic pest management have been shown to be effective at managing pests in organic orchards (Shaw, 2021) including in Washington apple and pear production (Jones et al., 2016; DuPont et al., 2021).



Soil-health promoting practices that are climate smart have also been developed within conventional agricultural systems and then adapted for use in organic farming. For example, systems to minimize or eliminate tillage in order to conserve soil carbon have been adopted within conventional dryland systems of the Pacific Northwest (Gray et al., 2015); these methods have been adapted for conventional irrigated cropping systems, where the amount of residue is much higher, necessitating different management (McGuire, 2014a; McGuire, 2014b; McGuire, 2014c; Grant County Extension, 2021). Reduced till and no-till are also being adapted for use within organic systems, with additional adaptations needed to suppress weeds without relying on herbicides that are not allowed in organic systems (Luna et al., 2012; Wayman et al., 2014; Wayman et al., 2015).

Given these examples, both organic and climate-smart practices can be seen as systems that catalyze innovation that can be beneficial to the entire sector, although practices must be adapted to fit within each of Washington's diverse agricultural production systems, and not all practices are appropriate for all farms.

III. Greenhouse Gas Accounting & Agricultural Emissions

According to the greenhouse gas inventory of Washington State², the agricultural sector produced 6.6 million metric tons of carbon dioxide equivalent (MMT CO₂e) greenhouse gas emissions in 2021, accounting for 6.9% of the state's total emissions (WA Department of Ecology, 2025). Following the methodology used by the U.S. Environmental Protection Agency (EPA), these emissions account for three agricultural activities: nitrous oxide emissions associated with agricultural soils (2.0% of all emissions), digestion of ruminant livestock (also known as enteric fermentation, 3.1%), and emissions relating to manure management (1.7%). Activities under these broad categories release greenhouse gases, primarily methane (CH₄) and nitrous oxide (N₂O),

² The latest inventory, published in January 2025, covers emissions for the period of 1990-2021 and is available here <https://apps.ecology.wa.gov/publications/documents/2414077.pdf>

both of which are much more potent than carbon dioxide (CO₂).³ Global warming potentials (GWP) are multipliers that estimate the warming impact on the basis of carbon dioxide: methane has a GWP of around 28 – meaning it traps 28 times more heat than CO₂ over a 100-year period – and nitrous oxide has a GWP of 273 (IPCC, 2023). These factors would change if one was to change the period; since methane has a lifespan of only around 12 years, its global warming potential over a 20-year period (GWP20) is much larger at around 80 (IPCC, 2023), and would be smaller if a timeframe longer than 100 years was considered. Across all economic sectors in the US, agriculture is responsible for almost 80% of all nitrous oxide emissions, and 40% of methane emissions (see Figure 3), underscoring the importance of finding solutions within the agricultural sector.

Figure 3: Share of methane and nitrous oxide emissions by sector, in 2020



Retrieved from Boston Consulting Group (2022) and used with permission of the Walton Family Foundation.

Emissions associated with soil management practices primarily take the form of nitrous oxide. Nitrous oxide is naturally produced in soils through the microbial processes of nitrification and denitrification that is driven by the availability of the element nitrogen (N). Several agricultural activities increase nitrogen availability in soils that lead to direct nitrous oxide emissions at the site of the activity, the most significant being the application of nitrogen fertilizers and the natural decomposition of manure from livestock deposited on croplands and grazing lands.

Both enteric fermentation and manure management primarily generate methane. The larger contributor of the two is enteric fermentation, which occurs during the digestive process in cattle and sheep. As the bacteria in these animals' guts work to process grass and other recalcitrant plant material, they release methane. Meanwhile, emissions from manure management are mostly driven by specific manure handling systems used in dairy cattle and swine operations (the latter having little presence in Washington). Anaerobic storage of manure tends to favor the release of methane, while aerobic storage tends to favor nitrous oxide emissions. Contributions from dairy and cattle operations dominate Washington's manure management emissions, due to the quantity of manure, cattle's larger size and longer lifespan.

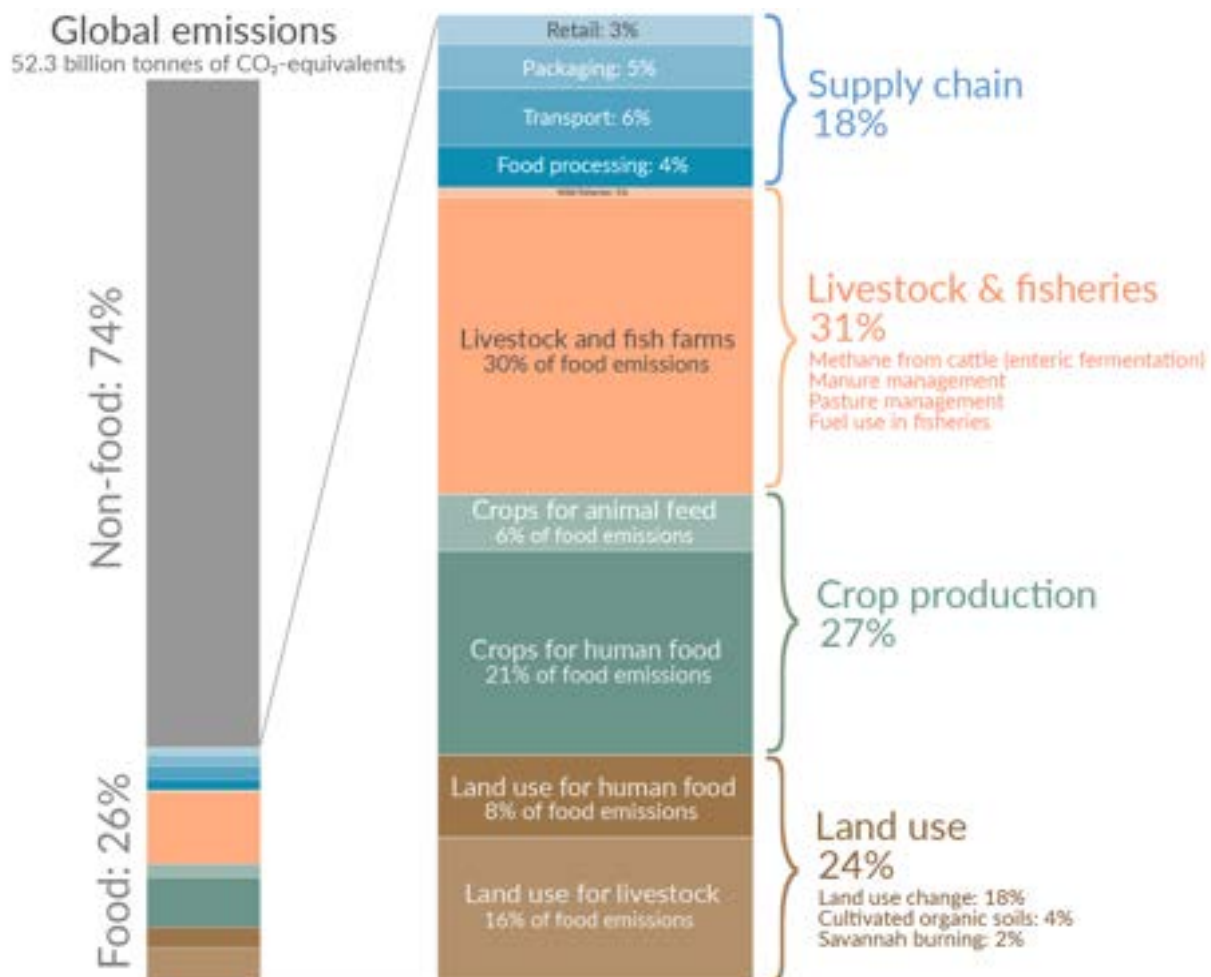
While emissions from enteric fermentation have been relatively stable since 1990 in Washington, contributions from manure management have increased (from 0.9 MMT CO₂e in 1990 to 1.6 MMT

³ Note that many carbon dioxide fluxes in agriculture, such as that from plant residues, or livestock respiration, represents short term fluxes that are not considered to have a warming impact. Since this carbon dioxide came recently from the atmosphere, was "fixed" by plants, and is then returned to the atmosphere after a brief time, it is generally not considered a net greenhouse gas impact.

CO₂e in 2021), and contributions by agricultural soils declined notably (from 3.4 MMT CO₂e in 1990 to 1.9 MMT CO₂e in 2021) (WA Department of Ecology, 2025). While the state inventory does not document reasons for these trends, emissions from manure management have increased across the U.S. primarily due to increasing use of liquid manure management systems alongside a shift toward larger dairy facilities (EPA, 2022). Liquid manure handling produces significantly more methane than dry manure handling systems. Meanwhile, the total amount of nitrogen fertilizers applied in Washington has declined roughly by a third in the last three decades, likely being the largest contributor to declining emissions from soil management.

Importantly, the state-level inventory captures only direct sectoral emissions from agriculture (those under the direct control of the farming sector) and does not consider fluxes in soil carbon or indirect emissions (those not under control of the agricultural sector but induced by farming activities). Taking a more systemic view, these figures contrast with widely published figures of the emission contributions of the entirety of the global food systems: the scientific community has accepted the latter to be in the range of 25-42% of all emissions (Crippa et al., 2021; Clark et al., 2020; Tubiello et al., 2021). An estimated breakdown is illustrated in Figure 4.

Figure 4: Breakdown of global food systems emissions



Produced by Our World In Data based on analysis from Poore and Nemecek (2018). Poore and Nemecek (2018) estimate the emissions contribution of food systems to be 26%, while this total has been corrected upwards in more recent analysis (Crippa et al., 2021; Clark et al., 2020; Tubiello et al., 2021).

Fundamentally, a large part of what explains this discrepancy is that *food systems* encompass more than just agricultural production. In these global accounting frameworks, 71% of the food systems emissions were associated with the combination of agriculture and associated land use and land-use change activities, putting their overall contribution to 18-29% of global emissions (Crippa et al., 2021), or to 14-18% of all emissions in the U.S.⁴ However, this does not warrant ignoring the aspects of the food system that happen off farm. Importantly, the overall share of food systems emissions has been increasing in North America, but this trend is almost entirely driven by pre- and post-processing activities (food processing, transportation, retail, waste, etc.) as emissions associated with these activities have almost doubled since 1990 (Tubiello et al., 2022). Figure 5 shows how the system-level emissions map to emissions within the framework that the Washington state level inventory uses.

Figure 5: Food systems activities, greenhouse gases they release, and mapping to the categories of the different accounting frameworks, including Washington state's emissions inventory

IPCC		Food systems activity	GHG			FAO			WA inventory				
			CH ₄	N ₂ O	CO ₂								
AFOLU	LAND-USE CHANGE	Net forest conversion	X	X	X	LAND USE CHANGE	AGRICULTURAL LAND	FOOD SYSTEMS	Natural & Working Lands				
		Peat fires	X		X								
		Drained organic soils	X		X								
	AGRICULTURE	Crop residue burning	X	X		FARM GATE			AGRICULTURAL LAND	FOOD SYSTEMS	Agriculture		
		Crop residues		X									
		Drained organic soils		X									
		Enteric fermentation	X										
		Manure management	X	X									
		Manure applied to soils		X									
		Manure left on pasture		X									
		Synthetic fertilizers		X									
		Urea and lime applications			X								
		On-farm energy use	X	X	X								
		ENERGY	Transport	X	X						X	PRE- AND POST-PRODUCTION	AGRICULTURAL LAND
Processing	X		X	X									
Packaging	X		X	X									
Fertilizer manufacturing	X		X	X									
Household consumption	X		X	X									
Retail energy use	X		X	X									
Retail refrigeration	X		X	X									
WASTE	Solid food waste	X			PRE- AND POST-PRODUCTION	AGRICULTURAL LAND			FOOD SYSTEMS	Waste management			
	Incineration			X									
	Industrial wastewater	X	X										
	Domestic wastewater	X	X										

AFOLU stands for agriculture, forestry and land use; IPCC is the Intergovernmental Panel on Climate Change and FAO is the United Nations Food and Agriculture Organization. Adapted from Tubiello et al. (2022).

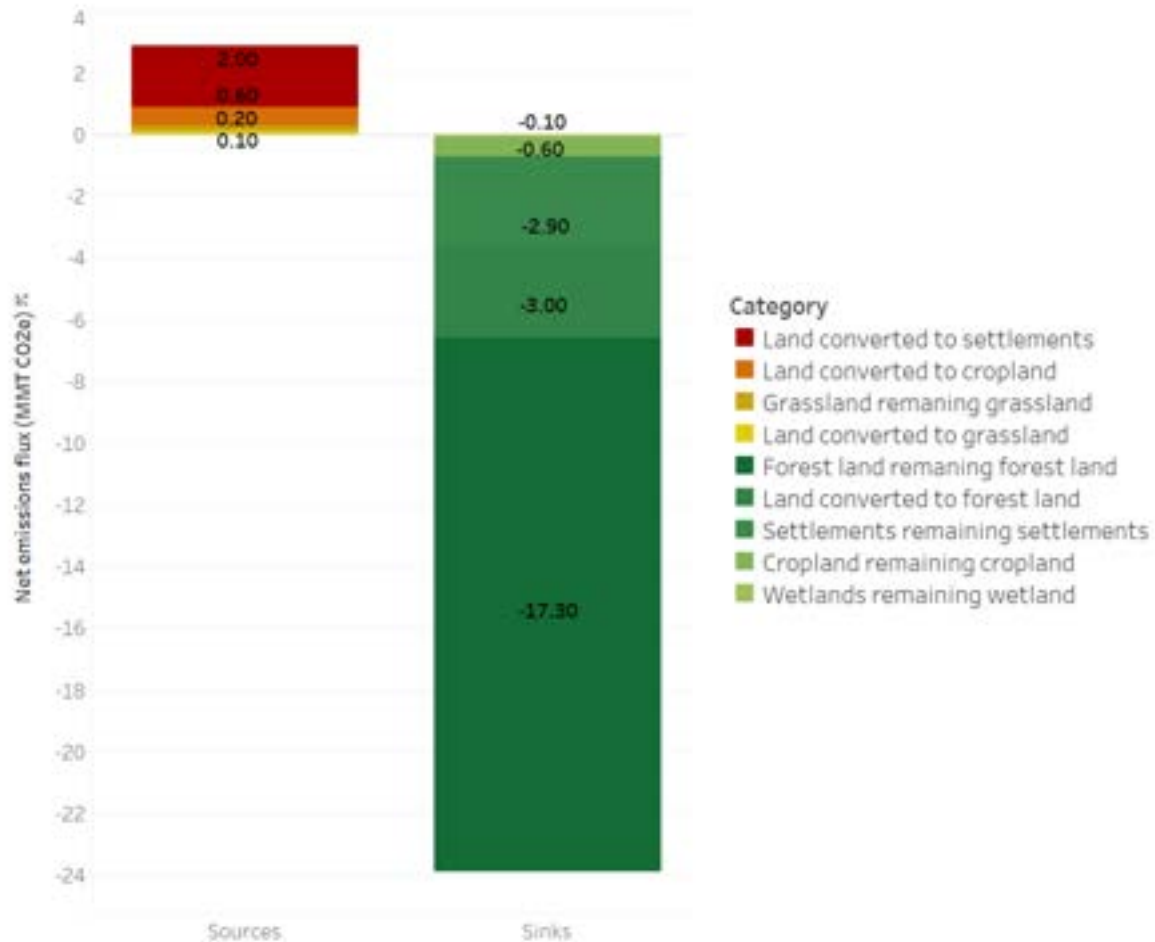
⁴ Relative (but not absolute) contributions of emissions from agriculture are smaller in industrialized nations.

There are also a number of specific methodological differences illustrated in Figure 5 that are worth noting. First, the current state-level emissions accounting categorizes any fuel and energy use by agriculture under the transportation, electricity and commercial/residential sectors. Energy and fuel use is mostly associated with carbon dioxide emissions (as opposed to CH₄ and N₂O), and this methodology results in lower CO₂ emissions attributed to agriculture. Nation-wide, on-farm energy use accounted for 0.8% of all emissions and on-farm electricity use for 0.5% (adding an additional 7% to agricultural sector's emissions between the two categories) (EPA, 2022). Direct energy use – on-farm diesel (44% of direct use), electricity (24%), gasoline, propane, natural gas as well as renewable energy use – accounts for an estimated 60% of agriculture's energy consumption nation-wide. Indirect energy use, linked to manufacturing of products and equipment used on-farm, accounts for the other 40% (Hitaj and Suttles, 2016; Matlock et al., 2023). Reducing fossil fuel demands for producing crops requires a strategy that prioritizes mitigating the highest energy demands: direct fuel, fertilizers, and pumping associated with irrigation water (Hatfield et al., 2023).

Second, land use, land use change and forestry (LULUCF) is an emissions accounting category that is incorporated in global estimates by IPCC and other sources. Note that this category includes not only agricultural lands, but also forestry and any changes in land use: for example, increasing use of corn for biofuels drives increased emissions as grassland gets converted to cropland (Lark et al., 2015). In many regions, LULUCF is a net source of emissions due to the large contributions of land clearance for agriculture and other purposes, whereas in Washington and in the U.S. more broadly, land use, land use change, and forestry *overall* have most often been a net sink (meaning that they absorb carbon), driven largely by carbon sequestration in forests.⁵ However, with more prevalent wildfires, land conversion, forests' pest infestations, and other disturbances largely driven by climate change and human activity, this is often not the case anymore; in California, for example, natural and working lands are now a net source of emissions (CARB, 2018; 2022). As to agricultural land use, historically agricultural use has resulted in carbon losses across much of the U.S., including in many areas of Washington (Flach et al., 1997; Paustian et al., 1997; Lal, 2001; Franzleubbers and Follett, 2005; Brown and Huggins, 2012). The Columbia Basin represents an important exception to this general trend, as irrigation brought higher levels of plant productivity to an arid area with low levels of plant growth and soil carbon (Cochran et al., 2007).

⁵ <https://www.wri.org/technical-perspectives/greenhouse-gas-emissions-natural-working-lands>

Figure 6: Natural and working lands emissions breakdown for 2019



Data from the Washington State Greenhouse Gas Inventory, 1990-2019 (Department of Ecology, 2022).

In terms of emissions accounting in Washington, the state level greenhouse gas inventory has a separate natural and working lands inventory that incorporates carbon sources, sinks, and fluxes from land use and land use change associated with forests, croplands, grasslands, wetlands and urban trees. In the latest inventory (from 2021), emissions from natural and working lands are estimated to be 19.3 MMT CO₂e, with removals estimated at 23.7 MMT CO₂e, for a net sink of 4.3 MMT CO₂e in 2021.⁶ The largest sink is the category of forest land remaining forest land, which is the primary driver for Washington's natural and working lands being a net sink overall. The largest source of emissions are forest fires that have converted natural and working lands into a net source of emissions in some recent years.

In terms of categories relevant to agriculture, the earlier inventory from 2019 indicates that cropland remaining cropland provides estimated net benefits of 0.6 MMT CO₂e via changes in soil carbon stocks, and land converted to cropland provides carbon emissions of equivalent magnitude

⁶ Note that this figure is drastically smaller from 2019, when natural and working lands made for a net sink of 20.6 MMT CO₂e (see [Figure 6](#)); the discrepancy is mostly driven by forest fires.



Cougar Creek fire (photo by Kaci Bartkowski)

(0.6 MMT CO₂e) (see [Figure 6](#)). While these two categories provide a net effect of zero, for rangelands, both categories result in small net emissions (of 0.2 and 0.1 MMT CO₂e, respectively).⁷ As discussed above, methane and nitrous oxide (as well as CO₂) are also produced by agricultural soils, but in the state inventory these emissions are classified under the agricultural sector. Finally, the current natural and working lands inventory relies primarily on national level methodology and comes with many uncertainties; for this and other reasons, these estimates are not yet incorporated into the main inventory.

The third major discrepancy is that waste management is a food systems process that is often accounted for in global accounting frameworks but is not part of the state-level inventory. Across industrialized nations, waste related to both food production and retail is responsible for almost 15% of all food systems emissions (Crippa et al., 2021), and in the U.S. it makes up 4% of all emissions (ReFED, 2021). See a more detailed discussion on food waste in [Section III.II](#).

Fourth, production of fertilizers and other important agricultural inputs happens mostly elsewhere. Producing ammonia for fertilizers using the Haber-Bosch

process requires a large amount of energy. Globally, the supply chain of synthetic nitrogen fertilizer is responsible for 10.6% of agricultural emissions. Producing fertilizers accounts for 39% of this footprint and transporting them for 3% (with the remaining 58% coming from the application of fertilizers, which is accounted for in the state-level agricultural emissions under soil management emissions) (Menegat et al., 2022). In terms of specific crops, a life cycle assessment estimates the relative greenhouse gas contribution of fertilizer production to represent 5-11% of the total energy use by apple orchards, for example (Mila i Canals et al., 2006).

Some of these differences arise from the state-level inventory being sector-based, as opposed to consumption-based. In contrast to the sector-based model, the consumption-based inventory

⁷ These figures are retrieved from the previous state inventory for 1990-2019, as the latest inventory does not cover natural and working lands emissions in the same level of detail.

accounts for the emissions associated with everything that people in a state (or other geographic unit) consume, regardless of where it is produced. Currently, the Solid Waste Management program of the Department of Ecology is developing a consumption-based emissions inventory for Washington (Pfeiffer, personal communication). The state of Oregon published a similar inventory in 2021, and it shows how, first, adding consumption-based accounting arrives at total state emissions that are almost two times higher than those of a sector-based approach, in line with a large share of consumable goods being produced elsewhere.⁸ For the consumption-based inventory, food and beverages are the second highest emitting category with 15% of total consumption-based emissions, or 14.6 MMT CO₂e (compare that to 5.4 MMT CO₂e attributed to agriculture in the sector-based inventory of Oregon). Of these emissions associated with food and beverages, only 2.2 MMT CO₂e occurred in Oregon (i.e., the associated product was produced and not just consumed in Oregon); the rest happened in other states (9.1 MMT CO₂e) or foreign countries (3.3 MMT CO₂e). On household level, food and beverages are similarly the second largest emissions category, responsible for almost as much emissions as the first category, vehicles and parts. These estimates from Oregon underscore the importance of holistic solutions to emissions reductions through food and agriculture, as agricultural production that happens elsewhere still results in emissions, even if not captured in the statewide inventory (also see [Section III.I](#)). By the same token, there are large potential reductions to be achieved via consumption-targeted interventions (see [Section III.II](#)).

As a final note on emissions accounting, it is important to acknowledge that the current state emissions inventory relies on the agriculture module and the natural and working lands module of EPA's State Inventory Tool (SIT) to calculate the respective emissions. The tool requires certain state-specific inputs, such as animal counts, volatile solids production, typical animal mass, total crop production and fertilizer use.⁹ Many inputs to the formulas, however, are set constant at the national level, and there is also an option to use default data in place of state-specific information. For the natural and working lands inventory, data on land-based emissions and removals is often not available at the state level, so SIT has relied on older and less accurate data to fill gaps.¹⁰ These factors mean that many management changes made at the farm-level may not be reflected as changes (reductions) in the state emissions inventory. For example, total acreage that is cover cropped is not an input to the current accounting methodology, and therefore any changes to emissions resulting from wider adoption of cover crops would currently not appear in the state inventory.

For agricultural management changes to support the state's climate mitigation goals, it is therefore also important to ensure that the emissions accounting systems evolve towards incorporating state-specific land management decisions that have greenhouse gas emissions implications. Importantly, the burden of these refinements should not fall on producers; the starting point should rather be incorporating existing state-level data, and fostering intra-agency coordination between different agencies and departments involved in record-keeping.

⁸ Oregon's total emissions from a sector-based inventory were 61.4 MMT CO₂e and from a consumption-based inventory 95.6 MMT CO₂e. Since some of these emissions overlap (e.g. electricity production and use in-state, vehicle and appliance use by households), the total emissions from the two categories, accounting for overlap, were 119.9 MMT CO₂e.

⁹ https://www.epa.gov/system/files/documents/2025-01/ag-module-users-guide_508.pdf

¹⁰ <https://www.wri.org/technical-perspectives/greenhouse-gas-emissions-natural-working-lands>

Addressing climate change through agriculture also requires a nuanced understanding of particular practices' impacts and trade-offs, within and across Washington's diverse agricultural systems. This includes the fact that a single change in management can have impacts on multiple greenhouse gas emissions. Given that agricultural systems are open, complex, biological systems, it is also true that a single change in management often has complex and cascading additional changes. Understanding is still evolving with respect to understanding the impacts of a particular change in management on greenhouse gas emissions overall.

For example, altering farming practices can simultaneously affect carbon sequestration, methane, and nitrous oxide emissions. Since each of these gases has impacts on the climate, this necessitates a comprehensive evaluation of their net effects on greenhouse gases. The impact of a particular practice on soil carbon sequestration, a cornerstone of many climate mitigation strategies, is variable depending on soils, climate, initial soil carbon levels, and other factors. When soil carbon is built, practices generally must be sustained over time to remain effective. Soil measurement depth is another critical factor, as most studies have focused on the top 30 cm of soil, whereas recent efforts emphasize assessing impacts across the entire soil depth profile. Additionally, uncertainties surrounding changing climate conditions, such as shifting weather patterns, pest pressures, and soil carbon dynamics, must be considered to ensure the long-term viability of these practices.



Onion seedlings in between residues of a wheat cover crop in Grant County (photo by Andrew McGuire)

Section II. Mitigation Potential of On-Farm Agricultural Practices in Washington

If financial, operational, technical, and other barriers can be overcome, voluntary actions by farm businesses across Washington could play a critical role in helping the state to meet its climate goals. Although it is not possible with current knowledge and tools to provide a single number summarizing the cumulative mitigation potential for specific agricultural practices that could be implemented across Washington's diverse agricultural systems, it is very possible to point to actions that are most likely to generate important contributions to this effort. This section summarizes those insights and where available, we point to Washington-specific or Pacific Northwest specific data.

This section should be interpreted in light of the information in [Box 2](#) (and the additional detail provided in [Appendix C](#)), which summarizes the scientific approaches that can be used to estimate mitigation impacts of management practices in agriculture, and describes ongoing scientific developments. It should also be interpreted in light of partners' and stakeholders' perspectives relating to these practices, and the barriers to implementing climate-smart (or conservation) practices and how the state can help remove those barriers. These stakeholder perspectives are summarized briefly in [Section III.IV](#) and more comprehensively in [Appendix A](#).

Agricultural systems, along with forestry and other working lands, are unique in that they can contribute to climate change mitigation in multiple ways (Nabuurs et al., 2022), whereas most sectors can only contribute by reducing their own emissions:

1. Carbon sequestration: Protecting carbon that is stored in soils, and where possible, removing carbon from the atmosphere and storing it in soils and vegetative planting.
2. Reducing emissions that are generated within the sector.
3. Bioenergy and bioproducts production: Providing raw materials that are used within the energy, industrial, and other sectors to mitigate emissions.

If implemented appropriately, these voluntary mitigation practices in agriculture can reduce emissions and sequester carbon over the coming decades, while also providing substantial other public benefits. These well-documented public benefits, coming primarily from soil health and nutrient management strategies, include contributions to preserving biodiversity, reduced erosion, improved air and water quality, improved soil water retention, increased microbial activity, improved nutrient cycling, enhanced productivity and food production, and even the potential for improvements in human health through the production of more nutritious foods (e.g. Brevik and Burgess, 2013; Brown et al., 2011; Cogger et al., 2013; Johnston, 1986; Reeve et al., 2012; Sharratt et al., 2016; Sharratt et al., 2018; Wuest et al., 2005).

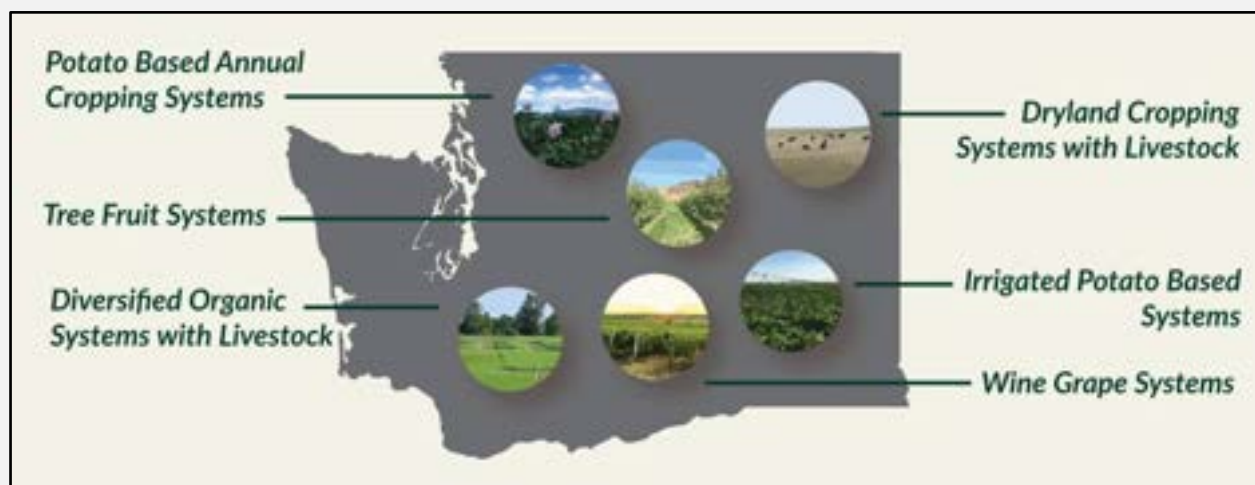
These strategies can also enhance the resilience of working lands and food security to climate change impacts (Bagnall et al., 2022), though improvements should not be treated as a blanket

panacea. For example, research across the United States has found examples in which organic farms have outperformed their conventional counterparts under drought conditions, due to higher water holding capacity in their soils (Reganold and Wachter, 2016). Implementing no-till practices in the Palouse watershed could similarly reduce erosion, increase soil organic carbon and therefore increase water holding capacity (Davis et al., 2023), which could improve yield stability during dry years given that water availability is the major limitation to yields in these rainfed systems. However, practices may also have tradeoffs that need to be managed, for example, no-till can accelerate soil acidification and negatively affect this aspect of ecosystem resilience (Davis et al., 2023). Thus, there is an ongoing need to develop site-specific information about the particular agricultural systems and situation(s) in which specific strategies can enhance resilience, and the limits of such strategies.

Box 2. Summary of the scientific process behind estimating climate mitigation potential of agricultural management practices

Continued scientific work towards more realistic estimates of the climate impact from particular management practices is vital. Agricultural stakeholders in Washington have expressed that high quality research to define baselines and evaluate the effectiveness of climate-smart practices over the long term are necessary. Modeling and meta-analysis approaches -- the two most used strategies for these estimates -- rely on relevant long-term data. The Washington Soil Health Initiative (WaSHI) has established long-term agroecological research sites in a range of cropping systems relevant to Washington agriculture from dryland wheat-based systems to diversified organic systems (Figure 7), across the state between 2020 and 2023. One of these sites specifically focuses on organic mixed vegetable systems. These sites will complement existing long-term agro-ecological research sites in the region: the Cook Farm long term research site (dryland wheat-based systems with higher rainfall) and some additional sites in Oregon and Idaho (mostly dryland wheat).

Figure 7: Long-term agroecological research and extension sites that are part of the Washington Soil Health Initiative (WaSHI)



As the research progresses, these sites will expand our ability to understand soil carbon dynamics and a host of other factors (Figure 8), though with two important limitations. First, none of these systems focus on dairy or rangeland systems. Second, nitrous oxide emissions (also important for understanding the climate impact of cropping systems) are not being measured

due to funding limitations, though the sites are continuing to seek funding to add this instrumentation. (Note that nitrous oxide emissions can be challenging and relatively expensive to measure.)

Long-term datasets are used in meta-analyses, a statistical method that combines data from multiple studies on the same subject to draw conclusions. In the Northwest, only dryland wheat systems have adequate long-term datasets for a meta-analysis to estimate soil carbon storage from specific practice changes. Brown and Huggins (2012) determined that mean changes in soil organic carbon were 0.09 Mg C/ac/yr for a change to no-till in the transitional zone (analogous to the intermediate-rainfall zone), 0.29 Mg C/ac/yr for a change to no-till in the annual cropping zone (analogous to the high rainfall zone), and 0.42 Mg C/ac/yr for mixed perennial-annual systems in the annual cropping zone (a fuller description of results is provided in [Table C2, Appendix C](#)).

Figure 8: Summary of experimental measurements on long-term agroecological research and extension sites that are part of the Washington Soil Health Initiative



Modeling approaches to estimating soil organic carbon have generally used biogeochemical models. These models synthesize the empirical understanding of processes that govern the flow of energy, carbon, and nutrients through the agroecosystem. Modeling approaches generally come with a tradeoff between complexity and usability (Ball et al., 2023). A more complex model will offer more precise site-specific emissions simulations and predictions but is often more expensive and time consuming than models that require low amounts of input data but will be more economical and efficient. Models rely on existing experimental measurements to evaluate their ability to represent real-life conditions. Improvements to models also require field-scale, spatiotemporally explicit information about agricultural practices. For example, ongoing work to classify regional scale tillage practices in eastern Washington through model development with satellite imagery is under development (Kandelate et al., submitted).

Continued experiments and scientific estimates will yield data that can support better statewide and regional estimates of the impacts of particular management practices on long-term soil organic carbon and methane and nitrous oxide emissions in agricultural soils. For further information, see [Appendix C](#).

I. Mitigation Approach 1: Protecting and Storing Carbon on Agricultural Land

The promise of carbon sequestration within working lands has been discussed in recent years. It provides a unique opportunity for climate change mitigation, as meaningful quantities of carbon can be removed from the atmosphere at relatively low costs (Almarez et al., 2023; Nabuurs et al., 2022). Each metric ton of carbon stored in soils removes 3.67 metric tons of carbon dioxide from the atmosphere (Flynn et al., 2010). While storing *additional* carbon is needed to provide climate mitigation, agriculture also has an important role to play in protecting the carbon which has *already been stored* in our working lands. These are two different aspects of the same topic, and both are critically important for the state to achieve its climate mitigation goals by 2050.

This section covers specific agricultural strategies that *primarily* protect or store carbon, keeping in mind that these same practices may impact emissions of methane and nitrous oxide at the same time. In some cases, reductions in the use of greenhouse gas-intensive inputs, such as chemical fertilizers, may also be achieved.

I. Farmland Preservation as a Core Climate Change Mitigation Strategy

When considering agriculture's potential to mitigate climate change, there are multiple reasons to pay attention to the loss of farmland, and especially agricultural land being converted to urban or low-density residential land use. Agricultural stakeholders, interested tribes, and government agency representatives in Washington have pointed out that climate-smart approaches should lead with keeping farmland in production ([Appendix A](#)).

Land-based climate mitigation measures are unique in that they can deliver carbon dioxide removal and provide substitutes to fossil fuels while producing food and fiber. And potential benefits associated with climate-smart and/or organic practices are most often expressed with respect to medium- or long-term time horizons. That is, the underlying assumption is that the land to which practices are applied stays in agricultural use. If agricultural lands are instead converted to other uses, carbon stored in the land is most likely re-released in the process and additional carbon will not be sequestered going forward. Furthermore, additional pressure is then put on the remaining acres to be farmed more intensively, potentially limiting sustainable management options. In other words, the benefits of climate-smart and organic agriculture are temporary unless the land they are applied to remains in agriculture.

Protecting farmland can also go hand-in-hand with limiting urban sprawl, a strategy that limits greenhouse gas emissions from transportation and development of infrastructure and housing. Urban sprawl is a leading cause of loss of farmland in the United States (Hunter et al., 2022), often consuming lands with high quality soils and abundant water supply due to their proximity to existing towns and cities (Jackson et al., 2012).

In Washington, developed land increased by 15% between 1997 and 2015, while 640,000 acres of farmland was lost in 2002-2017¹¹ (USDA, 2017). In the years 2017-2022 alone, the number of

¹¹ The losses did not happen universally across the state, as Skagit County, for example, saw a 2% increase in farmland. This was driven by targeted programming aimed at protecting farmland (Simonelli, January 2025).

farms dropped by 10.4%, or by 3,700 farms (Xie et al., 2023). For small farms of 10 acres or less, the share lost was nearly double that rate. The American Farmland Trust has modeled different scenarios of land use change by 2040, and while the outlook for Washington is better than for most other parts of the country, 0.8-1.5% of all farmland is still projected to be lost to development.

The reason that these developments matter from a climate change mitigation perspective is that conversion of farmland is generally associated with large increases in net greenhouse gas emissions. The respective estimates for Washington have not been produced yet, but several studies from California have looked at the relative emission intensity of urban or residential land compared to farmland and estimated that one acre of urban land is associated with 58-77 times higher emissions than one acre of farmland (Haden et al., 2013; Shaffer, 2016; Shaffer and Thompson, 2015). Specifically, the average emission intensity of California's top seven crops is 0.89 MT CO₂e/acre/year, while for 13 major cities it is 51 MT CO₂e/acre/year (Shaffer and Thompson, 2015).

Nation-wide, urban land grew by 1.36 million acres annually between 1982 and 2012 and this rate of urban growth is expected to continue. Studies have produced sizable estimates for how much additional carbon storage could be achieved just by limiting urban growth. The predictions by the U.S. Department of Agriculture show that if a 20% reduction in urban growth over the next 30 years was achieved, it would provide additional carbon storage of about 40 MMT CO₂e per year through 2050 (The White House, 2016). In Santa Clara County, one of the most productive agricultural areas of California, each 1,000 acres of farmland preserved (as opposed to being converted to urban use) is equivalent to annual greenhouse gas savings of taking 13,400 cars off the road (Shaffer, 2016).



Peri-urban farming at the Heritage Farm in Clark County (photo by Justin O'Dea)

This all suggests that land-use policies that aim to protect existing farmland from urban development can contribute to mitigating future emissions, particularly if they are aimed towards “smart growth” that prioritizes urban infill over expansion in form of low-density residential development, which is associated with the highest relative emissions (Jackson et al., 2012; Norman et al., 2006). Meanwhile, the concept of mitigating emissions via farmland preservation is likely to win support among rural stakeholders with long-term intentions to remain in farming, ranching, and related industries (Jackson et al., 2012).

There are many tools available to conserve farmland: strong agricultural zoning laws, conservation easements and land preservation programs, land use policies that incentivize and encourage retention of agricultural lands, well-defined urban growth and urban service boundaries, and municipal policies emphasizing infill development, to name a few (Brillinger et al., 2013; FPF, 2022; Jackson et al., 2012). The Washington State Food Policy Forum recommends that government land use actions resulting in the loss of agricultural land are mitigated by conserving adjacent farmland that is comparable in size, soil quality, and agricultural value, as well as substantial increases to funding for permanent farmland protection (i.e., for purchases of development rights and agricultural conservation easements) (FPF, 2022).¹² In California, a portion of the cap-and-trade scheme revenues are directed to farmland conservation and there is a methodology to calculate the climate benefits associated with that protection (McGill et al., 2022). The Agricultural Land Protection Scorecard ranks Washington as the 10th state in terms of the strength of its policy response to loss of farmland (Freedgood et al., 2020); the state performs well in terms of land-use planning to manage growth, and property tax relief on agricultural land, but not so well with regard to programs to purchase agricultural conservation easements that permanently protect farmland and ranchland from non-farm development, for which Washington places in the bottom half of all states (Freedgood et al., 2020).

In addition to urban and suburban development, farmland is also increasingly converted to renewable energy facilities – particularly solar and wind infrastructure – and industrial uses such as data centers. The state’s decarbonization goals have led to wide interest in solar developments on farmland as it fits the needs of new solar sites (it is already cleared, graded, close to transmission lines, etc.), leading to wide resentment from farming communities and moratoriums on solar developments by several counties (Godwin, March 2020; Jacroux, Sept 2023). While leasing land for renewable energy generation can provide farmers with an additional revenue stream for 20-45 years, and under certain conditions can be done simultaneously with crop cultivation or livestock, there is currently not enough evidence on whether such land can be used for farming again once the renewable energy project is decommissioned (Hannum et al., 2022). The quality of soil may be irreparably damaged, and there are likely long-term effects on soil health – losses of carbon built up with minimal till or other practices, potential for erosion and soil compaction, and hindered drainage (Hannum et al., 2022). One study found that a revegetated solar farm site had significantly lower total soil carbon (38%) and nitrogen (50%) levels than a similarly vegetated, undisturbed grassland, as well as soil moisture that was still unevenly distributed seven years after removal of panels (Choi et al., 2020).

Smart Solar principles developed by American Farmland Trust require, first, that solar energy is developed on buildings and land not suitable for farming; in Washington, the Least-Conflict Solar

¹² The GHG Avoided Conversion Project has developed a calculator to estimate the amount of emissions avoided by placing a farm of certain size and characteristics under an agricultural conservation easement, assuming it leads to smart growth development elsewhere. <https://farmland.org/project/avoided-conversion/>

Siting process on the Columbia Plateau can be used to identify suitable sites (FPF, 2022). If solar is developed on farmland or ranchland, policies should protect soil health for the future and be developed with wide stakeholder engagement to reflect farmer interests. Importantly, with appropriate planning, agrivoltaic projects (agricultural dual-use systems or agrisolar) can sustain agricultural production underneath or between solar panels, and in some cases can even provide co-benefits in form of partial shade and protection from extreme heat and drought for plants and animals (see more in [Section II.II.IV](#)).



A Burned Area Emergency Response team member inspects burned soil after the Okanogan Complex fire in 2015 (photo by Andrew Phay)

II. Rangeland Preservation as a Climate Change Mitigation Strategy

Prioritizing the security of existing rangeland soil organic carbon is important due to the extent of rangelands (with pastures and rangelands covering roughly 10 million acres across the state) and the size of their soil organic carbon pool. The drivers of degradation in these systems, mainly invasion by annual grasses and wildfire, are active areas of study under a changing climate (Maxwell et al., 2024). However, existing studies suggest that the potential for loss of sequestered carbon from rangelands is orders of magnitude greater than the changes that grazing

management can achieve, so avoiding the degradation or conversion of rangelands should be the dominant approach to rangeland carbon sequestration for these lands (IWJV, 2021; Maxwell et al., 2024; O'Connor et al., 2024; Stanley et al., 2024; SRM, 2023;).

In Washington, rangelands are generally located east of the Cascade Mountains and typically have low annual precipitation (5 to 25 inches per year). Beef cow-calf operations are the most common livestock enterprise. These rangelands vary from grasslands to shrublands and are interspersed with a variety of riparian areas, both wetlands and streams. The main ecosystem type, historically, has been shrub steppe, particularly plant communities dominated by sagebrush (*Artemisia tridentata* spp).

Sagebrush steppe ecosystems have the greatest potential among rangelands to retain soil carbon. However, carbon stores are threatened by the invasion of cheatgrass and the associated

increased wildfire risk, known as the “grass-fire cycle.” Cheatgrass (*Bromus tectorum*) is an exotic, invasive annual grass that has been expanding its dominance of rangelands since its introduction to the western U.S. in 1928 (Mack, 1981). Cheatgrass greens up earlier in the spring than the native perennials, allowing it to have first access to moisture, nutrients and other resources. It then dries out earlier in the season, creating a continuous layer of fine fuels that burn easily and carry fire from one perennial plant to the next. These characteristics have contributed to increased severity of wildfire impacts on those perennials, as well as to larger and more frequent fires overall (Crist et al., 2023). Further, in many cases cheatgrass can dominate the vegetation after fire because it produces large numbers of seed and can outcompete perennial regrowth, creating an ecological cycle that converts diverse, patchy, perennial vegetation to a monoculture of continuous annual vegetation that cures early in the season (Crist et al., 2023; D’Antonio and Vitousek, 1992).

These shifts from diverse, deep-rooted perennials to shallow rooted annual grasslands dominated by cheatgrass and other exotic annuals change the soil carbon stock (Doherty et al., 2022). A study in sagebrush steppe systems in central Idaho and southeastern Oregon estimated the losses of total soil carbon from systems invaded by exotic annual grasses and wildfires, concluding that either of these disturbances led to a ~50% loss in soil carbon (Maxwell et al., 2024). These soil carbon losses are similar in magnitude to those caused by tillage or other deep soil disturbance



On grazed rangelands in Kittitas County, native bunchgrasses, low cheatgrass abundance, and little bare soil are indicators of a healthy plant community (photo by Tipton Hudson)

(Guo and Gifford, 2002). Given estimates of conversion rates of rangelands due to invasive annual grasses and wildfire across the western U.S. of close to 1 million acres per year, the authors estimate that losses on the order of 20 MMT C are already occurring yearly in rangeland soils (Doherty et al., 2022; Maxwell et al., 2024). Notably, Maxwell et al.'s (2024) estimates of loss of soil carbon were based on measurements to 100 cm depth. Their results contradict previous hypotheses that deeper soil carbon was likely more stable and therefore more secure than surface soil carbon (Maxwell et al., 2024).

Though such detailed estimates of soil carbon changes do not yet exist in Washington, some modeling efforts suggest that eastern Washington's shrub steppe could be more vulnerable to conversion to annual grasses than other parts of the western U.S. (Bradley et al., 2010). Low-elevation and low-precipitation sites (such as those in much of the Columbia Basin) have low resilience to disturbance and are easily converted to a degraded but stable state in response to wildfire (Chambers, 2014; Chambers et al., 2019). Similarly, a recent conservation strategy for sagebrush steppe that identified core, intact lands (i.e., lands that maintain their soil carbon pools) that should be protected did not identify any such core areas in eastern Washington (Doherty et al., 2022), suggesting these threats are likely already impacting Washington rangelands' soil carbon.

Fire suppression across western U.S. has increased shrub densities (Fuhlendorf et al., 2011). While this might seem to increase aboveground carbon storage, these shrubs have further exacerbated fire risk and the fire dynamics dominate, marking a major reduction in below-ground carbon storage as well as loss of the above ground shrub biomass through recurring wildfires.

These rangeland systems are semi-arid, and the low average precipitation is associated with low primary productivity, leading to relatively small carbon inputs to the system (e.g. 0.02-0.2 Mg C/ac; Schuman et al., 2002). The large carbon stocks in the soils of intact rangelands, therefore, are the result of centuries of carbon accumulation (Hemstrom et al., 2002). Based on these factors, it is expected that new carbon accumulation in rangelands' soils would likely be slow, and that additional carbon sequestration associated with management changes would be small.

There is also reason to be concerned that climate change could exacerbate losses in soil carbon in rangelands across Washington, though these effects are understudied. Higher temperatures are expected to lead to more drought, even without reduction in precipitation (Cook et al., 2018; Overpeck and Udall, 2020; Palmquist et al., 2016). Both current trends and modeling studies project increasing wildfire risk and occurrence, potentially feeding the annual grass-fire cycle. More large storm events are expected, which can increase the loss of soil through soil erosion, also losing soil organic carbon (SOC; Bachelet et al., 2004; Tan et al., 2015 as cited in IWJV, 2021).

Directing and limiting wildfire will be necessary to both prevent short-term carbon release and to reduce long-term carbon loss through plant community state shifts away from perennial grasses and shrubs. Though these are challenging to address, there have been some efforts on which the state could build, especially around the issue of mitigating fire risk in rangelands through existing frameworks for semi-arid ecosystem conservation, including (a) the Defend the Core Framework (Doherty et al., 2022), used by the Sage Grouse Initiative to prioritize management actions including fuels treatments and targeted grazing; (b) the use of Potential Operational Delineations to prioritize the placing of fuel breaks and other specific fuel reduction treatments (Wollstein et al., 2022); and (c) the Conservation Readiness Framework, an approach for identifying land areas where sociological factors support collaborative fire mitigation efforts (Wollstein et al., 2024).



Restored rangeland in Grant County (photo by Tom English)

III. Building Soil Carbon on Well-Managed Rangelands: Small Potential of Grazing Management and Restoration

Soil carbon in rangelands varies significantly in space, depth and time. This variability, combined with the methodological challenges involved in trying to effectively capture such heterogeneity, has made it hard to reach conclusions on the effects of grazing management on the accumulation of soil organic carbon in rangelands. Such efforts have highlighted the need to understand and consider the effect of environmental and biotic factors when quantifying how grazing management decisions help mitigate greenhouse gases and store soil carbon (McSherry and Ritchie, 2013).

Existing research, much of it more broadly evaluating western U.S. rangelands or even global rangelands, has found that the spatial and interannual variation in environmental factors, such as soils or precipitation and temperature, contribute more to changes in soil carbon than do grazing management changes (e.g., Booker et al., 2013; MacNeil et al., 2008; IWJV, 2021). There is also evidence of interactions, such as between grazing management and changes in carbon losses due to wildfire, for example. In sagebrush steppe in southeast Oregon, ungrazed areas saw significantly greater invasion by cheatgrass after prescribed fires (Davies et al., 2016; 2022), which, as described above, is associated with significant loss of soil carbon (Maxwell et al., 2024).

Within these broader constraints, some evidence exists to suggest that grazing management could affect soil carbon stocks. A synthesis of long-term studies of soil carbon response to management variables such as grazing showed that in wetter plant community types soil carbon tended to decrease slightly with grazing but that in drier plant communities (below 21 inches annual precipitation, such as occurs across much of the remaining rangelands in Washington) grazing tended to increase soil carbon (Sanderson et al., 2020). The increase from grazing is low but

averages 7% over ungrazed semi-arid soils. Conversely, extreme overgrazing can result in soil erosion, which diminishes the soil's capacity to store carbon (Derner et al., 2006).

Rangelands in eastern Washington also include diverse types of wetlands and riparian areas. Restoration efforts have been shown to increase SOC in wetlands and wet meadows (IWJV, 2021). These systems naturally store significantly more carbon than the drier, surrounding uplands (IWJV, 2021), and their restoration may also have a greater likelihood of success than in the uplands, where lack of sufficient precipitation is commonly an impediment to effective establishment of seeded species (Shriver et al., 2018; Svejcar et al., 2017). However, as with the uplands, protecting wetlands and their “native” soil carbon—including from the effects of overgrazing—may be more cost-effective than trying to restore degraded wetlands that have already lost significant soil carbon (IWJV, 2021).

Restoring degraded or previously cultivated lands to perennial vegetation, especially grasslands, may also sequester additional carbon (Milchunas and Vandever, 2013). Conant et al. (2017) synthesized findings of hundreds of studies looking at effects of management actions on carbon stocks in grasslands and rangelands, and estimated carbon increases of 39% when cropland was restored to grassland, and of 10% with improved grazing. This global meta-analysis, however, appears to include only one location in the Pacific Northwest, with the next closest ones being in the Southwest, so these quantitative estimates cannot be relied on to provide robust hypotheses of the expected magnitude of changes in soil carbon in response to restoration practices in Washington State.



Rotational grazing is used to support plant productivity and soil health in Spokane County (photo by Matt Ziegler)

IV. Building Soil Carbon on Croplands: Intensifying Crop Production, Reducing or Eliminating Tillage, Perennial Crops, Soil Amendments, and Reduced Burning

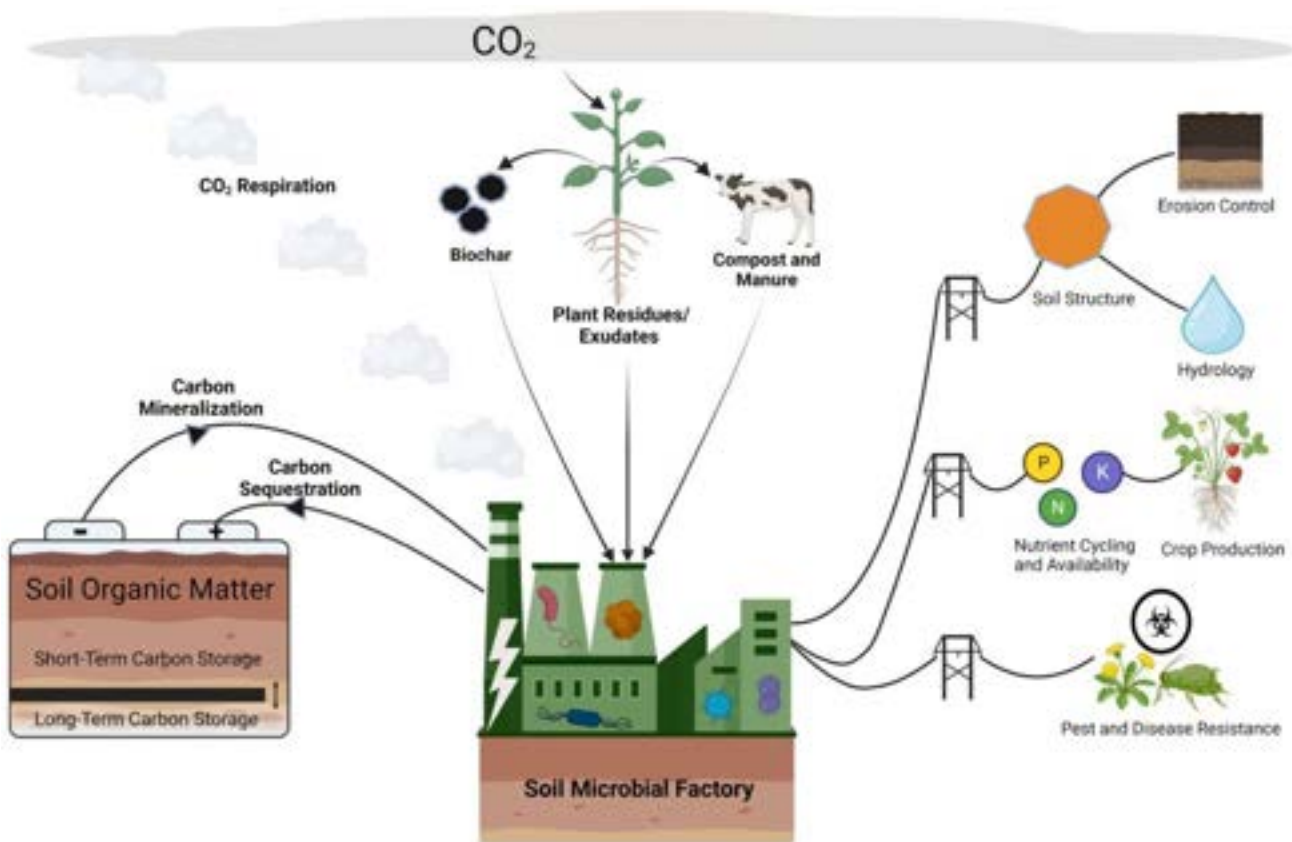
Existing data for Pacific Northwest cropping systems suggest that a number of long-established soil health practices that are relevant to both conventional and organic systems can provide modest, but real, contributions to new carbon sequestration. Practices for which we have regionally relevant data relating to carbon sequestration include intensifying crop production (through cover cropping, double cropping, eliminating fallow, crop rotation or other strategies), reduced or no-tillage, perennial crops, soil amendments, and reduced burning (Yorgey et al., 2023). In general, opportunities to build soil organic carbon are greater on a per acre basis in annually cropped systems with higher rainfall or irrigation, and therefore higher productivity.

[Appendix B](#) reproduces a table from the extension publication *Carbon Sequestration Potential in Cropland Soils in the Inland Pacific Northwest: Knowledge and Gaps*, Yorgey et al., 2023) that summarizes carbon sequestration data specific to dryland cropping systems of the inland Northwest, relevant to Washington's dryland wheat production systems. Fewer data are available for irrigated row crop systems of the inland Pacific Northwest and those available are summarized in Yorgey et al. (2023). The publication also provides additional important details about the science of soil carbon sequestration.

While available data show potential for these practices to store carbon in agricultural systems, it is important not to overestimate the contributions that could be made to climate mitigation from soil carbon sequestration. Within agricultural systems, atmospheric CO₂ is converted into soil organic matter (SOM) through processes driven by plants and microbes. When carbon is input into agricultural systems in the form of plant residues, microbial residues, or other organic materials, most of this carbon is eventually converted back into CO₂ and released into the atmosphere, while only 3-33% is retained (Gelardi et al., 2023). For most soils, there is also a practical upper limit to soil carbon sequestration, after which management does not result in *new* carbon sequestration.

However, this does not mean that carbon returned to the atmosphere is a “loss;” agricultural systems need to utilize carbon to support diverse soil microbial life and crop production ([Figure 9](#)). The real key is that utilization of climate-smart practices is needed to retain soil carbon in soils over the long term.

Figure 9: Conceptual diagram of how soil organic carbon is both accumulated and utilized by soil microbes to power a broad suite of ecosystem services



From Gelardi et al. (2023)

In understanding the potential scale that such contributions could make towards the state's climate goals, one recent analysis in Washington estimated the potential mitigation contributions from cover cropping, no-till, and nutrient management across the state could only mitigate 0.1–1.8 MMT CO_2e per year over a 30-year period (Robertson et al., 2021). However, this study has broad assumptions and does not include any assessment of which strategies may be feasible in particular locations or cropping systems across the state. Specific agricultural strategies that support soil health and store carbon need to be tested, and often adapted, to fit within the many diverse cropping systems of the Pacific Northwest. For example, cover cropping systems developed in the Midwest have not “translated” easily to the Pacific Northwest, and while work is ongoing in this region, the appropriate species, seeding rates, planting and termination timing, and other factors are very different within organic mixed vegetable systems, irrigated systems, or tree fruit.



Young organic cherry orchard fertilized with mulch in Douglas County (photo by David Granatstein)

V. Organic Production Systems

Organic systems are characterized by the holistic implementation of a collection of management practices that foster soil health and biodiversity, including, but not limited to, the practices discussed in the previous section. While the holistic nature of organic systems has long been emphasized, providing quantitative empirical evidence of the benefit of multiple practices implemented together is challenging – but newer research delves into this question. Though not specifically focusing on organic systems, Rasmussen et al. (2024) drew on 24 studies focusing on five diversification strategies: livestock inclusion and diversification, crop diversification, soil conservation and fertility management, non-crop plantings (e.g. hedgerows), and water conservation. They found that implementing multiple diversification strategies leads to more positive social and environmental outcomes than any individual strategy, with all five strategies applied together showing the strongest benefits. This new work adds to previous evidence on agricultural diversification leading to better environmental outcomes, including higher carbon sequestration rates (Beillouin et al., 2021; Kremen and Miles, 2012; Rosa-Schleich et al., 2019).

In the Pacific Northwest, we are aware of only one long-term study of organic vegetable production that explored carbon sequestration dynamics (Ball et al., 2022; Cogger et al., 2016). In these organic mixed vegetable production systems in Western Washington, a soil amendment with a high carbon to nitrogen (C:N) ratio (that also provided sufficient nitrogen for plant growth) positively

influenced cover crop growth and increased soil carbon over time, though soil carbon storage was not maintained over time in the absence of continued carbon inputs, consistent with similar studies from conventional systems and discussed in [Section II.I.III](#). Modeling to estimate full greenhouse gas fluxes (methane, nitrous oxide and carbon) suggested that these systems were net emitters of carbon, a finding that is consistent with other temperate mixed vegetable systems (Adewale et al., 2019; Pereira et al., 2021). But note that from a perspective of contributing to the state's climate goals the more important comparison would be to a baseline without soil amendments, something that was not included in this experiment.

Global reviews indicate most meta-analyses have found that organic systems have a smaller impact on the climate per unit area than their non-organic (conventional) counterparts, while emissions per unit of product vary and depend on the product involved (Nabuurs et al., 2022). A recent European review of existing relevant global meta-analyses of organic systems indicates that organic systems produced less methane and nitrous oxide per unit area than their conventional counterparts. Their chosen quantitative results, from a meta-analysis of studies conducted in the Northern hemisphere under temperate climate indicate slightly lower emissions of methane in organic arable lands, by 1.30 ± 1.01 kg CO₂e per acre per year and a mean reduction in nitrous oxide emissions of 201 ± 66 kg CO₂e per acre per year (Skinner et al. (2014) as discussed in Guerrero et al. (2024); Table 2).

Table 2: Effect of organic systems on greenhouse gas emissions (change of emissions per acre)

GHG	Systems	CI_LOW	Mean	CI_HIGH	Nc	Effect
CH ₄	Arable	-2.3	-1.3	-0.3	8	Positive
	Arable + grassland	-264	-199	-134	3	Positive
N ₂ O	Arable	-267	-201	-136	67	Positive
	Grassland	-1466	-441	583	3	Non-significant

From Skinner et al. (2014) as shown in Guerrero et al. (2024). All figures are in kg CO₂e/ac/yr. CI_LOW: confidence interval bottom. CI_HIGH: confidence interval top. Nc: number of pairwise comparisons.

Within livestock systems (that combined both livestock and associated cropping), soil organic carbon (SOC) levels have been widely shown to be higher in organic than in conventional farming. Within the European meta-analysis, the chosen meta-analysis indicated statistically significant and higher SOC concentrations (carbon weight per weight of soil) and SOC stocks (carbon weight per area), with changes in SOC stocks being roughly 6-10% higher in organic systems than their conventional counterparts. Carbon sequestration rates (meaning carbon weight per area over time, an indication of *new* carbon storage) was statistically significantly different only for all organic farms (including those relying on imported carbon inputs), not for those with zero net carbon inputs (Gattinger et al., (2012) as discussed in Guerrero et al., (2024); [Table 3](#)). Shallow soil sampling was a limitation in these studies.

Table 3: Effect of organic systems on carbon sequestration mostly for topsoil and temperate zones

<i>Impact and metric</i>	<i>Farm types</i>	<i>CI_LOW</i>	<i>Mean</i>	<i>CI_HIGH</i>	<i>Nc</i>	<i>Effect</i>
SOC concentration [g/kg]	All farms	1.2	1.8	2.4	200	Positive
	Zero net input	0.4	1.3	2.2	60	Positive
SOC stock [Mg C/ac]	All farms	0.97	1.42	1.86	204	Positive
	Zero net input	0.21	0.88	1.54	60	Positive
C sequestration rate [Mg C/ac/yr]	All farms	0.1	0.18	0.27	41	Positive
	Zero net input	-0.04	0.11	0.26	19	Non-significant

From Gattinger et al. (2012) as shown in Guerrero et al. (2024). SOC concentrations describe the organic carbon concentration on a weight by weight basis, SOC stocks on a weight by area basis, and C sequestration rates on weight by area and elapsed time since conversion to organic. CI_LOW and CI_HIGH: confidence interval bottom and top; Nc: number of pairwise comparisons.

Within cropping systems, SOC concentrations were 14-19% higher in organic systems than in their conventional counterparts in the two chosen analyses. (Aguilera et al. (2013) and Smith et al. (2019); both as discussed in Guerrero et al. (2024); Table 4). SOC stocks and sequestration rates were also higher in organic than in conventional systems. Interestingly, analysis by Smith et al. (2019) – as described in Guerrero et al. (2024) – found substantially higher SOC concentration and SOC stock in U.S. organic systems than in European, with the difference being roughly twofold. The reasons for this are unclear.

Table 4: Effect of organic systems on C sequestration of cropping systems

Impact and metric	Systems	CI_LOW	Mean	CI_High	Nc	Effect
SOC concentration (or SOC stock if missing) [%]	All crops	11.1	19.2	29.9	53	Positive
	Cereals rotation	2.2	7.8	17.2	20	Positive
	Horticulture	26.7	48.3	74.5	25	Positive
	Woody crops	4.6	15.7	27.9	35	Positive
SOC concentration [%]	All crops	10.2	13.9	17.3	209	Positive
	Annual	12.7	16.2	20.9	138	Positive
	Perennial	-0.6	5.1	11.6	54	Non-significant
SOC stock [kg C/ac]	All crops	3.7	4.7	6.1	209	Positive
	Annual	4.7	6.1	8.0	138	Positive
	Perennial	-0.69	10.0	3.4	54	Non-significant
C sequestration rate [change in Mg C/ac/yr]	All crops	0.22	0.39	0.6	24	Positive
	Cereals rotation	0.12	0.31	0.58	10	Positive
	Horticulture	0.19	0.43	0.63	24	Positive
	Woody crops	0.22	0.37	0.64	10	Positive

Source: Aguilera et al. (2013) and Smith et al. (2019) as shown in Guerrero et al. (2024). SOC concentrations describe the organic carbon concentration on a weight-by-weight basis, SOC stocks on a weight by area basis, and C sequestration rates on weight by area and elapsed time since conversion to organic. CI_LOW: confidence interval bottom; CI_HIGH: confidence interval top; Nc: number of pairwise comparisons.

Given these lower emissions per acre, by addressing current barriers to organic conversion, such as the cost of certification, or by supporting demand for organic food purchasing, the state could encourage broader adoption. One potential upside of such a strategy is that organic acreages are already regularly reported through the certification process, and standards are well defined.

However, note also that there have been some concerns about lower yields in organic systems (see [Section III.II](#) for a more full discussion of this concern, relating to both organic and climate smart practices). Thus, identifying crops and production systems where there are yield gaps compared to conventional systems, and supporting research and extension to close those yield gaps, is likely to be important.



VI. Non-Cultivated Lands within the Farm Landscape

Lands owned and managed by agricultural producers but not farmed are diverse and include wetlands, forested areas, and riparian areas. These lands play a crucial role in agriculture in maintaining biodiversity, providing wildlife habitat, supporting carbon sequestration, reducing reactive N losses, and sometimes also improving adjacent crop or livestock production (Young-Mathews et al., 2010; Smith et al., 2021). These lands are diverse, serving different purposes depending on their location and vegetation. For example, vegetated riparian buffers between farmland and waterways filter agricultural nutrients and pollutants, reduce erosion, moderate water temperatures, improve water quality, and provide wildlife habitat (Cole et al., 2020; Young-Mathews, 2010). Windbreaks, meanwhile, involve linear planting of trees and shrubs into an agricultural landscape and can be designed for wind reduction, soil erosion control, or providing shade for livestock (Smith et al., 2021). Note that these and other related practices cannot be implemented on every farm, especially depending on farm size and location. For example, many organic operations are smaller in size compared to conventional farms, so a riparian buffer would take up a higher percentage of land and remove important food production ([Appendix A](#)).

When sited and managed appropriately, these non-cultivated lands can also provide climate benefits. The conversion from agriculture to agroforestry generally increases soil organic carbon (Guerrero et al., 2024). For example, in temperate regions (40°N to 60°N), a meta-analysis found

that the amount of soil organic carbon increased by 18% in the 0-40 cm soil depth (Chatterjee et al., 2018). A recent study in rangelands of northern California estimated the amount of soil carbon stored from riparian restoration with varying restoration age from 1 to 45 years (Matzek et al., 2020). The authors found that soil carbon in the top 50 cm of soil increased at a rate of 0.35–0.45 Mg C/ac on the floodplain and upper bank. Because California has a cap-and-trade system for greenhouse gas emissions, the authors were able to calculate that 20 years after restoration, the value of the stored carbon at 2019 prices (\$17.45 per ton of CO₂e) would amount to \$15,000 per linear km of restored stream (Matzek et al., 2020).



Biochar from orchard waste is applied to a commercial tree planting in central Washington (photo by David Drinkard)

VII. Biochar

Because pyrolysis processes carbon into more recalcitrant forms that are more resistant to turnover in soils, biochar amendments may result in greater amounts of carbon sequestration than other types of soil amendments. However, it should be noted that although carbon storage will increase, variables can lead to locally different results due to soil type and depth, climatic conditions, crop rotations, and biochar rates and characteristics (Guerrero et al., 2024). For example, one meta-analysis found that biochar increased soil organic carbon by 54% (Albert et al., 2021) while another meta-analysis found a range of 30% - 60% increase depending on soil type (Bai et al., 2019).

Amonette (2021) has analyzed the potential climate benefit of biochar production and use in Washington State and concluded it is substantial. If only technical feasibility is considered, 31 and 161 MMT (million metric tons) CO₂e could be offset over 100 years by generating biochar from only municipal waste wood or crop residues, respectively. Including forestry residuals resulted in substantially higher values: 640–1,600 MMT CO₂e depending on the level of timber harvest and the processing locations assumed. At the maximum biomass-utilization rate, which is achieved after five decades, biochar production with application to agricultural lands could offset between 9% and 20% of all greenhouse gas emissions in Washington (taken at 2018 levels). Actual offsets would be lower than this range because this analysis considered only technical feasibility. For example, economic barriers relating to gathering and transporting biochar across the landscape, as well as the potential cost burden to agricultural producers need to be considered. However, the greenhouse gas reduction potential is significant enough to warrant further work to identify and address these barriers.

The attributes of biochar in soils, and thus their suitability and potential non-climate benefits within particular agricultural systems, are dependent on the organic materials used to make biochar (e.g. type of wood, wheat straw, or other material), the processing conditions, post-processing treatments and the climatic and soils conditions under which they are applied. Co-benefits of biochar application to agricultural soils have included improvements in soil water holding capacity, nitrogen use efficiency, biological nitrogen fixation, adsorption of organic pollutants and heavy metals, odor reduction from manure handling, reducing forest fuel loads, and sometimes yield increases (Amonette et al. 2021b; Naburrs et al., 2022).

A comprehensive effort to identify the most promising potentials to integrate biochar into Northwest agricultural systems called attention to a prescriptive approach. Within this approach, the emphasis is on specific situations where biochar can be used to address issues that are likely to be constraining yields or quality, therefore leading producers to be more interested in utilization (Trippe et al., 2021). Among the promising situations are applications to reduce disease pressure in nursery crops, potatoes, and small fruits (Jaiswal et al., 2018; Jaiswal et al., 2019), or applications of specific biochars to conserve water, raise pH and address acidification issues in dryland wheat production (Machado et al., 2018; Phillips et al., 2018). Additional specific examples are described in Table 8.2 of Trippe et al. (2021), although the authors note that cost remains a barrier, especially in dryland wheat-based systems.

From a climate perspective, understanding the emissions associated with the production and transportation of biochar can be critical to ensuring that the production and application of biochar produces a climate benefit (Amonette et al., 2021a). Producing biochar from residues that would otherwise be burned is one situation in which benefits are likely to be maximized due to the alternative fate of the biomass (Desjardins et al., 2024). In the Northwest, these situations could include on-farm biochar when residues might otherwise be burned (though burning is not a common agricultural practice in Washington, this could apply to orchard tear out and other situations), harvested (e.g. high residue wheat systems where residues impede no-till planting and need to be harvested or otherwise managed) or forestry systems (e.g. when harvest residuals at wood harvest are normally managed through controlled burning, or when thinning is being used to reduce risk of uncontrolled forest fires).

Worldwide, biochar systems producing biochar for soil application plus bioenergy have been recognized as an important carbon dioxide removal strategy, with greater mitigation potential than bioenergy production alone or other uses of biochar (Naburrs et al., 2022).

VIII. Enhanced Weathering

Enhanced rock weathering is a carbon sequestration technique that draws down atmospheric carbon through weathering of alkaline silicates on croplands. Crushed silicate rock, typically basalt, is spread onto agricultural fields where it reacts with water and atmospheric CO₂ to release alkaline cations and form bicarbonate and carbonate anions. These ions either precipitate to form carbonate minerals in soils or, more commonly, are transported via groundwater and surface waters to the ocean where they buffer atmospheric CO₂ levels. Enhanced rock weathering has demonstrated benefits to agriculture such as improving soil pH (thereby avoiding ag lime applications), providing important nutrients such as potassium, phosphorus, calcium, and magnesium to plants, and improving crop yields (Beerling et al., 2024; Kantola et al., 2023; Kelland et al., 2020). To cut down on application costs, enhanced rock weathering can use existing farm technology, such as a spreader, to apply rock dust to the field. This potential technique could take

advantage of Washington's large expanse of basalt (in the Columbia River Basalt flows), sourcing from existing mining industry in the state. Basalt applied in western Washington is more likely to generate alkalinity from higher precipitation than basalt applied in drier eastern Washington (J. Amonette, pers. comm.). Therefore, basalt could be mined on the east side and then applied on the west side.

According to modeling studies, the carbon dioxide removal potential worldwide from spreading a single 40 Mg/ha (18 tons/ac) application of basalt onto 10% of cropland could sequester 0.5 Gt CO₂ yearly (Beerling et al., 2020). In the U.S., enhanced rock weathering could sequester ~0.23-0.38 GtCO₂ yearly by 2050, depending on rock supply (Beerling et al., 2025). Field trials to date in the U.S. have been limited to the Midwest (e.g., Kantola et al., 2023) and northern California (Holzer et al., 2023). These field trials indicate a wide range of yearly carbon dioxide removal potential from 0.05 MT CO₂/ac to 3.5 MT CO₂/ac. Washington has the resources to implement enhanced rock weathering; however, it is unknown how much carbon could be sequestered in Washington through this strategy due to a lack of field trials. Importantly, field trials are also necessary to evaluate potential risks to the environment such as impacts from trace metal accumulation, dust inhalation, and pH impacts to waterways (Levy et al., 2024).

II. Mitigation Approach 2: Reducing Agricultural Emissions

Alongside carbon sequestration, reducing sector emissions can also make voluntary and important contributions to the state's climate goals. Reducing agricultural emissions generally focuses on the reduction of methane (CH₄) and nitrous oxide (N₂O), as these two greenhouse gases account for the bulk of agricultural emissions (see [Section I.III](#)). Generally speaking, short-term cycling of carbon within agricultural systems (for example, when it is "fixed" from the atmosphere in plants, or released to the atmosphere through plant decomposition or animal respiration) does not have a net greenhouse gas impact. On the other hand, carbon dioxide resulting from burning fossil fuels either on-farm or off-farm for electricity production, machinery (internal combustion engines) or fertilizer manufacturing is considered a net source of greenhouse gases. Primary sources of methane on agricultural operations include enteric fermentation of animals, and manure storage, particularly in conditions where oxygen is limited (i.e., anaerobic), such as in liquid storage. Primary sources of nitrous oxide include the application of nitrogen to soils through fertilizers or manures, and storage of manure under conditions where oxygen is readily available (i.e., aerobic conditions).

[Table B2 in Appendix B](#) summarizes key data relating to reducing agricultural emissions associated with enteric fermentation, manure management, and nitrogen application to soils (the three key components of sectoral emissions within the statewide emissions inventory).

I. Mitigating Emissions from Enteric Fermentation

Reducing emissions from enteric fermentation managing one or more of the many factors that affect the amount of methane generated by ruminant animals. Improving efficiency (the amount of milk produced per animal) can also contribute, if fewer animals are used to produce the same amount of milk. Feed conversion efficiency is a critical factor, explaining more than 50% of the observed variability in feed and enteric methane contribution to U.S. farm-gate dairy carbon footprints (Thoma et al., 2013).

Diet-related interventions have been broadly investigated, though any diet intervention needs to take account of animal health and well-being concerns, as well as potential impacts to milk or meat product quality. More digestible diets (e.g. greater in starch and sugars and lower in structural carbohydrates) leading to less methane production (Johnson and Johnson, 1995). While a diet high in concentrates provides more starch and sugars, it would also negate one of the major benefits of ruminant animals – their ability to convert an indigestible substance (cellulose) into an edible product with nutritional benefits (Place and Mitloehner, 2010). In practice, the amount of concentrates that animals consume is likely to be driven by productivity, economics, and system (e.g. cow-calf pairs and animals in organic systems are on range or pasture).

The inclusion of certain unsaturated lipids in the diet has also been shown to decrease methane production with no effect on or an increase in milk production in cows (Rabiee et al., 2012), with existing literature suggesting that decreases of 10-30% are feasible (Guerrero et al., 2024; Hristov et al., 2021). However, some fats, such as coconut oil, may severely depress milk production and milk fat levels. Appropriate lipids may come from byproducts such as oilseed meal or spent distillers' grains, or from edible vegetable oils – although availability and cost are important practical considerations, and inclusion must consider impacts to overall diet.

Feed additives to reduce methane emissions are an active area of scientific development. Feed additives that specifically inhibit the microorganisms that produce methane in the gut of ruminant livestock include nitro-oxypropanol (3-NOP) decreases methane production by between 8% and 60% in lactating cows (Hristov et al., 2022; Prathap et al., 2021). Meta-analysis indicates roughly 30% reductions have been most commonly achieved, but with complexity in terms of interactions with other factors including the amount of neutral detergent fiber in the diet (Kebreab et al., 2023). This additive has been approved for use in the European Union since 2022, and received approval for use in the U.S. in 2024. As of winter 2024, 3-NOP (known commercially as Bovaer) was being fed with economic support to several dairy herds in Washington (Edmonds, personal communication). At this stage, there are few long-term studies of the impacts of such supplements over time.

Other additives with similar, or different, modes of action are also under ongoing investigation. Among these, monensin likely has smaller impacts on methane production (under 10% reductions) but is in some cases already being fed to livestock in the Pacific Northwest, as it has long-standing improvements.

Each of these additives can be added easily to existing diets, at least for cows receiving routine feed. Given current technologies, it is difficult to feed routine additives to livestock on range, although scientific and technological work seeking to address this challenge is ongoing. Cost is likely to be an important barrier, especially given current constrained economics (see [Section I.I](#)). As of early 2025, costs of Bovaer were roughly \$0.50/cow/day, while costs of monensin were roughly \$0.02-\$0.04 /cow/day (Mickelson, personal communication).

For additional details on feed additives to reduce enteric fermentation, see recent reviews by Prathap et al. (2021) and Hristov et al. (2022).



Covered manure separator on a northwestern dairy (photo by Jim Jensen)

II. Mitigating Emissions from Manure Management

Manure management and storage also offers impactful and immediate opportunities for mitigation, with strategies and technologies that are readily deployable. Costs, including both the initial cost for installation and the ongoing operational costs, are an important barrier to broader deployment, and operational reliability is also critical. Appropriate strategies will be different for each farm, and will depend on scale, production system (e.g., organic versus conventional, housing/pasture type), and current manure management. Figures presented in this section relative to the achievable emissions reductions are expressed in terms of percentages for simplicity, but careful attention to the comparison (i.e. emissions reduction compared to what baseline practices) is important. Readers are cautioned that these should be interpreted as very

rough estimates, as regionally specific data are lacking and emissions depend on biological processes that are temperature-dependent. Where regional estimates exist, these are often from a single study. However, despite these limitations, some important insights are possible, especially relating to the relative potential impact of various practices in terms of their efficacy for mitigation emissions.

Because methane is generated when manure is stored anaerobically (without oxygen), strategies that reduce liquid storage of manure can effectively reduce greenhouse gas emissions. However, estimates of these impacts should take account of the fact that many manure lagoons in Washington are already less used during the summer months (Gearhart, personal communication), when warmer temperatures would result in methane generation as microbes in the stored manure become more active. For those cases where this is not already occurring, emptying the lagoon in the spring before warmer temperatures begin can reduce greenhouse gas emissions (Novak and Fiorelli, 2010). Extension specialists in New York calculated that summer daily spread with winter storage in a liquid slurry reduced the methane generation by 59% compared to 6-month summer and winter storage in a liquid slurry under their climatic conditions (Wright and Gooch, 2017).

Processing liquid manure with a solid-liquid separation system prior to lagoon storage removes volatile solids from anaerobic long-term storage and can reduce methane emissions, though nitrous oxide emissions can be increased, thus reducing the climate benefit. A recent estimate of the impacts of solid separation to remove 30% of volatile solids prior to liquid/slurry storage suggest that manure management emissions could be reduced by 29.4% in Idaho and Washington compared to liquid/slurry storage alone (Greene, 2024). A meta-analysis found ~27% reductions in methane emissions, with positive but highly variable impacts on nitrous oxide emissions, and some have estimated reductions to be smaller (Emmerling et al., 2020).

Methods of solid liquid separation vary in their efficacy, and methane emissions will be reduced more in systems that achieve higher levels of solids separation. Processes that can be used include gravity settling, in-channel flighted conveyor screens, rotating screens, screw presses, belt presses, rotary presses, centrifuges, and hydrocyclones, either alone or with multiple methods in sequence. Flocculants and coagulants can be used to enhance the removal of solids.

Different methods of solids separation may be most appropriate depending on the total solids of the manure to be treated, and other factors (USDA NRCS, 2019). Removing solids can also provide some operational benefits to the farm, which is likely responsible for the fact that these technologies are already being used on a number of dairy farms throughout the state. Benefits include facilitating pump handling of the separated liquids, reducing organic loading and sludge buildup in lagoons, and generating separated solids that can be composted and/or recycled as animal bedding. That said, these technologies do have both up-front capital costs and ongoing operational costs associated with them.

Solid-liquid systems are also often needed prior to implementing other technologies that reduce emissions and that are described below (e.g. prior to lagoon storage in a cover and flare system, or after an anaerobic digester). The amount of volatile solids removed is the primary driver of the amount of emissions reductions achieved, emphasizing the potential of methods that remove additional volatile solids. For example, centrifuges, flocculants, or membrane-based approaches (often used after a primary solids separation) can achieve higher solids separations, but with increases in costs (Frear et al., 2023). In some cases, increased challenges with operational reliability are also a concern for these fine solids separation approaches.

Once the solids are separated – or on farms where manure is managed as a solid rather than a liquid, additional treatment is possible. Composting with aeration can further and substantially reduce methane emissions and overall greenhouse gas emissions (Guillermo et al. 2015; Montes et al., 2013). In a meta-analysis, Guillermo et al. (2015) estimated reductions of 53% and 71% in nitrous oxide and methane, respectively, from composting as compared to stockpiling, though note that they also found substantial differences in emissions depending on how composting was carried out. Composting with biochar may again further reduce life-cycle global warming potential with an experimental study in northern California measuring a reduction of methane by 79% compared to composting without biochar, with non-significant differences in nitrous oxide emissions (Harrison et al., 2022). A synthesis study of composting with biochar estimated reductions of 67% (Cao et al., 2019).

As an alternative, solids separation can be followed by other forms of treatment. Vermi-filtration uses a biofilter in combination with earthworm activity to alter liquid wastewater and ultimately break down organic matter (such as orchard tear out) producing a nutrient dense soil amendment byproduct. Vermi-filtration on a dairy farm in central Washington was shown to be effective at



A vermi-filtration trickling system treats manure in Grant County before it is land applied (photo by Sina Pram)

reducing nutrient concentrations and reducing methane emissions but not emissions of nitrous oxide (Monaghan et al., 2023).

Two other manure strategies collect methane and utilize or destroy it, as opposed to preventing its formation. First, lagoons can be covered with impermeable covers (though solids separation must occur first to ensure that manure solids do not settle and reduce the lagoon capacity over time). When methane is formed, it is trapped under the cover and can be collected and combusted. As the flare converts methane (with its higher global warming potential) to carbon dioxide (with a lower global warming potential), the net global warming potential is reduced. Estimates of 90% combustion in a flare are often used (EPA, 2011), with additional benefits of a cover of controlling odors and excluding rainwater. Professional engineering is needed to avoid inadvertently creating hazardous conditions, prevent leaks, and ensure adequate design. While covered manure lagoons have been used widely in other areas of the U.S., to date they have not been used much within Washington. Covering liquid manure lagoons has the potential to reduce nitrous oxide by up to 98% (Guerrero et al., 2024; Hou et al., 2015).

Anaerobic digestion systems go one step further, seeking to transform much of the organic matter in manure into methane, and are the strategy that best mitigates greenhouse gas emissions (Aquirre-Villegas and Larson, 2017). The process creates anaerobic conditions that encourage methane generation and capture. The methane can then either be flared off (as in a covered lagoon), combusted to produce both carbon dioxide and electrical energy, or refined into renewable natural gas (RNG). These systems eliminate the bulk of methane emissions and provide additional climate benefits because they displace fossil fuel use with renewable energy. The

remaining emissions from digesters are from system leakage and from methane remaining in the digestate, both of which can be minimized through appropriate design. A meta-analysis indicated an 82% reduction of emissions (methane and nitrous oxide) from storage compared to slurry storage, and an emissions reduction of 36% during field application of digested slurry (Miranda et al., 2015 as cited in Guerrero et al., 2024).



Anaerobic digester at a Whatcom County dairy (photo by Regenis)

Anaerobic digestion of manure has additional environmental benefits including reduction of odors and stabilization of wastes. And from a holistic climate perspective, anaerobic digesters can be used as a platform to generate other bioproducts (e.g. peat moss, fertilizers, woven and non-woven fibers) to replace products currently derived from fossil fuels or with negative climate impacts, with a number of accompanying technologies implemented on some digesters, and many other products still in development. However, uptake has been somewhat limited in the U.S. due to high capital cost, operation and maintenance costs, and the need for access to the electrical grid or RNG pipeline.

Even with incentives, achieving financial viability for anaerobic digestion systems has been difficult, especially in the Pacific Northwest where inexpensive hydropower limits the prices received for the underlying energy. Under current incentive structures these systems are only viable for larger dairies with more than about 3,000 cows (sometimes much more), and systems may not be a fit with all production systems or marketing strategies.

That said, the *existing* dairy digesters in the Pacific Northwest (most of which were installed in the 2000s when economics were more favorable), were estimated to serve more than 16,000 cows and were already generating greenhouse gas mitigation of 0.12 MMT CO₂e per year collectively in 2017 (Bronstad and Yorgey, 2019), or 1.8% of the state's agricultural emissions with only 6% of

dairy cows served.¹³ Economics are particularly challenging for smaller farms, though an estimated 9% of cows in Washington and Idaho contributing to anaerobic digesters in 2023 were on farms of less than 2,500 cows (Greene, 2024). Readers wishing to learn more about anaerobic digestion on dairies can refer to *Anaerobic Digestion: The Basics* (Mitchell et al., 2015), *The Dairy Biorefinery* (Yorgey et al., 2019a), and other publications in the Anaerobic Digestion System Series from Washington State University. Either technology innovation or policy changes (or both) could make digesters relevant for smaller scale dairies in the future. Work on systems relevant to Washington's dairy production systems is ongoing (e.g. research projects funded by the Climate Commitment Act of the State of Washington and listed in Washington State Conservation Commission, 2024).

A recent life cycle assessment (LCA) concluded that anaerobic digesters could reduce greenhouse gas emissions from manure management at the farm level by roughly 60-70% in the Northwest (Greene, 2024). Regional impacts were also considered through the development of two scenarios. Continued adoption on larger farms of 3,500 cows, if policy remains similar to what it is currently, led to a regional benefit of emissions reductions of 287,000 MT CO₂e per year in Washington and Idaho.¹⁴ The relevant policy includes federal credits via the U.S. EPA Renewable Fuel Standard D3 RINs, and state level low carbon fuel standard markets that provide for both on farm emissions reductions and the benefits of renewable transportation fuels. A scenario considering potential future changes that could make digesters more relevant at smaller scales was also explored, based on hypothesized policy incentives for electricity production (e.g. through a federal "eRIN"), enabling systems that produce combined heat and power for electricity production to be economically viable. Because these technologies are less expensive and can be implemented at much smaller scale than for RNG production, this scenario provides opportunities for farms with 1,750-3,500 mature cows. Estimates specific to the Northwest suggest that anaerobic digesters could provide a benefit of roughly 483,000 MT CO₂e per year in Washington and Idaho if adoption were nearly doubled from current status, in line with their estimates of which dairies might be large enough for digestion to be economically feasible.¹⁵ Further details of the scenarios and analysis are available in Greene (2024).

Ultimately, anaerobic digesters provide the most climate mitigation and could be encouraged with economic support in situations where they are appropriate for the size and type of dairy, utilized alongside strategies that collect and process as much of the manure as possible. In situations where digesters are not appropriate, aerobic manure treatment, such as in organic pastured systems or dry lot dairies, will have lower emissions than liquid treatment. However, even organic and dry lot systems often have portions of the manure that are managed in liquid form. For dairies that manage part or all of their manure in liquid form, and for which an anaerobic digester is not viable, removing as much of the volatile solids prior to storage will reduce greenhouse gas emissions. After solids separation, covering lagoons and flaring the resulting methane may also be appropriate if financially possible.

¹³ Assuming 276,914 dairy cows in the state at the time (NASS, 2017) and using 2015 total emissions of 94.4 MMT CO₂e (Department of Ecology, 2025).

¹⁴ In this scenario, adoption was assumed to expand to 115,000 mature cows, though the number of participating cows was assumed to be higher due to contributions from dry lot dairies adopting vacuuming of feed lanes that captures a portion, but not all manure.

¹⁵ In this scenario, adoption was assumed to expand from 93,500 mature cows (current) to 181,500 mature cows (future), which would represent roughly 20% of the 2024 dairy herds of the two states combined. Note that the number of cows contributing to digesters was higher due to contributions from dry lot dairies adopting vacuuming of feed lanes that captures a portion, but not all manure.

III. Mitigating Emissions Through Nutrient Management

Nitrogen is one of the most important nutrients for growing crops, and if it is not supplied in sufficient quantities, it can limit yields. That said, nitrous oxide emissions are also an important source of emissions across agricultural systems. Nitrous oxide emissions are generated as a byproduct by naturally occurring bacteria in soils that transform nitrogen from fertilizers and other nitrogen sources such as manures or other amendments. On a mass basis, nitrous oxide is 273 times more powerful greenhouse gas than carbon dioxide and persists in the atmosphere for over 100 years (IPCC, 2024), with the result that nitrous oxide emissions that are negligible from an agronomic perspective can be very important from a climate perspective.

Inventory approaches usually estimate that roughly $1\pm0.8\%$ of applied nitrogen is lost as nitrous oxide in agricultural systems (IPCC, 2019). Understanding of the mechanisms of nitrous oxide generation is still evolving, but research to date has shown that emissions are generally non-linear (Hoben et al., 2011), with the proportion of applied nitrogen emitted as nitrous oxide increasing as application rates increase above needed rates. Currently, only 47% of the reactive nitrogen added globally onto cropland is taken up by harvest crops (Lassaletta et al., 2014). Agriculture in the U.S. accounts for 11% of the global excess nitrogen (West et al., 2014). Losses of nitrogen in other forms, especially nitrates or ammonia, are also important environmental issues, though neither of these directly impact the climate.

An excess addition of nitrogen beyond crop needs will lead to higher emissions of nitrous oxide on farmland. For example, globally, conventional farming systems on average receive 63 and 77 kg N/ac/year as external fertilizer and total N (fertilizer and plant residues) inputs, respectively, as opposed to organic farming systems that receive 36 to 50 kg N/ac/year (Skinner et al., 2014). As might be expected from these numbers, across all agricultural land use types, organically managed soils emitted 199 kg CO₂e/ac/year (0.2 MT CO₂e/ac/year) less than those managed by conventional farming (Skinner et al., 2014). The authors of this study note that nitrous oxide emissions from organically managed soils seem to be influenced more by soil properties than by nitrogen input.

The most straightforward way to reduce nitrous oxide emissions is to apply the four principles of fertilizer management: right rate, right time, right placement, and right source. The time and place of nitrogen application may be relatively easy nutrient management techniques to apply with no cost to potential yield and can reduce nitrous oxide emissions by 20-30% (Hassan et al., 2022). For example, placing nitrogen fertilizer near the roots of plants increases nitrogen use efficiency which in turn can curb emissions (Sharma and Bali, 2018). However, there is a need to ensure that yields do not suffer, to avoid both negative economic consequences, and the risk of expanding acreage to achieve the same production and increasing system-level emissions. A proposed solution is to focus on nitrogen use efficiency as opposed to rate, meaning the proportion of nitrogen taken up in the crop (Maaz et al., 2021; Omonode et al., 2017). This could include easily calculated indicators of efficiency such as partial N balance and partial factor productivity, which a global analysis has shown predicts nitrous oxide emissions as well as or better than nitrogen rate (Maaz et al., 2021; in this study partial nitrogen balance was defined as nitrogen application minus plant nitrogen uptake, and partial factor productivity was defined as yield/nitrogen application).

Adopting a portfolio of strategies for nitrous oxide mitigation has been estimated to have potential to reduce overall emissions by 22-49% globally (Grados et al., 2022). For example, using controlled-release fertilizers can decrease N₂O emissions by ~20% in drylands (Ti et al., 2018).

Other management factors that have been proposed to impact nitrous oxide emissions include urease inhibitors, biochar application, irrigation management, and fertilizer frequency (Hassan et al., 2022; Kallenbach et al., 2010; Thapa et al., 2016). Ongoing research into other potential management practices includes genetic modification (Demone et al., 2018) and blue/green ammonia (Kollar, 2023). While these may ultimately provide additional effective strategies for managing nitrous oxide emissions, additional study is needed to understand whether some may have potential tradeoffs with other forms of nitrogen loss (Pan et al., 2022), and to explore confounding effects due to management dynamics that co-vary with nutrient application practices (Maaz et al., 2021).



No-till drill in Whitman County (photo by Terry Travis)

IV. Mitigating Emissions from Farm Inputs Use and Production

As discussed in [Section I.III](#), emissions attributed to the agricultural sector in the current state inventory are those associated with enteric fermentation, manure management, and soil management, all covered in subsections above. However, there are also other emissions associated with farm activities, such as those from fuel and electricity use (categorized under other sectors in the state inventory), as well as emissions associated with the production of various inputs like fertilizers and pesticides.

Nationwide, it is estimated that around 7% of all emissions related to agriculture come from on-farm energy use (EPA, 2022). Direct energy use – that is, on-farm diesel (44% of direct use), electricity (24%), gasoline, propane, natural gas as well as renewable energy use – accounts for an estimated 60% of agriculture’s energy consumption, while indirect energy use – linked to manufacturing of products and equipment used on-farm – accounts for the other 40% (Hitaj and Suttles, 2016; Matlock et al., 2023). Studies in Europe have found organic farms to be more energy efficient than conventional ones (Reganold and Wachter, 2016; and cites therein), but the relevance of this research to the U.S. context may be limited.

Few detailed analyses specific to energy use in Washington’s cropping systems are available, but existing evidence suggests that energy use does not dominate the footprint, while still playing an important role. For example, for dairy, one sector for which we have more baseline data, energy use contributes around 6% of emissions on average in the U.S. Nevertheless, improvements to equipment and better energy efficiency in farm buildings can not only reduce emissions but also save farmers money, although they usually also require up-front investments that can be challenging.

Field-based production systems are currently heavily dependent on liquid fuels for tractors and other equipment. Liquid fuels are also important for highway transportation of agricultural commodities. Near term opportunities for reducing emissions from fuels include blending biofuels into conventional liquid fuels, utilization of renewable natural gas, more efficient internal combustion engines, and other fuel additives that increase performance (Awwad et al., 2023). Near-term opportunities for reducing emissions from farm equipment include electrification for smaller scale mobile equipment (<70 horsepower) and other applications which are already commercially available, or conversion of larger-scale fixed equipment (pumps, wind machines) to electrical power (Scolaro et al., 2023). A major challenge that still needs to be overcome for battery-electric options to be viable for field-based production is increased battery capacity or interchangeability. Many field-based agricultural applications (e.g. planting and harvest) require intensive, short-duration use (e.g. 12+ hours daily for 3-4 weeks annually) that isn’t conducive to regular breaks for recharging.

Long-term opportunities for reducing emissions for large-scale, mobile equipment likely will depend on either conversion to liquid biofuels, or the development of hydrogen-based equipment and fueling infrastructure (Wawer and Stroink, 2024), given energy density, power output, and refueling times that are comparable to diesel. While not currently occurring, generation of hydrogen on-farm at small scale has also been proposed as a method for promoting energy independence, building within sector capacity to produce fuels and fertilizer, and protecting growers from input price increases that are currently depressing farm incomes and contributing to the loss of small farm businesses (Shenton et al. in preparation; see [Section I.I](#)). Other existing opportunities for reducing emissions from farm-based inputs include use of distributed solar energy for direct applications such as pumping water, in order to replace the use of liquid fuel-based motors and pumps, and for electric fencing, to replace carbon intensive materials like steel fencing. Virtual fencing also has the potential to significantly reduce the embedded emissions in materials for fencing in rangelands.

With appropriate planning, agrivoltaic projects (agricultural dual-use systems or agrisolar) allow for agricultural production underneath or between solar panels, while providing co-benefits in form of partial shade and protection from extreme heat and drought for plants and animals. A recent study found that converting less than 1% of U.S. agricultural land to agrivoltaics could meet 20% of the country’s energy needs with no losses to production (Proctor et al., 2020). While much more

research on these systems is needed (AFT 2024), there are studies showing meaningful potential in different cropping systems of Oregon: Andrew et al. (2021) found that while pastures with panels on them produce less forage, it is of higher quality and thus no differences in lamb production are observed, and Garrett et al. (2021) show that in a hot year, potatoes grown in the shade of solar panels had a 20% higher yield compared those grown in full sun. Preliminary estimates for the installation of dynamic agrivoltaic solar panels over less than 2% of an apple orchard in Central Washington show that the generated energy could provide all energy required for orchard operations (Kruger and Mussachi, 2024).



As discussed in [Section I.III](#), the production of fertilizers has a high emissions footprint. Globally, the supply chain of synthetic nitrogen fertilizer constitutes 10.6% of agricultural emissions, where production of fertilizers accounts for 39% of this footprint, transportation for 3%, and the application of fertilizers for 58% (Menegat et al., 2022). The most apparent solution for mitigating these emissions is more efficient nutrient management through approaches discussed in [Section II.II.III](#). In addition, there are many traditional alternatives to nitrogen fertilizer (compost and other organic amendments), as well as emerging products with a lower footprint, including some with the potential to be produced in our region.

In terms of compost use, a study from California compared the emissions associated with producing and distributing municipal compost to nearby farms (including the impacts of substituting compost for mineral fertilizer and the resulting carbon sequestration benefits) with emissions occurring when organics are landfilled (Harrison et al., 2020). It found that the transportation distance beyond which there are no emissions savings to compost use (as a substitute to fertilizer) is 7,000 miles, while from a cost-effectiveness standpoint, this distance is 85 miles. While these estimates would differ for Washington, it is still clear that municipal compost produced and utilized within the state will result in smaller net emissions than using mineral fertilizers. Note however, that not all nitrogen in composts is immediately plant-available. Modeling of composting compared to landfills in Washington indicate that emissions are lower for composting than for landfilling (despite

the fact that many Washington landfills are capped, and most of these utilize methane for renewable energy production), with results driven by two factors: removing food waste emissions of methane from landfills and the soil carbon storage benefit of applying compost to soils (Jobson and Kohsravi, 2019).

Currently, little data is available on the greenhouse gas emissions associated with manufacturing of pesticides, complicated by the number and diversity of products (both conventional and organic) on the market, lack of publicly available data, and little focus on components beyond the active ingredient (while these other components may be important to total lifecycle emissions given their sheer volumes) (Heller, personal communication). According to a life cycle inventory database, manufacturing of pesticides contributes 2.3% of the total production emissions of spring wheat in Washington (Cooper, 2015), and similarly 2.3% for potato cultivation nation-wide (Blonk Agri-footprint BV, 2025). Emissions associated with pesticide production are likely higher for tree fruit and vegetables that generally require higher quantities of pesticides. On the other hand, it is likely that organic cropping systems have a lower footprint in terms of pesticide manufacturing given use restrictions; however, even less is known about the manufacturing emissions of organic plant protection products (Heller, personal communication).

III. Mitigation Approach 3: Bioenergy with Carbon Capture

Bioenergy refers to a number of energy products (fuels, power, or heat) that can be made from organic materials. These products have the potential to (albeit may not necessarily) produce energy with a lower climate footprint than their fossil fuel-based counterparts. There are persisting concerns about unintended consequences, such as displacing food production and thereby expanding the global land demand for agriculture, but global analyses suggests that the use of municipal organic waste, harvest residues, and processing by-products as feedstock is likely to have lower risk, provided that associated land-use practices are sustainable (Cowie et al., 2021; Naburrs et al., 2022). Some existing work in the Pacific Northwest has explored the extent to which crop harvest residues can be removed and utilized without resulting in soil carbon loss over time, as well as calculating the fertilizer value of such residues (Gollany et al., 2011; Huggins et al., 2014). Additionally, producing bioenergy from pre-commercial timber and forest residue is of interest as it provides significant potential to reduce catastrophic wildfire (Regos et al., 2016; US DOE, 2016).

When bioenergy is produced “with carbon capture”, it means that during the process, carbon from biological sources that would otherwise be emitted is captured and stored. This can be in geological, terrestrial, or ocean reservoirs, or in products (Cabral et al., 2019). In the Northwest, bioenergy strategies to date have focused on several areas including utilization of waste biomass through processing technologies that provide other co-benefits to the region. To date, economics and incentives have usually favored use of the produced energy by other sectors of the economy, but there is the potential to use regionally-produced biofuels to meet energy needs within the agricultural sector so that, for example, renewable natural gas from dairy digesters could be used to transport milk to processing facilities.

Specific technologies of interest in our region include anaerobic digestion (including manures and “co-digestates” that may be pre-consumer food wastes), pyrolysis of woody wastes, and oilseed bioenergy crops that provide benefits when added as a rotational crop within existing cropping systems. A longstanding research and extension project also investigated the potential of

bioenergy from purpose-grown poplar from 2011 through 2019 (AHB NW, 2020). Because anaerobic digestion and biochar have been covered from an agricultural perspective already, we discuss only oilseed integration in this section.

I. Oilseed Cropping

Though oilseeds are still a minor crop, acreage has grown substantially over the last decade, with canola (the most commonly grown oilseed) expanding to 160,000 acres by 2024, a 15-fold increase since 2010 (USDA NASS, 2024). Alongside innovative growers who have experimented and integrated oilseeds into their systems (e.g., Sowers et al., 2011; Sowers et al., 2012; Yorgey et al., 2016; Yorgey et al., 2019b), researchers have targeted both breeding efforts for spring and winter cultivars that perform well in the inland Pacific Northwest, and work to improve crop-, soil- and zone-specific management recommendations for seedling emergence and stand establishment, fertilization, and weed control strategies (Long et al., 2016; Kirby et al., 2017; Pan et al., 2016). These advances have helped to speed adoption and integration in both dryland and irrigated systems, though social and policy constraints are still relevant (Maaz et al., 2018).



Canola growing in Whitman County (photo by Diana Robinson)

Section III. The Big Picture of Climate Mitigation through Agriculture

Food systems are complex and operate within the global economy. The following sections describe some features that cannot be ignored when targeting emissions reduction via agriculture and encouraging organic and climate-smart agricultural practices.

I. Importance of Food Production in Washington State

As documented in [Section I.I](#), Washington is one of the leading agricultural states in the United States (WSDA): the total value of its agricultural production is \$14 billion, and agriculture and food processing together are the second largest export category of the state, supporting 164,000 jobs (USDA NASS, October 2024; WSDA). Equally important to the economic impact is the fact that the state's main products – fruit, potatoes, wheat, dairy and beef – are all nutritionally dense food products that play a crucial role in state, national, and global food security.

Washington's leading role as an agricultural producer is driven by several comparative advantages. It has one of the widest varieties of growing climates and regions in the nation, highly productive soils, some of the lowest energy costs in the nation, expansive irrigation coverage, and a strategic location connected to international markets. But it is not just the biophysical conditions and infrastructure: based on wages paid for agricultural labor (U.S. Bureau of Labor Statistics, May 2023) and laws in place to protect farm workers¹⁶, Washington State is also one of the more responsible producers of food in the U.S. and in the world. For these reasons, it is not optimal for the state's agricultural output to be produced elsewhere.

Additionally, any reductions in the state's cropland could also come with added greenhouse gas emissions: from conversion to suburban or urban land within Washington (see [Section II.II](#)), and from increases in emissions associated with resulting cropland expansion in other regions of the world. Studies have shown that if cropland contracts in production regions that are highly integrated in global markets and that have small domestic emissions factors for land-use change – such as Washington State – it generally leads to expansion of cropland in places where land use and land use change have a relatively higher emission intensity (e.g. countries that would have to clear rainforest to expand production, like Brazil), thus resulting in a net increase in emissions (Lobell and Villoria, 2023; West et al., 2010) (see also [Section II.I.I](#), relating to land use change and emissions).

The current and projected future impacts of climate change further underscore the importance of preserving Washington's productive agriculture. Disruptions to global food production and value

¹⁶ <https://legislature.vermont.gov/Documents/2024/WorkGroups/AgLabor/Legal%20Documents/W~Sophie%20Zdatny~Matrix%20of%20State-by-State%20Employment%20Laws~11-15-2024.pdf>

chains are increasing in frequency and intensity (Ortiz-Bobea et al., 2021), pointing to the need to bolster national and local means of food production and distribution.

More specifically, changing weather patterns are expected to push crop-productive areas further north and decrease the yield of several food crops (Sloat et al., 2020), increasing the relative importance of northern states like Washington. Although there are significant uncertainties, overall the state is expected to fare better than many other regions of the United States due to several factors, including more severe drought risk in regions like the Southwest and projected shortage of groundwater in California (Escriva-Bou et al., 2023; Whittemore et al., 2024). While Washington's agriculture is also expected to face many consequential impacts of climate change (see Whittemore et al. 2024 for a detailed overview), the state's surface water availability and extensive irrigation systems, relatively temperate climate, and diversity of crops underscore its potential as an agriculturally crucial region.

II. Addressing Leakage and Overall Food Systems Emissions

A frequent concern around the adoption of both climate-smart and organic agriculture is whether these practices could reduce farm productivity. Lobell and Viora (2023) studied a hypothetical scenario in which climate-smart practices reduce crop production by 5% in regions with different characteristics using the example of cover cropping. In places like the U.S. and Washington State that are highly integrated to markets and have a small domestic emissions factor for land use change (compared to main competitors), reduction in productivity leads to a contraction of domestic farmland (since productivity losses decrease competitiveness) that then leads to expansion in global cropland – which generally comes with a higher emission intensity. The resulting net effect is a large increase in total emissions. The paper concludes that the net climate benefits of practices like cover cropping are significantly reduced in most countries. That said, this and other related analyses rely on specific assumptions: here, a definite productivity loss, which other analyses have not found to be the case for cover crops (Bergtold et al., 2019).

Similar concerns have been raised relating to organic agriculture (Reganold and Wachter, 2016; Seufert and Ramankutty, 2017; and cites therein). At least for some crops (such as apples) for which organic yields are not demonstrably lower, these concerns are likely to be unfounded. Even then, an important takeaway is that given the nature of markets, any policies promoting adoption of climate-smart practices must take into account the potential implications of changes in productivity, and that not just from the perspective of farm profitability but also climate mitigation itself. For organic systems specifically, the current evidence base suggests that these systems can have a superior yield and environmental performance in the case of certain crops, regions, and conditions; while in others, benefits (including impacts to climate footprint) are less evident (Naburrs et al., 2022; Seufert and Ramankutty, 2017).

In addition to considering the “leakage” effects (i.e., net increase in emissions elsewhere) that could result from lower productivity per acre or from policies that lead agricultural production to leave Washington, there are also demand-side approaches within agriculture. Some of the mitigation benefits from demand-side approaches might not appear within Washington's greenhouse gas inventory but should nonetheless be considered as part of a holistic approach to reducing climate emissions (see [Section I.III](#) for a discussion on sector versus consumption based emissions accounting). One critical demand side strategy is to minimize both food loss (food that goes to waste before farmgate) and food waste (losses on the retail and consumer side). Reducing

waste and losses would result in twofold emissions reductions: first, in terms of the emissions “embedded” in wasted food (that is, associated with its production, distribution, and refrigeration), as well as in form of the methane emissions that result from wasted food breaking down under anaerobic conditions in landfills (Monroe et al., 2022; Vermeulen et al., 2012).

Food waste and loss together are responsible for 4% of greenhouse gas emissions in the U.S., a quarter of which results from crops that are not harvested due to cosmetic standards, labor challenges, or other reasons¹⁷ (ReFED, 2021). Washingtonians generated 1.2 million tons of food waste in 2015 (Monroe et al., 2022). Recommendations formed by Use Food Well Washington Plan¹⁸ have the potential to reduce greenhouse gas emissions by over 1.6 MMT annually, avoiding over \$150 million in climate change impacts in process (Monroe et al., 2022).

Generally, a key trend over the last decades is the increasingly important role of food-related emissions generated outside of agricultural land, as part of pre- and post-production processes along the agri-food system (Tubiello et al., 2022). These stages recently overtook farm-level processes to become the largest greenhouse gas component of agri-food system emissions in industrialized nations, including the U.S. This trend has important repercussions for food-relevant national mitigation strategies that until recently have focused on reductions of non-CO₂ gases within the farm gate and on CO₂ mitigation from land use change (Tubiello et al., 2022).

Another important demand-side strategy is supporting dietary changes that could reduce greenhouse gas emissions while also benefiting public health. A report analyzing potential emissions reduction pathways for U.S. agriculture projects that while changes to farming practices could eliminate ~40% of agricultural emissions in an optimistic scenario (via reductions in emissions from soil management, enteric fermentation and manure management), an additional ~17% reduction could come from changes to food consumption patterns (see [Figure 10](#); Boston Consulting Group, 2022). It is generally important to keep in mind that greenhouse gas emissions are only a fraction of the public costs imposed by the current food systems in the United States, with larger contributions from the cost of obesity and non-communicable diseases and the loss of biodiversity (Rockefeller Foundation, 2021), emphasizing the need to target actions that simultaneously address multiple issues.

¹⁷ 17% of produce in the U.S. is estimated to never be harvested (ReFED, 2021).

¹⁸ <https://apps.ecology.wa.gov/publications/documents/2107027.pdf>

Figure 10: Projected changes to selected food systems emissions under different scenarios



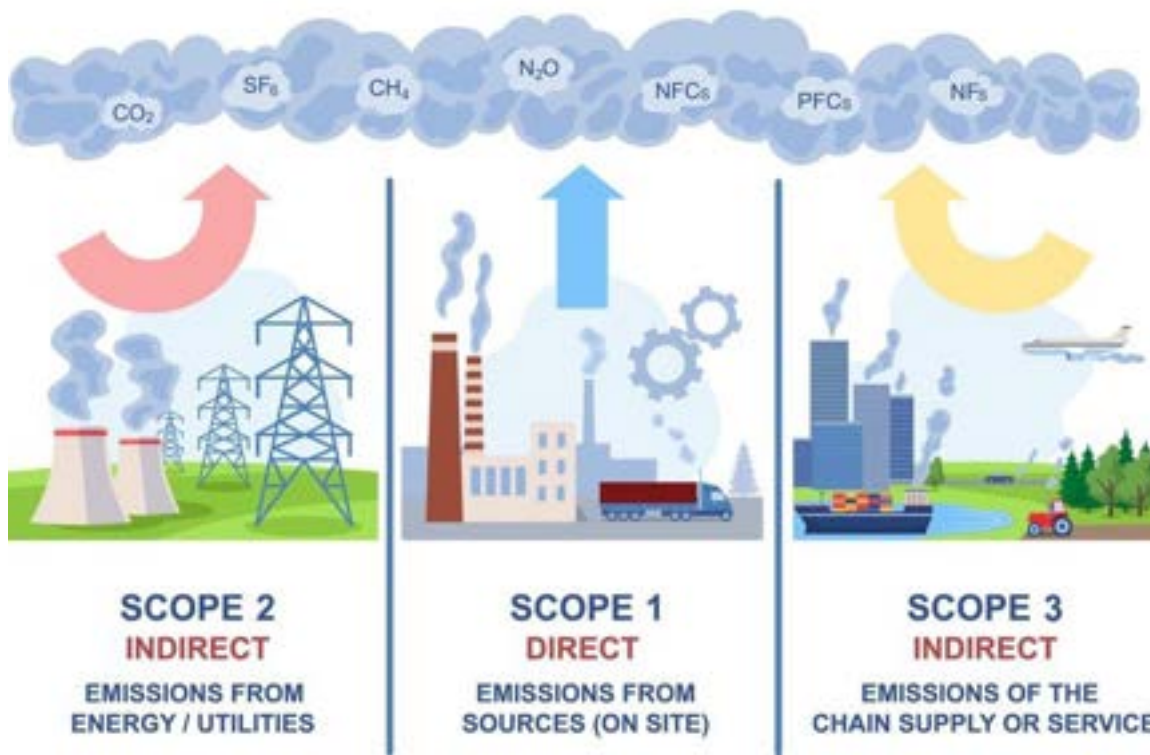
From Boston Consulting Group (2022) “US Agriculture and the Net-Zero Challenge”. Reprinted with permission from the Walton Family Foundation.

III. Agricultural Carbon Markets

In response to changing expectations from consumers and shareholders, the private sector has exponentially increased their efforts to develop decarbonization strategies in support of greenhouse gas emissions reduction targets they have set¹⁹ (Seymour and Langer, 2021). Due to organizations’ need to measure, manage and report on their emissions, both voluntary and mandatory disclosure initiatives have proliferated. Most of such initiatives cover direct emissions produced by a company (labeled as Scope 1 emissions), and indirect emissions from the production of any purchased energy (Scope 2; see [Figure 11](#)). However, in many cases emissions that occur in the value chain of a company – upstream and downstream of its own operations – make up most of its footprint (Seymour and Langer, 2021). The latter are called Scope 3 emissions. In the case of the agricultural commodities sector and the food, beverage and tobacco sector, Scope 3 emissions comprise 92% and 87% of all emissions, respectively (CDP, 2024). In turn, a large share of these Scope 3 emissions are associated with agriculture. For Nestlé, for example, ingredient sourcing makes up 67% of their total emissions (Nestlé, March 2023).

¹⁹ Many large companies producing food and beverages have set net-zero emissions targets for 2050, and separate reduction milestones by 2030: Nestlé has pledged to reduce all of their emissions by 50%, PepsiCo their Scope 3 emissions by 40%, Unilever their emissions associated with agriculture by 30.3% and McDonald’s by 16% (all by 2030).

Figure 11: Scope 1, 2 and 3 emissions of a company; emissions from most agricultural activities fall under Scope 3



Source: iStock.com/Rudzhnan Nagiev

In March 2024, the U.S. Securities and Exchange Commission (SEC) finalized a rule that requires companies to disclose some of their emissions if they are deemed financially material to investors²⁰ – similar to what is done in the European Union, as well as on the state level in California.²¹ While the draft version of the SEC rule had mandated companies to disclose Scope 3 emissions across their value chain, it was not required in the final version, meaning that most agricultural emissions are not covered by mandatory disclosure yet.

To voluntarily reduce their emissions, companies rely on two broad strategies: directly reducing emissions from their operations and supply chains and purchasing voluntary carbon credits. Such purchases, generally called carbon offsets, mean that a reduction in greenhouse gas emissions or an increase in carbon storage in one place is used to compensate for emissions that occur elsewhere (Broekhof et al., 2019). From a farm perspective, “offsets” could be generated and sold to those in other economic sectors who are hoping to reduce their carbon footprint.

Offsets are the basis of most emerging agricultural carbon markets through which farm-level interventions are used to advance corporate decarbonization strategies (Perez et al., 2023). As defined by the American Farmland Trust, an agricultural carbon market is a set of agreements and monetary transactions between buyers and sellers, where buyers are corporations who have made

²⁰ <https://www.sec.gov/newsroom/press-releases/2024-31>

²¹ In Washington state, a senate bill considered mandatory disclosure of all greenhouse gas emissions by businesses above a certain size in early 2024.

voluntary commitments to lower their greenhouse gas emissions or who face mandatory regulations; sellers are farmers who can implement climate-smart practices to achieve emission reductions more cost-effectively than the buyer; and carbon market developers serve as intermediaries who establish eligibility rules and terms, monitoring and verification, etc.

As of 2023, there were at least 27 active agricultural carbon markets in the U.S., some of which are voluntary offset markets, some compliance offset markets, and the newest form to emerge are inset markets specific to individual corporations (e.g. Cargill, PepsiCo) (Perez et al., 2023).

“Insetting” is characterized by emissions reductions or removals that are within the Scope 3 emissions boundaries of the company itself (WWF, 2019), and often includes interventions at farm level (i.e., emission reductions from which then get counted towards mitigation goals of the food manufacturer that the farm supplies to). While a carbon offset credit is a payment for an outcome – 1 MT of CO₂e emissions reduced/sequestered – that is verified by an independent third party, certified, and registered with a unique serial number into a secure ledger called the “registry”, insets most often pay for practices themselves (e.g. per acre of adoption) (Plastina, 2022). Their outcomes are thus hard to quantify, and they are often deemed as lower quality.

Importantly, many of the well-established agricultural carbon markets are not open to farmers in Washington because of geographic or crop limitations. Plastina et al. (2024) summarizes eight well-known carbon initiatives, and none one of them are available in Washington State²² (see Table 1 of Plastina et al. (2024)). Most agricultural carbon programs have so far focused on specific commodities: initially, the focus was on livestock and rice. More recent programs are targeting large acreages of commodity row crops, particularly corn, soybeans, and wheat (Perez et al., 2023). The focus on large row crop acreage rather than grazing lands or specialty crops is driven largely by a greater understanding of soil carbon dynamics in row crop systems, or rather, a more significant gap in understanding soil carbon dynamics in grazing and specialty crop systems. There are, however, newer programs that are open to participants from any state (see Table 8). Based on information available as of early 2025, Agoro Carbon, Indigo Ag, ADM Partners and TruTerra Financial Assistance are four programs available in Washington. The crops they support, however, are almost exclusively row crops, with some also supporting rangeland management. Prices paid vary greatly. All programs have minimum size requirements ranging from 150 to 500 acres.

²² Table 1 of Plastina et al. (2024) indicates that Nori operates in Washington, but this market closed in 2024.

Table 8: Prices paid for outcomes (carbon removal) and adoption of practices by different agricultural carbon programs operational in Washington.

Company	Payment
<u>Agoro</u>	\$16.50-\$20 / ton of CO ₂ e
<u>Carbon by Indigo Ag</u>	up to \$10 / acre for no till up to \$20 / acre for cover crops
<u>ADM Partners / re:generations</u>	\$2-5 / acre for nitrogen management \$2 / acre for no till or strip till \$10 / acre for cover crops
<u>Truterra Financial Assistance</u> (a USDA program)	\$20 / acre for no till \$80 / acre for cover crops \$100 / acre for no till and cover crops

Table adapted from Bonnie McGill (American Farmland Trust) and updated in February 2025.

Nationwide, the top three practices that agricultural carbon programs currently pay for are no-till or reduced till, cover crops, and nutrient management (Perez et al., 2023; Plastina et al., 2024). While it is an attractive concept for a farmer to be paid to transition into using these practices – which could help with both equipment purchases and recovery of any foregone revenue (Boston Consulting Group, 2023) – participation in these markets remains low. This has several reasons. First, the payments offered are usually modest, ranging from \$1-34 per acre for inset markets to \$15-45 per credit for offset markets (Perez et al., 2023). Meanwhile, in the Midwest where these programs are most active, the variable costs of cover cropping, for example, could range anywhere from \$42 to \$119 per acre depending on the crop (Bergtold et al., 2019). (For comparison, the USDA’s Environmental Quality Incentives Program (EQIP) pays about \$62/acre for cover crops and about \$17/acre for no-till for a short-term contract in Illinois²³, for example.) Recent estimates from Washington put the cost of establishment and maintenance of cover crops to \$106-368/acre for non-irrigated land and to \$166-337/acre for irrigated land²⁴ (Santosa et al., 2021). A recent farmer survey in the western U.S. finds that cost of cover crops is the top-ranked barrier to adoption (Golden et al., 2023), which is why these economic considerations cannot be overlooked.

Second, carbon markets – and particularly offsets – are complicated by the requirement of additionality: any carbon program has to ensure that a buyer’s payment results in new greenhouse gas reductions or carbon sequestration beyond what would have occurred without the payment.²⁵

²³ From USDA NRCS, FY23 EQIP Payment Schedule for Illinois.

²⁴ The study estimated the following total costs (in 2020 USD) of cover crop adoption and maintenance: at a non-irrigated Puyallup site, \$106/ac for crimson clover, \$107/ac for hairy vetch, \$368/ac for triticale, and \$815/ac for fava bean; at an irrigated Othello site, \$212/ac for crimson clover, \$166/ac for hairy vetch, \$337/ac for triticale, and \$245/ac for winter pea (Santosa et al., 2021).

²⁵ This definition is adapted from the Greenhouse Gas Protocol, the standard-setting body for greenhouse gas measurement and management led by World Resources Institute (WRI) and World Business Council for Sustainability

That is, their payment serves as an incentive for farmers to accomplish a reduction through their adoption of *new* climate-smart practices – the same logic that USDA’s Environmental Quality Incentives Program applies (USDA NRCS, 2017). Unfortunately, this criterion means that farmers who are early adopters of carbon sequestering practices such as cover crops or no-till are not eligible for participation in most carbon markets and programs. This is seen as a major shortcoming by farmers and many other stakeholders, and especially so within those practicing organic agriculture as they are deemed ineligible directly because of having applied many qualifying practices for years or sometimes decades (Barbato and Strong, 2023).

Similarly, rangelands experts argue for rewarding active management to maintain existing carbon stocks in rangelands (IWJV, 2021; Maxwell et al., 2024; SRM, 2023). Given the magnitude of potential emissions from rangelands when they burn or are converted by invasive annual grasses, as well as the significant costs of and challenges to effectively restoring these systems once impacted, mechanisms focused on carbon security rather than additionality are critical to effective mitigation of greenhouse gas emissions in rangelands. These mechanisms will also need to address the disconnect between the private costs to ranchers of securing soil carbon, and the public benefits of those actions (SRM, 2023).

The American Farmland Trust has devised recommendations to alleviate the concern of farmers missing out on program participation due to having been early adopters (Parkhurst et al., 2023). They suggest an updated definition of “new” practices that considers climate-smart practices that were started and disadopted more than 10 years ago as new if re-adoption of them can be shown to decrease net greenhouse gas emissions and call for carbon programs to stop capping participation once adoption of a practice reaches a certain threshold in a given area, which is currently a common practice. They also encourage additional opportunities for rewarding early adopters, for example, via peer-to-peer training where early adopters are paid to teach other farmers to uptake similar practices (Parkhurst et al., 2023). Early adopters could also be encouraged to participate in programs such as USDA’s Conservation Stewardship Program that rewards producers who have adopted multiple conservation practices and are addressing at least two resource concerns. The program also incentivizes adoption of more advanced versions of the same practice on the same acres or new acres if certain conditions are met.

There are a handful of other considerations. While most carbon markets do not exclude leased or rented land, they may require the landowner to co-sign the carbon contract or at least give written permission for the renting farmer to participate in the contract, while losing a land lease may result in default on the contract (Carpenter and Kuehn, 2023; Perez et al., 2023). Of the 13.9 million acres of active farmland in Washington, roughly 38% is rented out, although there is great spatial variation with much higher ownership rates on the western side of the state, and lower rates in the southeast where commodity wheat is grown (Bigelow et al., 2016). Sustainable leasing agreements have the potential to provide financial support for farmers who rent land, especially since well managed land may appreciate in value, resulting in no benefits (or even a net financial loss) of practice adoption for a farmer who rents (Boston Consulting Group, 2023).

Participation in carbon programs also requires high administrative capacity and at a very minimum access to high-speed internet, which can be a challenge in rural areas (Pankhurst et al., 2023).

(WBCSD). They define additionality as, “The intervention (e.g. project or activity) reduces emissions or increases removals relative to the amount of emissions or removals that would have occurred without the incentives provided by the credit” (WRI & WBCSD, 2022).

Almost all of the eight carbon initiatives summarized by Plastina et al. (2024) require three to five years of historical field management data as a prerequisite for joining the program (although some also incorporate data collected by the program via remote sensing). Measurement of carbon outcomes requires soil testing and use of a model like DayCent or COMET-Farm, and annual interactions with a verifier are expected. All these things – in addition to explicit minimum farm size requirements which are occasionally in place (Plastina et al., 2024) – can exclude smaller, older, less connected and less technologically capable producers from financial incentive programs.

Historically, programs allowed farmers to ‘stack’ payments by private carbon programs and by state and federal programs, and often even encouraged farmers to seek financial assistance from public conservation funds. However, some emerging carbon programs do not allow farmers receiving federal (USDA) conservation program funds to participate.²⁶ Given that many practices come with both fixed starting costs as well as continuous maintenance (variable) costs, and that public and private programs often only cover (or partially cover) one of these cost types, there is a crucial opportunity for such programs targeting emission mitigation to complement each other. It is not unheard of, for example, that a grower receives funds from a cost-share program to purchase equipment for purposes like alternative manure management but later ends up disadopting the equipment because of the regularly occurring operating costs (e.g. electricity, maintenance, labor) that become difficult to cover in a cost-constrained environment. Therefore, as one possible arrangement, where public funding aimed at climate mitigation can be well positioned to support one-time on-farm investments, private carbon markets can then support the on-going maintenance costs, especially in the initial years of practice adoption. Regardless of the arrangement, increased attention by policymakers to the role that private carbon markets can play – and the constraints therein for agricultural producers, especially those underserved by the markets – is warranted.

IV. Farmer Perspectives on Climate-Smart Practices

Farmers’ motives to adopt practices, as well as the various constraints they face in doing so, are nuanced and a comprehensive account of them is beyond the scope of this report. Here we will, however, discuss a few key factors.

A central motivation for farmers to implement climate-smart practices are benefits to soil and crop health, and the long-term economic sustainability garnered from those benefits (Buck and Palumbo-Compton, 2022; Greiner and Gregg, 2011). A recent study from California sought to investigate how farmers who are heavily invested in soil health perceive the newly emerged and rapidly changing carbon offset marketplace. Barbato and Strong (2023) interviewed conventional row-crop farmers who were participating or seeking to participate in carbon offset markets, and organically certified row-crop farmers who were engaging in soil carbon sequestration practices but not in carbon markets (nor were eligible due to additionality requirements). They found that the motives for practice adoption, regardless of participation for financial incentives, were based on concerns for sustainability. Farmers were motivated to adopt practices like conservation tillage, cover cropping, and compost/soil amendments because of interest in long term sustainability, crop health, and farm profitability, while some wanted to improve their resilience to floods and droughts. The authors concluded that payments from the carbon offset market are not the main driver for

²⁶ In Washington state, 22% of agricultural land is enrolled in federal conservation programs as of 2019, a higher share than in most other states (Newton, 2019).

participation in programs; many farmers found the compensation to be too low and the markets to be skewed to benefit larger-scale agriculture (Barbato and Strong, 2023). It is clear that while incentives matter – if they are sufficient – efforts to promote certain practices would always gain from having farm-level, production-system specific data to clearly communicate the expected benefits to growers.

There are many barriers to adoption of climate-smart practices. In Washington, these include ineffective communication about current science, inadequate funding, and insufficient technical education and assistance ([Appendix A](#)). Agricultural stakeholders are under the impression that climate-smart agriculture can have outcomes that conflict. For example, no-till systems might have a greater capacity to store carbon, but at the same time chemicals are used to control weeds which degrade soil health. Ineffective communication also results from the use of exclusive language. The term “climate-smart agriculture” is not a common phrase among farmers who instead might use the term “conservation practices.” High costs of implementation and inadequate funding can be significant barriers, as any long-term funding is absent in the state. For example, there is adequate funding to support a farm’s transition from conventional to organic farming, but once the transition is complete, funding declines. Another barrier specific to organic systems mentioned by stakeholders is the requirement of large riparian buffers that especially challenge the viability of small acreage farms. Finally, there is insufficient conservation technical assistance for farmers to rely on to enroll an individual in programs. Without adequate technical assistance from well-informed staff, producers can have trouble navigating programs that support particular practices of interest.

Washington State can scale up climate-smart agriculture practices through additional flexible funding, improved research and data, effective communication and technical assistance with farmers, and enhanced access to tools and technology ([Appendix A](#)). Additional funding that is flexible in regard to eligibility and timing would expand opportunities to farmers. High quality research to define baselines and evaluate the effectiveness of climate-smart practices over the long-term can indicate advantages and disadvantages of different practices. Communicating to farmers about climate-smart practices and emphasizing the on-farm benefits to producers, such as the saved time and money, will generate more engagement with farmers. Developing new tools and improving existing equipment such as soil sensors and manure digesters can help farmers add valuable services and enhance their contributions to the state’s climate goals.



Section IV. Conclusion

Diverse climate and productive soils, robust energy, irrigation, and transportation infrastructure, and innovative producers have made Washington one of the leading agricultural states, producing nutritionally dense food products that play a crucial role in state, national, and global food security. The state is also one of the more efficient and environmentally and socially responsible producers of food in the U.S. and the world.

Voluntary greenhouse gas emissions reductions in agriculture could be supported by the state to create both immediate and longer-term benefits. While some of these benefits would accrue to the sector, many of them would accrue to the public in the form of climate mitigation, improved air and water quality, increased soil water retention, reduced erosion, improved biodiversity, and maintenance of rural landscapes.

Policymaking in this space must consider the larger picture of greenhouse gas emissions from food systems and the societal role of agriculture. Farming is a cornerstone of society that also has unique potential for reducing greenhouse gas emissions, preserving soil carbon, and potentially sequestering extra soil carbon. From that perspective, an acre of farmland converted to urban or residential development is associated with a larger change in emissions than any shift in

agricultural practices. Similarly, the potential for loss of sequestered carbon from the degradation of rangelands is orders of magnitude greater than management changes can achieve.

Any agricultural production that gets pushed out of the state and moved elsewhere has a high likelihood of being associated with higher net emissions due to land conversion and/or higher emission intensity of production elsewhere. Therefore, for both food security and reduced greenhouse gas emissions, it is important to invest in permanent farmland protection via conservation easements, strong agricultural zoning laws and other measures, limit urban sprawl, and support rangeland preservation. Ensuring that economic viability is supported and regulatory impacts are streamlined is another likely piece of the puzzle.

Existing data relating to the climate mitigation potential from particular climate-smart agriculture strategies in Washington's agricultural systems are limited. We are thus unable to make comprehensive quantitative conclusions regarding the mitigation potential of organic and climate-smart practices in terms of MMT CO₂e. Instead, we can direct the state toward short-term and long-term opportunities based on our limited data.

In the short term, opportunities to mitigate greenhouse gas emissions in agriculture should focus on supporting voluntary action by producers in implementing existing management strategies and technologies that could make a big difference. This could include ongoing investments in:

- Ongoing work to ensure that governments at multiple levels support agricultural viability across the state.
- Continued support for and evaluation of the effectiveness of targeted grazing, where livestock are grazed in ways that target invasive annual grasses to achieve wildfire risk reduction goals. These strategies are now more achievable through virtual fence systems and a strong research base for outcomes-based grazing.
- Improved manure management on smaller farms (solid-liquid separators, manure lagoon covers).
- Anaerobic digestion (for larger farms with more than ~3,500 mature cows in a given location).
- Feed additives for reductions in methane emissions from enteric fermentation.
- Encouraging a portfolio of strategies for mitigating nitrous oxide emissions, including the four principles of fertilizer management (right rate, right time, right placement, and right source), knowing that there are likely to be strong co-benefits to air and water quality from any continued improvements in this area. Supporting the growth of organically certified farms could also lead to lower nitrous oxide emissions.
- Continued support for implementation of soil health practices and non-cultivated perennial plantings that enhance carbon sequestration on both organic and conventional farms, while being realistic about the potential climate benefits – but also knowing that these practices support preservation of existing carbon, agricultural climate resilience and many other important public benefits including clean air, water, and soil health.
- Strengthening efforts to increase yields from organic systems, especially where there is a “yield gap” between conventional and organic production.
- Continued support for training, technical expertise and extension to educate growers and communicate about practices in ways that meet farmers’ and ranchers’ needs.
- Adequate staff to assist producers with navigating programs that fund climate-smart practices.

Any strategy implemented needs to consider both the initial up-front costs *and* the financial mechanisms that are going to support ongoing costs of operating and maintaining the use of

practices and technologies over time, with consideration to both public and private market-based mechanisms. On the public side, agricultural stakeholders in Washington have emphasized the need for flexible grant funding, continued financial support after converting from conventional to organic farming, and expanding eligibility and timing for grants. Washington can also help support demand for organic food purchasing to further support organic farms.

Over the longer term, continued opportunities for climate change mitigation are likely to rely on advances in science and implementation to reduce the global warming impact of food production, with a focus on emissions that may be more challenging to abate. Improved data over the long-term can demonstrate the advantages and disadvantages of different climate-smart practices, and long-term investments may be needed to drive technological development that adds new options for reducing the climate footprint of agriculture, and address cost and scale barriers of current technologies. These strategies will need to be informed and refined by continued strong collaborations between industry, the research community, and agencies, to identify additional practical situations in which advanced carbon sequestration strategies could maximize benefits for the public and for agricultural producers while creating meaningful climate benefits. Our review suggests that initial priorities could include:

- Identification and then implementation of feasible and meaningful ways to continue to reduce nitrogen losses in specific Washington cropping systems, while maximizing the benefit-to-cost ratio.
- Ongoing technology investments into anaerobic digester and biofuel strategies that focus on regionally appropriate implementation within a systems approach that maximizes holistic benefits (e.g. in terms of nutrient and carbon management), with a particular focus on making the technology economically viable for smaller farms.
- Continued research and integration of best practices with respect to utilization of agrivoltaics in different cropping systems, electrification and energy efficiency improvements in farm machinery, and development of lower emissions fertilizers.
- Continued investment into strategies with the potential for more durable carbon sequestration on working lands (that likely complements but certainly does not replace more traditional methods):
 - Biochar as a means of processing agricultural residues (e.g. woody orchard or hop residuals, wheat straw in those areas where residues complicate no-till planting).
 - Biochar production from forest residuals in areas where thinning is needed to reduce fire risk and preserve standing forestry carbon.
 - Work to explore enhanced rock weathering with a likely initial focus on applying basalt from eastern Washington to western Washington agricultural sites. Research should aim to determine the practical long-term potential for carbon sequestration; while investigating and mitigating the risks such as impacts from trace metal accumulation, dust inhalation, and pH impacts to waterways.
- Supporting and expanding rangeland wildfire risk mitigation efforts using established frameworks for semi-arid ecosystem conservation. Limiting and managing wildfire will be necessary to both prevent short-term carbon release and to reduce long-term carbon loss through plant community state shifts away from perennial grasses and shrubs.
- Supporting collaboration across agricultural sectors, including rangelands and croplands, to design and establish mechanisms that can translate the public benefits of securing existing soil carbon stocks into funding that enables and supports private producers' efforts to ensure such carbon protection.

Alongside these practical strategies, ongoing work to improve the estimates for climate mitigation potential of specific strategies would help refine prioritization of state actions, and potentially also support market-based approaches. Like other actions, this could build on strong linkages between industry groups (who have insights into the practice(s) that may be most appealing and realistic within their agricultural systems), the scientific community (who have insights into the climate mitigation benefits that can be expected, and who can implement longer-term research strategies to overcome remaining barriers), and agencies (who have insight into the most effective state strategies for support). This work will require ongoing scientific development, including the collection of additional data from both organic and conventional long-term experiments linking management practices to primary long-term data on soil carbon sequestration and methane and nitrous oxide fluxes, meta-analyses across long-term datasets, and modeling approaches. Further, an assessment of cost effectiveness of practices would be the next step to better understand what climate-smart practices can make the biggest impact to the state's climate goals.

Without quantified baselines, it is difficult to measure progress. Washington State's current greenhouse gas inventory relies largely on national data and assumptions and thus would not reflect many changes in local management. Ongoing collaborations to improve the statewide greenhouse gas inventory in ways that do not put additional administrative burden on farmers and ranchers can help ensure that any progress by agricultural producers is evident at the state level.

There are limits to what can be achieved via on-farm practices. Food waste and loss is responsible for over a third of all food systems' emissions. Measures that prevent food loss before food reaches consumers and that curtail food waste by consumers include optimal regulation for diverting food to the highest possible use (e.g. food recovery to address food security, feeding to animals); developing direct-to-consumer distribution models and regional supply chains; and developing demand base for compost and other processes used to sustainably manage food waste.

Overall, changes that reduce emissions and sequester carbon into soils must be financially viable to and well understood by the producer. To that end, the state can make sure that its efforts complement voluntary carbon markets emerging in the Pacific Northwest in that any support mechanisms are not duplicative. Several advancements in tools could also help farmers receive "credit" for management practices they implement and support the development of financial and other mechanisms for promoting climate-smart practices over time: ongoing improvements to tools that are currently used at the individual farm level (e.g. COMET-FARM, Farm-ES), incorporating estimates of associated emissions uncertainty into these models, and developments that allow farmers to easily "translate" between tools used within the public and private sectors.

By supporting investments in climate-smart and organic practices, Washington has the potential to drive innovation and agricultural competitiveness. These investments will benefit the whole sector, while producing nutrient-dense foods, supporting rural livelihoods, and positioning the state as a leader in climate-smart agriculture.

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Appendix A: Summary of Interviews

Summary of Findings

To support this evaluation, the SCC contracted with KR Creative Strategies (KRCS) to conduct stakeholder interviews and document the results. This appendix provides a comprehensive summary of the findings, drawing on insights from 29 interviews conducted between July and August 2024. It highlights key themes that emerged from stakeholder responses, offering a detailed analysis of the feedback gathered.

Stakeholders from production agriculture and non-production agricultural partners offered a variety of perspectives on climate-smart and organic agriculture in Washington and how to optimize approaches to achieve climate goals. Among these, four prominent key themes emerged.

Themes and theme descriptions reflect the responses and perspectives most frequently heard during stakeholder interviews—they are not an endorsement of a specific position or a representation of the views or opinions of the entities involved in conducting this evaluation.

Theme 1: Funding, Risk Mitigation & Expert Assistance

Agriculture needs flexible, grantee-driven funding & assistance to navigate change.

Stakeholders overwhelmingly emphasized the need for grantee-driven funding that can adapt to the rapidly evolving conditions within the agriculture industry. These shifts are impacting farmers across multiple areas, including weather patterns, farming practices, crop selection, feed availability, supply chains, insurance, easements, and equipment. Current funding for climate-smart agriculture falls short in supporting farmers as they navigate these changes and in addressing the risks involved in modifying their operations. Moreover, the complexity and frequent changes to various funding programs make it difficult for farmers to assess their eligibility and relevance for their specific needs. Washington must increase on-the-ground conservation technical assistance to guide farmers in identifying and securing the most suitable funding opportunities.

Theme 2: Research & Data

Agriculture needs baseline data & proven, on-farm results.

State and federal governments offer several programs that promote adoption of climate-smart practices. Without baseline data, it's extremely difficult to measure progress and track impact. The complexity and site-specific nature of collecting reliable data on the mitigation potential of many climate-smart practices, such as cover crops, adds another layer of challenge to this issue.

Making any operational change can present significant risk for farmers, whose livelihoods often stand in the balance. Without better baseline data and on-farm results, producers assume an even higher level of risk when they're asked or expected to implement new or unproven practices.

Theme 3: Recognition for Agricultural Contributions & Value

Climate-smart policies in Washington should support agriculture, not target it.

All agricultural land has value. Climate-smart approaches should lead with keeping farmland in production, regardless of whether it's conventional or organic farming. There is a lack of public understanding about the role and economic impact of the agriculture industry in Washington and internationally. People expect food to be readily available and affordable, without understanding all that it takes to grow, harvest and transport it.

Family farms and the agriculture industry feel unfairly targeted as the culprit for climate-related issues and environmental degradation. Many feel that farmers are vilified and the subject of policies that force land out of production, while at the same time they're being asked to solve the climate crisis and supply the world with healthy and affordable food. This feels unfair and misguided. Many perceive an increase in regulation, unviable operations and distrust of government. This has resulted in growing concerns about mental health for those working in the agriculture industry.

Theme 4: Inclusive Approach for a Collaborative Process

Build approaches to climate-smart agriculture from the farm up.

Some existing programs and approaches for implementing climate-smart agriculture in Washington are out of touch with on-farm realities. For example, many interviewees noted that grant funding cycles are misaligned with the growing season, making participation impractical. Others noted that even the language used in the climate-smart space—including the term “climate-smart agriculture” itself—can feel disrespectful and dismissive of the agricultural community. In conversations with agricultural producers, many interviewees asked for clarification about what practices are considered “climate-smart;” when they saw the practice list, many quickly identified what they more commonly referred to as “conservation practices” from that list that they have implemented or are interested in adopting on their farm.

From terminology to funding program design, more needs to be done to acknowledge and integrate farmers' perspectives into approaches to meet Washington's climate goals.

Interview Approach & Participants

The SCC identified a list of potential interviewees, and SCC, WSU and KRCS crafted interview questions. KRCS contacted the potential interviewees provided by the SCC; scheduled and conducted interviews; and compiled findings in this report.

In consultation with SCC, KRCS adopted the USDA Natural Resources Conservation Service (NRCS) definition of climate-smart activities for the purpose of these interviews. The definition includes saving energy or fuel; improving nutrient management; conserving water; keeping carbon in the soil or improving soil health; establishing pollinator, fish, or wildlife habitat; and improving efficiency of farm forage or grazing land.²⁷ Prior to each interview, production agriculture

²⁷ NRCS Climate-Smart Mitigation Activities. (n.d.). Natural Resources Conservation Service. <https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/climate/climate-smart-mitigation-activities>

stakeholders were provided examples of climate-smart activities as identified by NRCS ([Climate-Smart Agriculture and Forestry Mitigation Activities for FY25](#)).

Interview Questions

Questions for Production Agriculture Representatives

The goal of interviews with production agriculture representatives was to understand which climate-smart practices are of greatest interest to each agricultural industry in Washington and what investments or supports would help increase adoption of these practices, (e.g., technical assistance, research, incentives).

KRCS clarified with interviewees what “climate-smart” and “climate-smart practices” refer to in the context of this evaluation. However, interviewers adapted language to the audience, using the terms “conservation” and “conservation practices” more frequently during communication with producers to use more common, inclusive and accessible terminology.

Each production agriculture stakeholder was asked the same series of questions:

1. What is your role?
2. Describe the geographic region served by your association/commission/organization and the type of agricultural producers you work with.
3. Do you work with organic farms, conventional farms, or both?
4. What are the most common conservation practices used within your industry? *If interviewee works with both organic and conventional growers, add: ...and do the most common practices vary between organic and conventional farms?*
5. Are there barriers that prevent farmers in your industry from scaling up conservation practices? If so, what are the top two barriers? *If interviewee works with both organic and conventional growers, add: ...and do those barriers vary between organic and conventional farms?*
6. For producers in your industry, what existing resources do they use most to support adoption of conservation practices?
7. What additional tools and resources are needed to support producers in adopting conservation practices? *If interviewee works with both organic and conventional growers, add: ...and do those needs vary between organic and conventional farms?*
8. Do you have any additional comments?
9. Would you like to be added to our list to receive an announcement of the webinar to be held this fall to go over results of this work and receive a copy of the final report?

Questions for Non-Production Agricultural Stakeholders

The goal of interviews with representatives from non-production agricultural stakeholders (e.g., representatives from agencies, tribes and non-governmental organizations who support or are peripherally affiliated with Washington agriculture) was to identify existing and new programs that support climate-smart and organic agriculture in Washington and perspectives on where there is potential for additional investment.

KRCS clarified with interviewees what “climate-smart” refers to in the context of this evaluation. However, interviewers balanced technical terminology with more accessible language when appropriate, such as by using the terms “conservation” and “conservation practices.”

Each non-production agricultural stakeholder was asked the same series of questions:

1. What is your role?
2. Describe the geographic region served by your organization and the type of agricultural producers you work with.
3. Do you work with organic farms, conventional farms, or both?
4. Inside your organization, please give examples of programs and resources that support climate-smart agriculture (if applicable).
5. Outside your organization, what resources are available to support Washington state climate-smart agriculture (e.g., grant opportunities, tools, and educational opportunities from NGOs, federal, state, local or other sources)? Give specific examples (e.g., WSDA Compost Reimbursement Program, NRCS Environmental Quality Incentives Program, Tilth Alliance programming)
6. What tools and support are needed to scale up climate-smart efforts in Washington state agriculture (e.g., technical assistance, financial assistance, research, economic data). If possible, please tell us *where* in the system the tools are needed (e.g., at the private sector level, farmer level, research).
7. What should we be asking?
8. Do you have any additional comments?
9. Would you like to be added to our list to receive an announcement of the webinar to be held this fall to go over results of this work and receive a copy of the final report?

Interview Format & Participants

Following a list of contacts provided by SCC, KRCS sent interview invitations to 45 individuals representing Washington agriculture producers and to representatives from tribes, commodity groups/commissions, agencies, non-governmental organizations, corporations and conservation districts. When invitations went unanswered, interviewers followed up with reminders via email and/or phone.

KRCS conducted 29 stakeholder interviews online and over the phone from July through August 2024. Interviews lasted between 30-60 minutes.

Interview Participants

- AgriNorthwest
- American Farmland Trust
- Intertribal Agriculture Council (Northwest – WA)
- Organically Grown Company
- PNW Direct Seed Association
- Producer - Dryland Wheat Farmer
- Save Family Farming
- Simplot
- Starbucks Sustainability (dairy focus)
- Tilth Alliance
- Washington Association of Wheat Growers
- Washington Cattle Feeders Association
- Washington Cattlemen's Association
- Washington Dairy Federation
- Washington Potato Commission
- Washington Red Raspberry Commission
- Washington State Department of Agriculture (three separate interviews with representatives from different divisions)
- Washington State Department of Commerce
- Washington State Department of Ecology
- Washington State Department of Fish & Wildlife
- Washington State Department of Health
- Washington State Department of Natural Resources
- Washington State Tree Fruit Association
- Washington State University (two separate interviews with representatives from different divisions)
- Whatcom Conservation District
- Wilcox Farms

Invited (Unresponsive or Otherwise Unable to Participate)

- Cenex & Harvest States
- Daritech
- N3 Dairy Consulting
- NW Washington Annual Cropping Systems
- PCC Community Markets
- Snoqualmie Tribe
- Swinomish Tribe

- The Nature Conservancy
- Vineyard Industry
- Washington Farm Bureau
- Washington Farmland Trust
- Western WA Agriculture Association
- Whatcom Family Farmers
- Zirkle Fruit

Climate-Smart Practices Used by Washington's Agriculture Industry

For the 16 interviews with production agriculture representatives, stakeholders were asked to identify the most common climate-smart practices currently used within their industry.

Most Widely Adopted Climate-Smart Practices (Conventional & Organic)

This section highlights the climate-smart practices most commonly identified by agricultural industry interviewees as being widely adopted by both conventional and organic producers to date. It is not an all-inclusive list of climate-smart practices used by producers in Washington.

See [Interview Response Summaries](#) for a more comprehensive summary of responses.

No-Till & Direct Seed/Reduced-Till

No-till and direct seed systems continue to gain momentum across the state and are becoming more commonplace on wheat farms. This is more prevalent in organic operations than people realize with the use of plastic or biobased mulch. Reduced-till is a priority within root crops, such as potatoes and onions, to reduce soil erosion between the planting and harvest seasons. Wheat farms are also practicing reduced till as weeds can be an issue in a no-till system.

Waste Management & Storage

This is a priority within the beef cattle and dairy industry. There's a great deal of effort to handle and store manure in a way that not only reduces or eliminates loss but converts greenhouse gas emissions into renewable energy (e.g. methane digesters). Organic producers also rely on manure and compost to meet their fertility needs.

Cover Crops

Use ranges across multiple farm types, including livestock production and various cash crops, such as potatoes, wheat, tree fruit orchards and others. Producers are trying this practice with varying degrees of success.

Precision Agriculture/Technology

Use ranges across multiple farm types. Variable rate technology significantly reduces input costs (e.g., from fertilizers, irrigation water) and reduces passes through the field.

On-Farm Energy Efficiency

This is a priority across many cropping systems, and many producers are pursuing this on their own. Lowering costs has been a main driver to improve energy efficiency on many farms, and now farmers see it as a potential source of revenue through voluntary agricultural carbon markets.

Barriers to Adopting Climate-Smart Practices

For the 16 interviews with production agriculture representatives, stakeholders were asked to identify the top barriers that prevent farmers in their industry from adopting climate-smart practices.

Top Barriers (Conventional & Organic Systems)

This section highlights the barriers to climate-smart practice adoption most commonly identified by agricultural industry interviewees as impacting both conventional and organic producers. Two additional and frequently mentioned barriers specific to organic systems are listed in the following section.

See [Interview Response Summaries](#) for a more comprehensive summary of responses.

Conflicting Outcomes Among Agricultural Systems

Many stakeholders feel climate-smart, regenerative, organic and other agricultural systems have outcomes that conflict. For example, no-till systems disturb less soil and have been found to have a greater capacity to capture carbon; but most of these systems use chemicals to control weeds, which according to some interviewees, degrades soil health. Social justice issues have arisen from investments into dairy methane digesters production of renewable natural gas, a form of clean energy, that also results in degraded local air quality, according to an interviewee. There is confusion about what the industry and government are trying to accomplish and what outcomes are a priority.

Ineffective Communication & Exclusive Language

The phrase “climate-smart agriculture” is not commonly used by agricultural producers. It may be a barrier in and of itself as many people aren’t sure what it refers to. Some farmers who otherwise may be willing to adopt a “climate-smart practice” may be deterred by what they hear as politically or ideologically charged terminology. Several interviewees noted that reframing terminology with more farm-familiar language will invite people to feel more included and willing to participate. Further, producers don’t need to identify climate mitigation as a goal in order to be interested in conservation practices that offer climate-friendly outcomes and co-benefits. Policy-makers should meet agricultural operators and workers where they are—focus on and frame these practices based on the producers’ primary goals, and use common, inclusive language.

High Costs & Inadequate Funding

Climate-smart equipment and infrastructure upgrades may help advance Washington’s climate goals. However, a farm operation, large or small, must incur significant costs to add or implement such changes. For many, it simply isn’t a viable option. The costs of inputs (e.g., water, feed, fertilizer, and equipment) continue to rise as markets continue unpredictable cycles. Conservation districts offer valuable funding to make practice changes/adoptions less risky and more financially viable, but their funding allotments are disproportional to the actual need. A few representatives from larger agricultural operations referred to conservation district funding as “a drop in the bucket.” Interviewees indicated that federal programs, such as the Environmental Quality Incentive Program (EQIP) and Regional Conservation Partnership Program (RCPP), may currently be preferred by producers as the funding capacity is better scaled to the actual need.

Distrust in Government & Complicated Programs

Several interviewees mentioned that fear of retaliation often inhibits producers from engaging with agency staff or participating in government programs—the very thing they need help with could get them written up. If a producer decides to participate in a government program, interviewees noted they become overwhelmed by the sheer number of programs, eligibility requirements and rules that are attached. If adequate conservation technical assistance isn't available to help the producer navigate this (e.g., via direct assistance from a conservation district or NRCS employee), it leads to the individual doing it on their own (where they risk making mistakes) or completely giving up.

Insufficient Conservation Technical Assistance (CTA) Capacity

Distrust in government and complicated and confusing programs are exacerbated by inadequate CTA. Many stakeholders believe this is due to decision-makers' and funders' misunderstanding the importance of CTA, resulting in inadequate funding availability through grants and state budgets. Without adequate CTA, there aren't enough boots-on-the-ground staff to assist producers with navigating programs that fund climate-smart practices. Progress is further hindered by high turnover rates for those who are employed in these positions. Producers mentioned several experts they rely on have left for different positions that pay better. There's also a need to "train the trainer" and help newly hired technical assistance staff to quickly and effectively help their customers. According to those interviewed, more CTA and better trained technical assistance staff and conservation professionals would significantly help Washington accomplish climate-smart goals.

Top Barriers (Organic Systems)

Stakeholders frequently mentioned two additional barriers that specifically impact organic production systems:

Inadequate Funding Support for Long-Term Organic Producers

When converting from a conventional operation to organic, many interviewees commented on the abundant resources, both CTA and funding, to help make the transition. However, it was broadly noted that after the transition is made to organic, funding substantially declines. The price premium organic products receive is helpful, but the cost of production is also high. Organic producers interviewed feel there should be more support to keep long-term organic farms competitive alongside conventional operations.

Large Riparian Buffers Challenge the Viability of Small Acreage Farms

Several representatives from production agriculture commented on their issues with large riparian buffers taking land out of production, but the loudest opponents of the scale of this practice were organic producers. Many organic operations are smaller in size when compared to conventional farms, so the percentage of land removed from food production when implementing a large riparian buffer is substantially higher. This is challenging for small-scale organic farms to overcome as they lack the flexibility or options to maintain or scale up production on less acres, according to interviewees. It was also noted that rotational grazing efforts are complicated by large riparian buffers. For example, the number of livestock paddocks and/or size of paddocks must be reduced as pastureland is lost.

Scaling Up Climate-Smart Agriculture

All 29 interviewees were asked about solutions and additional investments needed to scale up climate-smart agriculture in Washington.

Representatives from production agriculture (16) were asked to identify existing and additional resources that are needed to support adoption of conservation practices. Non-production agriculture stakeholders (13) were asked to identify tools and supports that are needed to scale up climate-smart agriculture in Washington.

Most Frequently Identified Solutions (Conventional & Organic)

This section highlights the most commonly identified solutions needed to scale up climate-smart agriculture in Washington for both conventional and organic systems.

See [Interview Response Summaries](#) for a more comprehensive summary of responses.

Additional Funding That's Flexible, Farmer-Focused and Mitigates Risk

All 29 interviewees identified the need for more funding to scale up climate-smart agriculture. Many felt that improved flexibility of funding program rules, eligibility and timing would expand opportunities to those previously excluded and make implementation of climate-smart activities more accessible. Several noted that current grant funding cycles are misaligned with growing seasons in Washington. More funding is needed to directly support the implementation and the ongoing management of climate-smart practices. Without guarantee of long-term funding, farmers may be left on the hook for significant management responsibilities that are not feasible to do on their own. Where applicable, programs should be consolidated and simplified to more efficiently serve producers. Programs need to help the farmer and not just check a policy box, as interviewees noted these programs need to result in both climate-smart outcomes and viable and profitable farming operations. Continuing to support long-term organic producers through additional funding past initial certification, and providing additional resources for certification itself, will help these producers expand their participation in climate-smart ag activities, according to those interviewed.

Improved Data & Relevant Research

The vast majority of those interviewed communicated the value of continuing to invest in high quality research to define baselines, evaluate the efficacy of climate-smart practices and identify innovative approaches for future progress. With the duration it can take to measure outcomes (e.g., improvements in water quality or gains in soil health), interviewees stressed the need for long-term research that can show both shortcomings and advantages of different practices. Research also plays a key role in reducing the confusion and conflicting outcomes identified by interviewees in the various agricultural production systems. For example, riparian buffers and cover crops often harbor pests that, when left uncontrolled, can damage crops.

Communicate in a Familiar & Inclusive Way That Resonates with Target Audience

During the interview process, several individuals mentioned that tailoring the wording or language used by government and non-governmental organizations to local audiences when promoting climate-smart agriculture would help communities gain a better understanding and view it more favorably. Slightly modifying existing messaging to use more familiar words will reduce

misconceptions and help build trust, according to those interviewed. It was noted that reframing climate-smart benefits to emphasize on-farm benefits to producers—such as savings in time and money—will generate more engagement while still accomplishing the desired climate outcomes. Both production agriculture representatives and non-production stakeholders shared that public-private partnerships are strengthened with effective communication that provides transparency and builds trust, paving the way to scale up climate-smart agriculture in Washington.

Sufficient CTA to Engage, Educate, & Support Producers & the Public

Building conservation technical assistance capacity was highlighted frequently amongst interviewees. More CTA is needed to help producers navigate programs, determine eligibility, and “jump through the hoops.” One interviewee mentioned that farmers really need to have their own HR department, and CTA supports that need in part by offering a variety of training and support. Another interviewee commented that an older generation is still calling the shots on most farms, and they still prefer one-on-one talks. Scaling up climate-smart agriculture can only be accomplished alongside additional investments in CTA. Without it, too many members of the public are unwilling or unable to navigate complicated programs, or are simply unaware that the programs exist, according to interviewees.

Improved Access to Tools, Technology & Equipment

Developing new tools and improving existing ones—including soil sensors, manure digesters and artificial intelligence (AI)—can unlock value-added services, like carbon programs. Streamlining data-sharing—such as collecting real-time data from the cab to the computer—will improve accessibility. This added value and improved accessibility will encourage more engagement with climate-smart agriculture, according to those interviewed. It was also noted that organic production systems often lack the flexibility and tools enjoyed by their conventional counterparts, and additional research into unlocking innovative techniques to add to their existing options would be highly valued.

Opportunities for State Agency Engagement

While identifying needs and opportunities to scale up climate-smart agriculture in Washington, interviewees noted several agency-specific opportunities.

Department of Commerce (Commerce)

- Encourage more engagement with the under-utilized Inflation Reduction Act (IRA) climate resilience funding matched by Commerce. Grants can be used to fund state conservation district work (e.g., energy efficiency, building retrofits, solar, EV).
- Revise energy grant funding application language and increase outreach so farmers/producers are aware of funding opportunities. Producers could be eligible for Commerce energy funding but grant funding application language doesn’t explicitly invite/encourage them to apply.
- Review Commerce energy grant funding applications and propose how best to incentivize creativity and broaden definitions to include farmers/producers. Small and mid-sized farmers are not well informed about funding opportunities to support climate-smart approaches.

Department of Natural Resources (DNR)

- Explore opportunities to weave climate-smart agriculture elements into lease agreements. DNR can’t require action from tenants but can add elements to lease agreement and offer

rent offsets for improvements made by tenants (e.g., modified grazing practices, virtual fencing towers, water efficiency measures and water meter installation).

Department of Agriculture

- Help dairy field inspectors implement more climate-smart agriculture.

Innovative Approaches

Some interviewees shared innovative ideas and approaches when discussing efforts to scale up climate-smart agriculture in Washington. While these ideas may only have been mentioned in a single interview, they offer creative approaches that decision-makers may want to consider while exploring opportunities to leverage climate-smart agriculture as a tool to achieve climate goals.

Agriculture Industry Innovations

- Explore the frontier in climate-smart livestock, including cost-effective strategies to reduce agricultural greenhouse gas emissions (e.g., feed additives, enteric fermentation).
- Explore opportunities for industrial symbiosis at state and regional levels (e.g., partnerships between industrial facilities or companies in which waste or by-products of one become raw materials for another).
- Delve into solar technology opportunities currently available (e.g., agrivoltaics, agrisolar, dual-use solar, low impact solar). The practice of using land for both agriculture and solar energy generation involves placing solar panels in a field where crops are also grown, either beneath or between rows of panels. Specific recommendations:
 - Avoid taking land out of production by siting solar panels on storage buildings.
 - Install in feedlots to power the farm while providing shade for livestock.
 - Demonstrate the technology works at a large-acreage scale.
 - Monitor and communicate accurate data on the benefits and risks/challenges of solar.

Farming Practice Innovations

- Move to annual crop wheat and use cash crop to control weeds.
- Engage custom applicators in climate-smart activities.
- Recognize that small incremental changes add up to big results:
 - Adjust water use on crops and timing of planting to capture more rainwater.
 - Some vineyards use compost to capture water and keep soil moist.
 - Experiment with grazing stubble height and rest periods.
 - Track emerging tech solutions (e.g., Tri Cities' [Carbon-Free Fertilizer plant](#) working on energy efficient farm equipment and alternative fuel sources).

Funding Innovations

- Create a state program similar to the federal Conservation Reserve Program (CRP), retiring land for habitat and hunting. Pay landowners to keep land undeveloped so long as it doesn't impact landowner access and eligibility for other federal funding (e.g., USDA programs, risk loans). CRP benefits wildlife, helps landowners have a reliable income for 10-15 years and helps achieve climate-smart agriculture goals.
- Reconsider caps on the percent of agricultural land retired for habitat (e.g., CRP caps the percent of agricultural land out of production in each county in the state).
 - Douglas County consistently hits the cap and can't apply more land to the program—a missed opportunity. This land is often unsuitable for production and

provides native habitat vital to the survival of many endangered species in Washington, especially Douglas County.

- Reconsider who and where in the system is incentivized. Producers tend to receive incentives yet supply chain partners could also incentivize growers to shift to climate-smart practices.
 - Instead of orchardists burning pruning piles with diesel, canceling any greenhouse gas reduction benefits, incentivize a company to chip or biochar pruning piles.
- Explore conservation district match rates related to [Saving Tomorrow's Agriculture Resources \(STAR\)](#) and see if landlords would be willing to provide a match.
- Adjust the timing for easement matching funds. Make them available early on to align with implementation. Create guaranteed funding for easements throughout the state.

Policy & Research Innovations

- Reform crop insurance to provide better flexibility to producers trying climate-smart practices.
- Washington state should fund region-specific, crop-specific and in-field research related to the Dairy Nutrient Management Act's "additionality" metric—it is challenging to track.
- Explore ways to leverage the [Nitrous Oxide Protocol](#) developed by Michigan State University. The protocol is creating an incentive for farmers to limit NO₂, but it's difficult to implement.

Private Industry & Supply Chain Innovations

- De-risk adoption of technologies and grow Washington-based agriculture tech companies. Majority of agriculture tech solutions are imported from abroad. To overcome reluctance:
 - Create a cross-sector community of technologists, academics, manufacturers and farmers that meet regularly to exchange information, learn about funding opportunities and work on collaborative projects.
 - Without intervention, agriculture technology will only be adopted by large corporations, further concentrating their power and leading to more consolidated commodities. Supporting small and mid-sized agricultural producers to adopt technology is key to their competitiveness and survival.
 - Establish through-line with producers. Clear connection and support between each required action and available funding for that specific approach.
- Recognize that private industry is the biggest driver in innovation and government agencies are behind. Private sector grants and donations are easier and more accessible. Identify potential partnerships to scale up climate-smart agriculture in Washington.

Discussion & Key Themes

Interview responses indicate that Washington has made significant progress in developing supports and resources for implementing climate-smart agriculture. However, further efforts are necessary to effectively expand these solutions to address challenges and support the farmers who are implementing these practices on the ground.

Among the many perspectives shared by interviewees on the contributions of climate-smart agriculture to our state, analysis of interview data indicates four prominent themes. Given the frequency with which these themes emerged in the interview data, they warrant particular consideration by decision-makers when assessing future directions and expectations for the state's approach to climate-smart agriculture.

Each theme is presented below, accompanied by bullet points highlighting examples of supporting perspectives shared by interviewees.

Themes and theme descriptions reflect the responses and perspectives most frequently heard during stakeholder interviews—they are not an endorsement of a specific position, or a representation of the views or opinions of the entities involved in conducting this evaluation.

See [Interview Response Summaries](#) for a more comprehensive summary of responses.

Theme 1: Funding, Risk Mitigation & Expert Assistance

Agriculture needs flexible, grantee-driven funding & assistance to navigate change.

Stakeholders overwhelmingly emphasized the need for grantee-driven funding that can adapt to the rapidly evolving conditions within the agriculture industry. These shifts are impacting farmers across multiple areas, including weather patterns, farming practices, crop selection, feed availability, supply chains, insurance, easements, and equipment. Current funding for climate-smart agriculture falls short in supporting farmers as they navigate these changes and in addressing the risks involved in modifying their operations. Moreover, the complexity and frequent changes to various funding programs make it difficult for farmers to assess their eligibility and relevance for their specific needs. Washington must increase on-the-ground conservation technical assistance to guide farmers in identifying and securing the most suitable funding opportunities.

Examples of interviewee perspectives on this theme include:

- **Offer long-term support beyond the early phases of implementation.** Prioritize the long-game approach over short-term gain. The current funding structure focuses on front-end start-up costs, then abruptly drops away when state and federal funding ends or legislative priorities change. It can take a few years before new climate-smart practices are fully established and the producer begins to see results. It can take several years before the producer sees a tangible return on investment. Establishing viable enduring climate-smart practices over time requires longer-term, adaptable funding.
- **Create the conditions for more grantee-driven funding.** Current practices and innovation are driven by funding streams—it's too rigid. Address the gap between the priorities of fundable practices and the needs of the producer.
- **Reconsider and revise grant requirements** for long-term climate-smart agriculture implementation. Many producers are reluctant to sign a 10–20-year agreement.

- **Include multiple funding categories.** Most funding sources only involve a single aspect or category, missing out on important opportunities to capture beneficial interdependencies (e.g., water, soil, air, habitat, producer financial well-being).
- **Producers need production system-specific support.** This includes technical assistance, financial assistance, and research.
- **Assistance promoting and navigating funding programs.** More capacity is needed to keep producers up to speed on funding availability and provide assistance navigating what can be complex and ever-changing grant eligibility, guidelines and applications.

Theme 2: Research & Data

Agriculture needs baseline data & proven, on-farm results.

State and federal governments offer several programs that promote adoption of climate-smart practices. Without baseline data, it's extremely difficult to measure progress and track impact. The complexity and site-specific nature of collecting reliable data on many climate-smart practices, such as cover crops, adds another layer of challenge to this issue.

Making any operational change can present significant risk for farmers, whose livelihoods often stand in the balance. Without better baseline data and on-farm results, producers assume an even higher level of risk when they're asked or expected to implement new or unproven practices.

Examples of interviewee perspectives on this theme include:

- **Increase funding for baseline research and data** that takes into account the various landscapes, crops, soils and people of Washington, as well as impacts of a changing climate.
- **A one-size-fits-all approach to practices won't work in Washington**—there's a need for more localized and crop-specific data for varying micro-climates and regions across the state.
- **Establish proven, measurable results** that clearly demonstrate successful on-farm implementation, in addition to the associated risks and estimated time frames for full implementation.
- **Explore how to better measure greenhouse gas reductions related to agriculture**, such as in soil, composting and cover crops—to date, this has been very difficult.

Theme 3: Recognition for Agricultural Contributions & Value

Climate-smart policies in Washington should support agriculture, not target it.

All agricultural land has value. Climate-smart approaches should lead with keeping farmland in production, regardless of whether it's conventional or organic farming. There is a lack of public understanding about the role and economic impact of the agriculture industry in Washington and internationally. People expect food to be readily available and affordable, without understanding all that it takes to grow, harvest and transport it.

Family farms and the agriculture industry feel unfairly targeted as the culprit for climate-related issues and environmental degradation. Many feel that farmers are vilified and the subject of policies that force land out of production, while at the same time they're being asked to solve the climate crisis and supply the world with healthy and affordable food. This feels unfair and misguided. Many perceive an increase in regulation, unviable operations and distrust of

government. This has resulted in growing concerns about mental health for those working in the agriculture industry.

Examples of interviewee perspectives on this theme include:

- **Address the unfair burden placed on producers.** Many producers pay 25 percent of implementation costs, then are required to continue climate-smart agriculture practices for 10-20 years or risk a fine if they fail to implement.
- **Foster respect for the risks** associated with adopting climate-smart practices and the producer's business decisions.
- **Raise awareness about the nexus of mental health of producers and climate change.** It is a serious issue and barrier to longer-term, sustainable adoption of climate-smart practices. Farmers have always adapted, but now change is extremely rapid with non-stop farming schedules, financial hardship, and loss and grief related to extreme weather events.
- **All agricultural land has value.** Climate-smart agriculture should lead with keeping farmland in production, regardless of whether it's conventional or organic farming. Don't squeeze out other land stewardship approaches in a rush to achieve state climate goals.
- **Identify the root causes that reinforce a lack of public understanding** about the role and economic impact of the agriculture industry in Washington state and internationally. People expect food to be readily available and affordable, without appreciating all that it takes to grow, harvest and transport it.

Theme 4: Inclusive Approach for a Collaborative Process

Build approaches to climate-smart agriculture from the farm up.

Some existing programs and approaches for implementing climate-smart agriculture in Washington are out of touch with on-farm realities. For example, many interviewees noted that grant funding cycles are misaligned with the growing season, making participation impractical. Others noted that even the language used in the climate-smart space—including the term “climate-smart agriculture” itself—can feel disrespectful and dismissive of the agricultural community. In conversations with agricultural producers, many interviewees asked for clarification about what practices are considered “climate-smart;” when they saw the practice list, many quickly identified what they more commonly referred to as “conservation practices” from that list that they have implemented or are interested in adopting on their farm.

From terminology to funding program design, more needs to be done to acknowledge and integrate farmers' perspectives into approaches to meet Washington's climate goals.

Examples of interviewee perspectives shared on this theme include:

- **Reframe the “climate-smart agriculture” language.** Farmers shouldn't be solely responsible for solving climate change. This is a collective issue. Many farms are implementing practices that benefit the climate but not labeling them as “climate-smart.” The language can be off-putting and a barrier to talking about options and opportunities.
- **Raise awareness about the Indigenous roots of regenerative agriculture.** Some feel the term “regenerative agriculture” is appropriation, dismissive and erases Indigenous history and the contributions made to the modern world.
- **Meet farmers where they are and shift away from paradigm of “funder knows best.”** This requires capacity (including staff capacity) to listen to farmers one-on-one, understand their unique situation and work collaboratively to achieve mutually beneficial goals.

- **The timing of grant cycles and Washington’s growing season is misaligned.** Many funding timelines are impractical and don’t consider the time it takes to apply for funding, receive funding, purchase necessary equipment, plant crops and implement new practices.

Interview Response Summaries

KRCS captured raw notes from each of the 29 interviews conducted and submitted them to the Washington State Conservation Commission in August 2024. The following sections provides summaries of responses to primary interview questions.

Climate-Smart Practice Adoption

What are the most common climate-smart practices used within your industry?

- Cover Crops
- Windbreaks
- Precision Ag
 - Mobile drip irrigation, micro sprinkler, pump upgrades
 - Drones and center pivot sensors to detect pest infestations
 - Grid sampling, zone sampling, soil moisture monitoring
- No-Till or Direct Seed
- Reduced-Till
- Waste Storage & Nutrient Management
 - Composting
 - Waste Separation
 - Covered Lagoons
 - Digesters
- Rotational Grazing of Cover Crop & Crop Residue
- On-Farm Energy Efficiency
 - Lowering cooler cost
 - Fuel efficient equipment
 - Solar
- Conservation Rotation
- Feed Management
- Polyacrylamides (PAM)
- Filter Strips
- Weed Management
 - Electric zapping used but not on a large scale
- Riparian Buffers
- Grassed Waterway
- Wildlife Habitat Planting
- Water Recycling
- Woody Residue Treatment (chipping, burning)

Barriers to Climate-Smart Agriculture

Are there barriers that prevent farmers in your industry from scaling up climate-smart practices; if so, what are the top two?

Barriers for Conventional & Organic Production Systems

Agriculture Land Preservation & Succession Planning

- Taking conventional and organic farmland out of production is problematic solution to climate-smart agriculture
- Preserving ag land is challenging with no heirs wanting to return to farm and/or land is only equity owners have (e.g., need to sell to afford retirement)
- Lack of farm succession plan may lead to farmers less invested in long-term viability
- Fear of missing out leads to some farmers selling land to developers

Conflicting Perceptions & Principles

- Practice results in conflicting outcomes (e.g., cover crops to build soil health, but soil health damaged by spraying pests living in cover crops)
 - Taking out dams good for salmon and rivers, but puts more trucks on roads to haul grain, increasing emissions
 - Perception that regenerative ag, climate-smart ag, and other conservation ag systems have outcomes that conflict with each other
 - Dairy methane digesters produce renewable natural gas for clean energy but degrade air quality for residents in the Lower Yakima Valley
 - Social justice issue

Cost

- Precision technology, equipment, and infrastructure are most expensive
- Inadequate cost-share at times to offset risk of trying something new
 - Many industry leaders called CD funding inadequate to influence larger operations to change practices (referred to as drop in the bucket)
 - Several interviewees used their CD for initial technical support but used federal programs with better funding for implementation
- Cost of more climate friendly feed more expensive
- Upgrading weed control technology costly
- High cost of water prevents some conservation work (e.g., cover crops)
- High farmer debt leads to inability to acquire loan for equipment upgrades to support climate-smart ag
- Adjusted Gross Income (AGI) requirements restrict larger operations from receiving financial assistance

Language & Framing of “Climate-Smart”

- “Climate-smart” and other language not often used in ag community can be misunderstood and poorly received
- Framing farmers as problem and not solution is divisive and breaks down trust
- Term “regenerative ag” viewed as appropriation to some Tribes, feel their history and culture are being erased
- Ag industry not doing a good enough job communicating climate-smart benefits of existing practices and systems

Mental Health & Safety

- Mental health issues exacerbated in ag community by climate change (e.g., severe flooding, severe drought, wildfires)
 - Stressful to take on more risk in an already stressful industry
 - Producers can't afford many mistakes with low margins and high costs
- Not enough boots on the ground to visit farmers one on one to share resources

On-Farm Challenges

- Time, patience, learning curve
- Weeds
- Lack of labor
- Lack of options in feedlot setting
- Lack of anonymity in research participation
- Permanent decisions unpopular (e.g., easements, banking water rights)
- Riparian buffers unreasonably large
 - Reduces viable farmland
 - Creates grazing challenges
 - Biggest problem in small plot orchards and organic farms
 - Problematic in larger conventional operations if several water channels cut through property
 - Concern over who manages weeds on riparian buffer ground
- Quantifying greenhouse gas reductions from carbon sequestration in soil, composting, and cover cropping is challenging
- Convincing farmers to share their story to influence others
 - Don't want to be in limelight, but need to be for effective storytelling

Private Sector

- Development of farmland presents challenges:
 - Less viable farmland to grow food
 - Increases cost of food, purchasing farmland, and renting farmland
 - New residents unfamiliar with agriculture complain and cause problems
- Infrastructure too far away to support:
 - New market opportunities to expand crop options and rotations
 - Feed ingredients that are more climate-smart
- Lack of opportunity and/or eligibility for carbon programs
- Crop insurance rules restrict certain climate-smart efforts

State Agencies & Public Sector

- Lack of consistent messaging across state agencies related to climate-smart ag
- State agency strategies getting in the way of each other (Ecology, WSDA, DNR, etc.)
- State and federal agencies are difficult to work with
- Public programs are numerous, complicated, lack flexibility
 - People lack the time to learn various programs, eligible practices, and rules
- Contracts lack flexibility when enrolling producer in unproven climate-smart practice

Technical Assistance

- Lack of capacity and educated staff to foster practice adoption
 - Perception of inadequate funding to retain top employees and hire new ones
- Lack of in-state climate-smart ag expertise

- Leads to reliance on out-of-state assistance to help producers
- Understaffing of NRCS and FSA results in producers waiting for assistance

Urban - Rural Divide

- Growing disconnect between the public and food production
 - Many people don't know the effort and cost required
 - Lack of education and efforts to connect people to their food source

Barriers Specific to Organic Production

- Large riparian buffers reduce viability of small plot orchards
- Buffers and cover crops harbor pests that damage crops
 - Using brush management and composting techniques to control this
- Organic lacks flexibility of conventional crop systems in regard to nutrient management and pest management
- Carbon offset programs only look at on farm carbon footprint, not considering upstream carbon footprint of manufacturing and delivery of products (e.g. herbicides, pesticides, fertilizers)
- Cost share available to producers converting to organic, little support after that
- Misconception of what minimum or no-till mean
- Riparian buffers take up too much land on small acreage organic farms, also complicate rotational grazing efforts
- Funding often not enough to sway producers' decision from one system to another
- Lack of program awareness among smaller scale producers
- Challenges arise for long-term organic management on leased farmland
- Organic and climate-smart practice outcomes can be conflicting
- Cost and time for producers and processors to get certified is challenging
- Not enough program support in this area

Existing Programs & Resources

What current programs and resources exist that support climate-smart agriculture in Washington?

State Programs & Resources

American Farmland Trust – Pacific NW Region (Washington, Oregon, Idaho)

- Advocacy, tech assistance, and education for all stripes of farming including organic and conventional with an emphasis on regenerative agriculture
- [Women for the Land](#) program: Peer-to-peer learning circles, tech assistance, community of practice. Empowering women, including women veterans, in agriculture to protect the land and embrace conservation. The future of agriculture is increasingly female. 43% of U.S. farmland (nearly 388 million acres) is now farmed or co-farmed by women.
- [Smart Solar Program](#): Aims to place solar development on land that minimizes its impact on the environment and agriculture. Program goal is to increase climate resilience and farm viability while also expanding renewable energy. Promising approach, but we need more research and pilot projects to show success at large scale – current projects are usually about 5 acres. As WA State moves to achieve climate goals, we can't squeeze out other approaches to land stewardship.

- Partnering on a national project advocating benefits of biochar. Launching on-farm pilots in 2025.

Carbon Reduction Incentives

State Member Associations

- Cattlemen's Association
- Dairy Federation
- Direct Seed Association
- Fruit Growers Association

Cascades to Coast Landscape Collaborative

- [Conservation Explorer Tool](#): Untapped resource. Developed for landowners, producers, and organizations. Purpose is to raise awareness of available programs and connect landowners to agencies and organizations that implement programs.

Coordinated Resource Management Partners

- [Coordinated Resource Management Group](#) (CRM): Memo of Understanding between WDFW, DNR, WSDA and others. Contact Angie Reseland at WDFW.

Conservation Districts

- Key providers of local conservation technical assistance; various state/federal/private programs.

Conservation Technology Information Center

- [OpTIS 4.0](#): Operational Tillage Information System. CTIC partnered with [Regrow](#) and [The Nature Conservancy](#) on development, testing and application of OpTIS, an automated system to map tillage, residue cover, winter cover, and soil health practices using remote sensing data.

Intertribal Agriculture Council

- Regenerative agriculture, Indigenous agroforestry, Tribal land environmental trusts, dryland farming
- Tribal food sovereignty (traditional food medicine, water quality, farming, ranching) and sustainability (improving access to hydroponics, greenhouses)
- American Indian-Made Certification: Working on label for food produced using regenerative agriculture
- USDA Farm Service Agency & NRCS definitions: Working on agreement to include indigenous definitions, practices and values into grants/resources/opportunities so Tribes have access to funding for specific indigenous practices
- Aqua culture: Advocating for Farm Bill revisions to add aqua culture category
- Youth summits: 3 hosted annually, national focus on tribal agriculture and tribal land
- Cultural burning: Working on lifting WA State ban
- Solar development: Working with WA State legislators on rule development

Investments in Long-Term Soil Health

- WA State is part of the hydrogen hub to produce fertilizer rather than natural gas
- Gates Foundation Grant

Irrigation Districts & Irrigation Contractors

- This was brought up in general and no specifics were shared during the interviews.

Puget Sound Grand Uncertainties Matrix

- [Researchers are compiling a strategic list](#) of scientific uncertainties related to Puget Sound recovery. The list will be used to prioritize future funding and research to address critical knowledge gaps about the ecosystem.

Tilth Alliance

- Programs support farmers working on implementing climate-smart, regenerative, organic
- [Washington Sustainable and Organic Farming Fund](#)
- [Coalition for Organic and Regenerative Agriculture](#): advocating for policies to support organic and climate-smart ag
- Annual conference (November): Climate change, soil health, organic agriculture
- Farm walks: Conversations about what practices the farmer is implementing
- Podcast
- Online forum and community of practice: Peer to peer learning, sharing resources and knowledge

WA Farm Bureau

WA State Conservation Commission

- Sustainable Farms & Fields
- VSP: Perceptions that this program is more for planning than implementation; the Commission mostly helps ranchers; and that conservation districts mostly help with planning (not just in VSP)

WA State Dept of Agriculture

- [Commodity Commissions](#): Climate-smart policy for dairy. Includes data collection and tech assistance for dairies and other state agencies for CS practice implementation.
- [Compost Reimbursement Program](#)
- [Dairy Nutrient Program](#): Expanding climate resilience for dairies. WSDA offers tech assistance, funding passes through to conservation districts who work directly with producers. Implementation of best management practices has an impact on air quality and GHG emissions.
- Fertilizer Use Efficiency: Launching new effort aimed at reducing nitrate leaching
- Fertilizer Scheduling Tool: Launching technical guides, on-farm tech assistance
- Food Relief Programs: Incentivize purchasing and procurement of local food
- [Natural Resources and Agricultural Sciences](#) (NRAS)
- [Organic Certification Program](#)
 - Certification focused on producers and handlers
 - Tech assistance built into certification, support for continuous improvement
 - Material registration program
- Pest management
- [Soil Health](#) and [State of the Soils Assessment](#)
- [WSDA's STAR program](#)

Washington Soil Health Initiative

- [Soil Health Ambassadors](#)

- [Soil Health Roadmap](#)

WA State Dept of Commerce

- Economic Development & Effectiveness
 - Focused on agriculture technology and forestry product industry sectors, including exports, biochar, bioenergy
 - Networking, advancing policy recommendations
- Energy & Renewables
- Funding related to renewables (e.g., wind, solar, methane capture, wood biomass, wood products)
- Clean tech funds

WA State Dept of Ecology

- [Agricultural burning and permitting](#)
- Climate pollution reduction: Working on economy-wide climate planning, including investments and implementation support
- [Concentrated Animal Feeding Operation General Permit](#) (CAFO): Water quality permitting for wastewater discharge, including ag
- Dairy digester program
- Natural working lands GHG inventory and modeling: Vera vpfe461@ECY.WA.GOV
- [Washington's Climate Resilience Strategy](#): Legislatively mandated, involving multiple WA State agencies, report available in September 2024.
- [Water Resources Program](#)

WA State Dept of Fish & Wildlife

- Fire Recovery: [WA Shrubsteppe Restoration and Resiliency Initiative](#) (WSRRI)

WA Dept of Health Office of Environment Health & Safety

- [Climate Change and Health Program](#): Health impacts, including agriculture and shellfish, reduced food supply, pesticides
- DOH National Estuary grants (mostly funding for dairies)
- DOH funds Swinomish and Tulalip Tribes to support shellfish growing areas, reducing fecal biotoxins, sampling/testing, and routine monitoring partnerships
- [Shellfish Strategic Initiative](#): Focus on increasing harvestable shellfish beds through its annual allocation of NEP Geographic Funds

WA State Dept of Natural Resources

- [Drought Resilience Planning](#): Metrics for ag and water related to drought resilience
- [Product Sales & Leasing](#) (ag, commercial real estate, water rights and claims). DNR calculates for market rent on land and adjusts for increased lessee/producer expenses (e.g., increasing fertilizer costs). Tries to recognize producers need support.

WA State University

- Bio Ag Grant program: Consistent seed grant, but not ongoing funding
- Cover crops: Doug Collins' work
- Dairy, municipal carbon markets, waste-to-fuels: Georgine's work
- Mustard green manures: Andy McGuire's work
- Soil conservation education, Soil Health Initiative
- WSU Center for Sustaining Agriculture & Natural Resources (CSANR)

- WSU Extension Mount Vernon NW WA Research & Extension Center (NWREC)

Federal & Out-of-State Programs & Resources

CA State Dept of Food & Agriculture

- [Healthy Soils Program](#)
- [Nutrient Management Program](#) – Office of Environmental Farming & Innovation
- [Dairy Digester Research & Development Program](#)
- [Alternative Manure Management Program](#)
- [CA Climate Investments](#)

COMET-Farm

- Whole farm and ranch carbon and greenhouse gas accounting system.

Dry Farming Institute

- [Western Water Resilience Collaborative](#)

Farmland Information Center

- [Soil Health Case Studies](#)

Inflation Reduction Act

- [Advancing climate resilience](#)
- Climate resilience funding matched by WA State Dept of Commerce support state conservation districts (e.g., energy efficiency, building retrofits, solar, EV)

Truterra Program

- [Truterra](#) offers the leading farmer-driven ag and food sustainability program in the U.S.

National Estuary Program Grants

Pacific Northwest National Laboratory / U.S. Dept of Energy

- [Maximizing the Value of Cover Crops in the Pacific Northwest](#): Aaron Esser and Steve Norberg

Regrow Ag

- [Regrow](#) combines industry leading science and tech to help companies across the value chain measure, report and take action to reduce on-farm emission.

SARE

- [Sustainable Agriculture Research and Education](#): Grants and farmer-driven innovations in agriculture that improve profitability, stewardship and quality of life.

STAR

- [Saving Tomorrow's Agriculture Resources \(STAR\)](#): Getting landowners to incentivize tenants to adopt practices through reduced lease rates or matching costs for amendments or implements.

USDA / NRCS / FSA

- National funding equals square peg in a round hole

- [Conservation Innovation Grants \(CIG\)](#)
- [Conservation Stewardship Program \(CSP\)](#)
- [Conservation Reserve Program \(CRP\)](#)
- [Environmental Quality Incentives Program \(EQIP\)](#) provides financial and technical assistance to agricultural producers and non-industrial forest managers. Untapped opportunity for farmers switching to organic production.
- [Regional Conservation Partnership Program \(RCPP\)](#)
- National Organic Program Organic Integrity Learning Center [New Microlearning: Climate-Smart Agriculture](#)
- [Organic Management Practice Standard 823](#) is a program focused on organic and has received mixed reviews in terms of implementation.
- [Organic Market Development Grant](#)
- [PL-566 Small Watershed Program](#)
- [Rural Energy for America Program \(REAP\)](#)
- [State Acres for Wildlife Enhancement \(SAFE\)](#)
- [Transition to Organic Partnership Program \(TOPP\)](#) is a farmer-to-farmer mentorship program providing direct farmer training, education, and outreach activities.

Solutions to Scale Up Climate-Smart Agriculture

What tools and support are needed to scale up climate-smart agriculture in Washington?

Solutions for Conventional & Organic Production Systems

Financial Risk Mitigation

- Long-term funding for full implementation and support of climate-smart practices
 - Legislature needs to give climate-smart activities time to show results
 - Offer back-end financial support and production risk safety net (i.e., after project implementation) to help producers carry financial risk over time
 - Increase risk mitigation for organic farmers
- Absorb financial risk and remove financial barriers:
 - Work with individual producers to replace income loss from adopting sustainable practices for 3-5 years. See [Idaho Nature Conservancy demonstration farm](#).
- Cost-share to finance infrastructure and support adoption of new practices

Funding

- Establish balance between regulation and financial assistance
 - Support solutions for the producers, not just public policy outcomes for the government. Foster respect for producers and their business decisions.
 - To build widespread adoption of climate-smart practices, requirements and mandates must be matched with long-term financial and tech support. Foster beneficial cycles where one action has a positive effect on the next.
- Practices and innovation should be driven by producer need, not funding streams
 - Funding categories are too rigid and there is a disconnect between priorities of fundable practices and producer needs. Need flexible, responsive funding driven by grantee/recipient needs to address their varied conditions.
 - Shift paradigm of “funder-knows-best”: Involve ag producers in conversations! Some programs imply they hold the knowledge, “You farmers ask the questions, then we

match your need with the available program.” Instead, we should meet farmers where they are, listen, understand what’s going on and how best to accomplish their goals

- Offer adaptable funding
 - Big need for regional-scale infrastructure and equipment investments (e.g., processing, handling, cold storage, slaughter facilities).
 - Microgrants: \$5-10K to support infrastructure, shift to climate-smart practices, purchase new equipment (e.g., plant pollinator strips, solar panels)
 - Funding is constrained by watershed boundaries. Whatcom CD received USDA funding, but excludes Sumas because it’s outside watershed, even though Sumas represents 25% of their farm planning efforts. Missed opportunities.
 - Need flexible funding sources in our swiftly changing weather conditions. The 2021 flooding in Whatcom County when manure lagoons were at capacity before heavy rain season. WA State DOH was able to quickly shift unused funds to support transport and manure containment. Whatcom eventually used other funds, but DOH’s offer ignited quick action.
 - Examples of adaptable funding: Washington Sustainable and Organic Farming Fund and WSDA Food System Infrastructure grants
- Better align timing of grants, matching funds & growing season
 - Funding timelines don’t consider time it takes to receive funding, purchase equipment, plant crops, and implement new practices
 - SCC Sustainable Farms and Fields: Research and development grants don’t fit full production window (design, engineering, implementation)
 - Timing of matching funds is an issue: Grants that involve reimbursement where farmers must front the funds are problematic
- Funding should encompass multiple aspects of agricultural production
 - Most funding sources only involve a single aspect or category, missing out on important opportunities to capture beneficial interdependencies (e.g., water, soil, air, habitat, producer financial well-being)
 - Need to talk about the whole system when considering climate-smart ag, including impacts that extend beyond the field (e.g., upstream footprint of chemicals, fertilizers)
- Expand funding categories
 - Rewards and incentives for small producers ready to adopt climate-smart practices. Current focus is on big farms and big impacts, yet small producers are contributing too.
 - Increase funding and resources for new farmers to help them get started
 - Establish funding equity across land and water uses and scale of operation (e.g., shellfish producers need more funding opportunities)
 - Anaerobic digesters: Big growth opportunity with increased funding and subsidies
 - Aqua culture, shellfish, fisheries: Increased focus and support for coastal communities
 - Fertilizer: Subsidy for growers using fertilizer produced with hydrogen

Research & Data

- Baseline data and research
 - State and federal government are pouring money into the adoption of climate-smart practices, but we don’t have a baseline so it’s impossible to document and measure progress.

- What are the benefits and outcomes of climate-smart ag? Many climate-smart practices are not reducing emissions and sequestering carbon, despite other ecosystem service benefits.
- Lots of focus on climate-smart, organic and regenerative ag, but research results are mixed. We need better grasp of what is impactful and what farmers can do to maximize their positive impact on climate, soil health, carbon sequestration.
- Localized & crop-specific
 - Localized data, proven practices for varying conditions, and tangible results. Shouldn't be one-size-fits all approach.
 - On-farm demonstrations for varying production systems and micro-climates across Washington state. Data should help answer this question: "When you implement X production system, the impact is typically X."
 - Research should include the producer implementing the practice and the geographic area.
 - Provide anonymity to farmer if requested to encourage more on-farm research
- Cover crops
 - There's not much practical experience in growing them and they're challenging to grow in WA State because shoulder seasons are much shorter
 - There is no basic planting date research available
 - Much of what we know about cover crops is based on research done elsewhere in places with different growing seasons
 - Producers aren't receiving relevant info
 - Look into more drought tolerant and low water use cover crops
- Other topic-specific research
 - AI: Explore ways to implement more AI in agriculture (e.g., managing & interpreting data, better integration across platforms and partners for seamless storing and sharing - especially important with increase in carbon programs)
 - Carbon reduction options
 - Climate change forecasting: Need to plan ahead to take on crops moving to WA from CA due to drought
 - Erosion reduction, drone technology, relay cropping
 - Feed additives to reduce emissions
 - Heavy metals: How to reduce buildup from manure use
 - Soil health
 - Water saving techniques and improved sensors
 - Weed control
 - Plants that maintain pollen production in PNW despite higher temps
- Proof of concept and return on investment
 - How long will it take before you see benefits and financial return? Producers lack extra time to learn about and implement new practices unless they're proven. Producers are a skeptical crowd, won't try new practice or tech unless they know it works and will save them money.

Technical Assistance, Tools & Equipment

- Expand tools, incentives, and curriculum to improve nitrogen efficiency and water quality
 - Improved irrigation planning
 - Improved manure management plans
 - Improved timing of manure application
- Develop more efficient fuel use technologies

- Look into using solar arrays over man-made drainages to cool water
- Increase access to virtual fencing and funding to protect wetland and riparian buffers and prevent fires
- Need reliable real-time weather information in WA State: Farmers need to know what's deemed "drought." Weather conditions can vary widely within a single county. WA State needs mandatory agriculture weather reporting similar to North Dakota and Montana (Condition Monitoring Observer Reports on Drought, [CMOR-Drought](#)).
- Create centralized resource hub for small and mid-sized operations: Help producers make decisions (e.g., recommended consultants, funding, on-farm tech assistance).
- Offer equipment rental: Some conservation districts rent new equipment so farmer doesn't need to purchase
- Explore remote sensing/remote learning for soil carbon sequestration
- Avoided Conversion Calculator to measure GHG emissions avoided by protecting farmland from development. There are benefits from both permanent protection of land and conventional farming, regardless of the type of farming.
- Need tools for calculating and quantifying carbon, GPS tools, and irrigation equipment for farmers transitioning to new CS practices
- Case management approach with support tailored to individual needs of farmer and their microclimate. Offer application resources (e.g., funding program staff visit producers and explain what programs people are eligible for and help them apply)
- Need to "train the trainer"
 - Many professionals are retiring / changing careers to pursue something different - lack of knowledgeable replacements results in lack of trust, bad experiences, and low engagement
- Need more education about food production for kids and politicians
- Need to improve information and data channels between farmers, co-ops, conservation groups to improve efficiency and eligibility for new programs and value-added services
- Government agencies need to do a better job communicating in a way their target audience wants to receive it
- Farmers could use their own HR to better know and understand all rules and regulations they need to follow
 - conservation districts could offer on-farm compliance review
- Carbon program training for conservation districts, WSU, co-op staff, etc.

Solutions Specific to Organic Production Systems

- Provide support and additional resources to veteran organic farmers
- Research reducing cost of production on organic farms
 - Enhance fertility use and efficiency of manure and compost
 - Ways to offset build-up of heavy metals from continued manure use
- Consider all soil health factors when promoting regenerative and climate-smart agriculture
- Improved / additional research quantifying benefits of organic over multi-decade time frame
- Greater focus and resources towards upgrading infrastructure and equipment
- Simplify programs
- Add support for program delivery
- Improved flexibility and timeliness of programs by USDA delegating program delivery and funding to the local level
- More research to backup good practices and provide flexible options to organic growers (e.g. farmer who plants a cover crop but then incorporates it into soil through tillage)

Resources

The following resources were offered by non-production agriculture stakeholder interviewees:

- NRCS Climate-Smart Agriculture and Forestry Mitigation Activities List
- USDA National Organic Program: Organic Practices and Climate-Smart Agriculture – How Organic Mitigates Climate Change, Crosswalk and Resources
- WA State Dept Agriculture [Manure and Compost Application Timing](#)
- WA State Dept Agriculture [Preventative Practices: Crop Pest, Weed, and Disease](#)
- WA State Dept Agriculture [Water Quality Factsheet](#)
- WA State Dept Agriculture [Natural Resources and Biological Diversity Conservation](#) (AGR 3016)
- WA State Dept Agriculture [Use of Micronutrients in Organic Production](#)
- WA State Dept of Fish & Wildlife SAFE fact sheet
- [WSU AgrAbility Team - Farm Stress & Suicide Prevention Program](#)
- [Farm and Ranch Stress Assistance Network](#) (FRSAN)
- Western Regional Agricultural Stress Assistance Program (WRASAP)

Appendix B: Additional Tables Describing the Climate Mitigation Potential of Specific Practices

Table B1. Summary of research relevant to estimating the potential for changes in management to increase carbon storage in dryland soils in the Pacific Northwest

To support estimates of the regional carbon sequestration from agricultural croplands, estimates of dryland production in the inland Pacific Northwest were as follows for 2007–2014: 1.44 million acres of annual cropping, 1.85 million acres of transitional, and 2.52 million acres of grain-fallow (Kirby et al., 2017). (Reproduced from Yorgey et al., 2023; References within the table are all provided within Yorgey et al., 2023).

Strategy	Estimates of carbon sequestration potential per acre. Some estimates are based on relatively robust data, while others on more limited datasets. See Yorgey et al., 2023 for further detail.	Current technical and financial considerations.	Additional references supporting quantitative estimates of carbon sequestration potential in the Pacific Northwest
Eliminating tillage	Annual cropping area: Experimental results indicate 1.05 ± 0.93 MT CO₂ e acre⁻¹ yr⁻¹ over an average of 14 years following conversion from conventional tillage to no till (Brown and Huggins 2012). (See Table 2 for cumulative probabilities.) Modeling results for a rotation with barley, a relatively high residue crop, indicate gains of 0.13 to 0.24 MT CO₂ e acre⁻¹ yr⁻¹ more than 12 years after conversion. Transitional cropping area: Experimental results indicate 0.31 ± 0.15 MT CO₂ e acre⁻¹ yr⁻¹ in the surface 20 cm over an average of 10	In some parts of the grain-fallow area, no-till fallow can lead to more limited near-surface moisture available for seeding winter wheat in late summer (compared to conservation tillage with undercutter), and this can create a substantial yield loss in the following wheat crop (Schillinger and Young 2016). Eliminating tillage may make other carbon-beneficial strategies more practical, by conserving moisture (for intensification) or reducing the time needed to prepare and plant fields. Concerns around herbicide resistance may make the complete elimination of tillage impractical in the future. Shifting tillage strategies generally requires a completely new complement of equipment and represents an expensive transition. Making the shift may require significant other operational	Estimates of 2012–2013 adoption across the region (percentage of producers, note that this is not an estimate by acreage; Gray et al. 2015): • 30% use no-till • 39% use conservation tillage (either reduced or no-till) • 25% use conventional tillage For additional information on the role of tillage in dryland cropping systems, see Bista et al. (2017). Based on data from Stöckle et al. (2012), Pan et al. (2017b) projected that a 10% increase in no-till and reduced tillage in existing

	years following conversion (Brown and Huggins 2012). (See Table 2 for cumulative probabilities.) Modeling results indicated 0.09 to 0.14 MT CO₂ e acre⁻¹ yr⁻¹ over 12 years after conversion. Grain-fallow cropping area: Limited experimental data suggest gains are small.	changes (e.g., adding new leases, changing crop rotations, managing new diseases, changing markets) to be profitable.	cropping systems could reduce greenhouse gas (GHG) emissions by >1,550,000 MT CO₂e/yr over the inland Pacific Northwest (PNW) due to soil organic carbon accumulation over a decade.
Reducing tillage	Annual cropping area: One experimental study indicates an average of 0.07 MT CO₂e acre⁻¹ yr⁻¹ Transitional cropping area: Summary data not available. Grain-Fallow cropping area: Modeling results indicate gains of 0.1 to 0.12 MT CO₂ e acre⁻¹ yr⁻¹ over 12 years after conversion (Stöckle et al. 2012).	See above for technical and financial considerations for changing tillage.	See above for estimates of current adoption of conservation tillage in the inland Pacific Northwest.
Amendments (e.g., manures, biosolids, composts, straw pulp, biochar)	Biosolids: 47–91% of applied carbon retained as stable carbon long term (Brown et al. 2010; Pan et al. 2017a; Wuest and Reardon 2016). At the high rate of application (9.0 dry MT ha⁻¹ [4.0 MT acre⁻¹] every 4 years), carbon was stored at a rate of 1.14 MT CO₂ e acre⁻¹ yr⁻¹ over 20 years (Pan et al. 2017a). Manure: 21% of carbon stored long-term in soils 7 years after application every year for 5 years (manure with no bedding) (Wuest and Reardon 2016).	While research has suggested that transportation does not have a substantial impact on GHG balance for amendments (Brown et al. 2010), transportation costs are a significant financial constraint to the availability of amendments for many dryland crops in the PNW. The fact that these crops are relatively low value on a per acre basis further increases the economic barrier. There is relatively little regional field research investigating long-term carbon storage from amendments and very little field research on application of biochar to regionally relevant crop and soil combinations.	Washington State Biomass Inventory (Frear et al. 2005) provides estimates of a wide variety of potential amendment materials. For additional information on amendments and their potential role in dryland cropping systems, see Yorgey et al. (2017d). Considering only technical feasibility, Amonette (2021) estimated that biochar generated from crop residues, forestry residues, and waste wood, and applied to the state's agricultural croplands, could offset (depending on timber-harvest levels) about

	Compost: 11% of carbon stored long-term in soils 7 years after application every year for 5 years (composted wheat residues) (Wuest and Reardon 2016). Biochar: Laboratory studies suggest that 21–47% of biochar carbon would be retained in soil long-term (Zhao et al. 2013; Windeatt et al. 2014).	Food safety concerns limit timing for manure applications to some potential receiving crops (especially produce generally consumed raw).	9–20% of total statewide greenhouse gas emissions.
Intensification of cropping/ reducing or eliminating fallow	No systematic quantitative estimate. Based on data from several experiments at the Columbia Basin Agricultural Research Center in Pendleton, OR, in the intermediate cropping zone, Albrecht et al. (2008) estimated a difference of 0.10 MT CO₂e/ac/yr in the carbon accumulation between two conventionally plowed cropping systems (annual grain or grain-fallow).	Fallow typically only occurs in the drier parts of dryland cropping systems and are a response to water limitations, which may limit opportunities to intensify cropping or make intensification riskier. Some innovative producers continue to develop appropriate strategies (Yorgey et al. 2016a; Yorgey et al. 2016b). Intensification of cropping (e.g., through double cropping) may also provide opportunities in irrigated annual cropping systems. The lack of historical yield information can be an impediment to insuring new crops in some cases.	For additional information on this strategy and its role in dryland cropping systems, see Kirby et al. (2017).
Reducing burning	Limited data found that burning accelerated carbon losses compared to unburned treatments by 0.07 MT CO ₂ e/ac/yr.	The number of acres burned has been greatly reduced, thus there may be limited opportunities for further reductions.	
Increasing perennial crops in rotation with annual crops	Annual cropping area: Experimental data suggest gains of 1.53 ± 0.61 MT CO ₂ e/ac/yr (Brown and Huggins 2012).	Profitability of some perennial crops is a barrier. Different equipment or infrastructure needed, and markets for current perennial crops (e.g., alfalfa) may present a barrier. Landscape level impacts need to be better understood.	

		Perennial crop development to replace existing annual crops (e.g., perennial grain crops) remains a long-term aspirational research effort.	
Cover crops	No systematic quantitative estimates available.	Focus is on cover cropping that integrates with existing food production systems, rather than cover crops that replace food production. To date, cover cropping has more successfully been integrated into irrigated cropping systems (e.g., as green manures prior to potatoes). Viable cover cropping systems have not yet been developed for dryland systems, though this is an area of ongoing work (Pan et al. 2017b). The profitability of incorporating cover crops can be a barrier, especially where cover crops use water that would otherwise be available to cash crops.	

Table B2. Summary of greenhouse gas mitigation potential of agricultural practices that are covered in Section II.II and fall under the general areas of enteric fermentation, manure management and nutrient management

Note that mitigation potential depends heavily on the baseline (i.e. the specifics of agricultural practices used prior to implementation of the practice). In several areas, science is still evolving. As such, the following percentage reductions achievable through a particular practice should be interpreted as generalized and rough estimates.

Area	Practice	Mitigation potential For references, see table footnotes.	Current adoption in WA	Ease of use across farm sizes	Estimate is region-specific
Enteric fermentation 3.0 MMT CO₂e (2.1% of statewide emissions)	Inclusion of unsaturated lipids in diet	Methane production in cows reduced ~10-30% ^{28,35} with no impact or increase in milk production ²⁹	Utilization of leftover agricultural and food processing materials is likely good.	Unclear, depends on availability of feed materials.	No
	Feed additives: 3-NOP (Bovaer)	Methane production in cows reduced by 8-60% ³⁰ , most typically by ~30%	U.S. approved in 2024, currently in a few dairies	Applicable at all farm scales. High cost (\$.50/day/cow as of early 2025).	No
	Feed additives: monensin	Typically considered low, less than 10% ²²	Some herds feed monensin for productivity reasons	Applicable at all farm scales. Cost \$0.02-\$0.04/day/cow as of early 2025.	No
Manure management 1.6 MMT CO₂e (1.7%)	Lagoons emptied for summer	Methane emissions lowered by 59% for summer daily spread compared to 6-month year-round slurry storage. ³¹	Some variation of this strategy is widely used.	Applicable at all farm scales.	No
	Solid-liquid separation prior to lagoon storage	Variable depending on degree of solids separation achieved; Overall emissions (methane and nitrous oxide) may be	Mixed.	Applicable at all farm scales.	Yes

²⁸ Guerrero et al. 2024

²⁹ Rabiee et al., 2012

³⁰ Prathap et al., 2021; Hristov et al., 2022

³¹ Wright and Gooch 2017

		lowered by ~25% ³² , though meta-analyses suggest the impact may be smaller. ³³			
	Composting separated solids with aeration or biochar	Depending on the baseline, addition of bulking agents significantly reduced nitrous oxide (N ₂ O) and methane (CH ₄) emissions by 53% and 71%, respectively; specifics of composting (windrow, aeration, etc.) had large impacts. ³⁴ Methane emissions lowered by further 79% for biochar co-composting. ³⁵	Mixed.	Applicable at all farm scales.	No
	Impermeable covers on lagoons (i.e., cap and flare)	GWP reduced by 57% (compared to manure that has already undergone solid-liquid separation) ³⁶ or 74% (no separation). ³⁷	Little use.	Applicable at all farm scales where manure is stored in lagoons; may be most applicable at smaller scales where anaerobic digestion is not an option.	No
	Anaerobic digestion of manure	Manure management emissions reduced by 60-70%. ³⁸ Additional benefits result from the generation of renewable fuels that replace fossil fuels.	8 digesters within WA ³⁹	Adoption limited to larger farms (generally >3,500 cows)	Yes

³² Emmerling et al., 2020

³³ Greene, 2024

³⁴ Guillermo et al. 2015

³⁵ Harisson et al., 2022

³⁶ Wright and Gooch, 2002a

³⁷ Wright and Gooch, 2022b

³⁸ Greene, 2004

³⁹ Livestock Anaerobic Digester Database, AgSTAR (<https://www.epa.gov/agstar/livestock-anaerobic-digester-database>)

Nutrient management 1.9 MMT CO₂e (2.0%)	4Rs (right rate, right time, right placement, and right source)	20-30% reduction in nitrous oxide emissions. ⁴⁰	Nitrogen applications have been reduced across the state since 1990; unclear what magnitude of opportunities still exist for ongoing improvements.	Applicable at all farm scales.	No
	Controlled-release fertilizers	20% reduction in nitrous oxide emissions in drylands. ⁴¹	Low adoption.	Applicable at all farm scales.	No

⁴⁰ Hassan et al., 2022

⁴¹ Ti et al., 2018

Appendix C: The Science of Estimating Emissions Reductions from Agricultural Practices

While [Appendix B](#) provides a comprehensive look at existing regional data relating to the potential for carbon sequestration from specific agricultural practices, readers should be cautious in trying to use these data to calculate a precise quantitative estimate of the amount of carbon that could be stored through adoption of particular strategies across Washington agricultural lands. This is because the benefits of particular management practices are variable and depend on a multitude of factors, including whether or not the soils were depleted in soil organic carbon when a management change was implemented, the characteristics of the location and soils, the presence or absence of other important soil nutrients (e.g. N, P, K, micronutrients), and time elapsed since a management change occurred.

Progress towards more realistic estimates of the climate impact from particular management practices will likely require ongoing scientific work. Washington stakeholders have expressed a need for improved research and data, noting that high quality research to define baselines and evaluate the effectiveness of climate-smart practices over the long-term are necessary ([Appendix A](#)). This includes the collection of additional data from long-term experiments relating management practices to soil carbon sequestration and methane and nitrous oxide fluxes, meta-analysis across long-term datasets, and modeling approaches.

Both modeling and meta-analysis approaches rely on adequate amounts of relevant long-term data, which can be a challenge. However, the Washington Soil Health Initiative (WaSHI) has established long-term agroecological research sites across the state between 2020 and 2023 ([Figure C1](#) and [Table C1](#)), with support from the state Legislature. One of these sites focuses specifically on organic systems. These sites will expand our ability to understand soil carbon dynamics in a range of cropping systems relevant to Washington agriculture, complementing the Cook Farm long term research site (dryland wheat-based systems with higher rainfall) and some additional sites in Oregon and Idaho (mostly dryland wheat). In the years to come, these will be an invaluable resource for continuing to refine approaches to estimating carbon sequestration benefits from particular agricultural practices. Note however, that these sites focus on soil health and carbon sequestration and are not currently collecting data on nitrous oxide or methane fluxes due to funding limitations. From a scientific perspective, nitrous oxide emissions are challenging, and relatively expensive, to measure.

Figure C1: Long-term agroecological research and extension sites that are part of the Washington Soil Health Initiative (WaSHI)



Table C1: Long-term agroecological research and extension sites that are part of the Washington Soil Health Initiative (WaSHI).

<i>Practice</i>	<i>Potato-based annual cropping systems</i>	<i>Irrigated potato-based systems</i>	<i>Wine grape systems</i>	<i>Diversified organic systems with livestock</i>	<i>Tree fruit systems</i>	<i>Dryland cropping systems with livestock</i>
Cover crop	X	X	X	X	X	X
Added organic matter	X	X	X	X	X	X
Reduced tillage	X		X	X		X
Livestock integration				Sheep		Cattle
Leaving plant residue	X		X	X	X	X

Most approaches used to estimate the amount of carbon that can be stored in soils over time rely on either a meta-analysis approach, or a modeling approach.

I. Meta-Analysis

A meta-analytical approach analyzes multiple long-term datasets, usually focusing on datasets that meet particular criteria in terms of longevity, data quality, and applicability. In the Northwest, the only cropping systems with adequate datasets to support such an approach are dryland wheat-based systems. Brown and Huggins (2012) found 131 data sets in the peer-reviewed and non-peer-reviewed literature (e.g., bulletins and project reports), with data concentrated in two different dryland grain-growing areas: annual cropping and annual crop-fallow transition. To a lesser extent, they also found data for the grain-fallow area, where a crop is grown only once every other year due to rainfall limitations (to see the distribution of studies across practices and agro-ecological zones, see Table 1 in Brown and Huggins (2012)).

The authors converted each data set from its original units to mass per unit volume of soil per year, allowing them to (a) compare the values of different studies, (b) assess the depth-distribution of soil organic carbon change, and (c) estimate the total profile changes in soil organic carbon. For many combinations of practices and agroclimatic zones, only limited data existed, and these results were summarized. For the two practices (no-tillage and mixed perennial-annual systems) with adequate data for particular combinations of management changes and agro-ecological conditions, they carried out a comprehensive analysis to estimate mean soil organic carbon change (Table C2). Cumulative probabilities of SOC change were also provided and were suggested as an approach to accommodate high variability in the data. Methods are described in detail in Brown and Huggins (2012).

Table C2: Changes in soil organic carbon (SOC) across studies evaluating tillage and inclusion of perennials in the crop rotation in the inland Pacific Northwest

Management	Agroclimatic zone	Number of studies	Period covered (years)	Mean SOC change (Mg C/ha/yr) †	Cumulative probability of SOC change (Mg C/ha/yr) ‡		
					25th	50th	75th
No-tillage	2 (annual cropping)	12	14	0.71 (± 0.63)	0.21	0.64	1.04
	3 (transition)	5	10	0.21 (± 0.10)	0.12	0.19	0.25
Mixed perennial-annual	2 (annual cropping)	8	12	1.03 (± 0.41)	0.69	0.94	1.12

Source: Reproduced from Table 2 in Brown and Huggins (2012).

† Values in parentheses indicate plus or minus one standard deviation from mean value.

‡ The 25th, 50th, and 75th percentiles of the cumulative probability function.

Meta-analysis approaches have also been utilized elsewhere in the world, including in California (Cullman et al., 2014). A recent European “analysis of meta-analyses” is among the most comprehensive (Guerrero et al., 2024). In this context, meta-analyses were ranked according to statistical quality, relevance to the European context, and the goals for their use in EU policymaking. Numerical coefficients are drawn from the highest-ranked study, while ensuring that the overall effect (positive, negative, neutral) was consistent with the majority of the studies for a particular management practice. Practices of interest were defined by the policy context, but include 34 practices, ranging from manure storage techniques, manure processing technologies, landscape features, fallowing, crop rotation, crop residue management, and others.

II. Biogeochemical Models

Biogeochemical models synthesize current empirical understanding of the processes that govern the flow of energy, carbon, water, and nutrients through the ecosystem. They can model the exchange of nutrients such as nitrogen, and phosphorus between the atmosphere, the biosphere (i.e., crops and the soil), hydrosphere, and lithosphere. The models quantify the size of nutrient and carbon pools and the rates of the flows to quantify carbon inputs, outputs, and pool sizes under defined environmental and management conditions. Modeling studies depend on existing experimental measurements to evaluate their ability to represent real-life conditions and can be used to look at carbon changes over wider spatial and time scales than can be measured experimentally. There are multiple models used across the U.S. for these purposes.

Modeling approaches often come with a tradeoff between complexity and usability, with more complex models offering the potential for more precise site-specific emissions simulations and predictions. Meanwhile, in a trade-off for ease of use, models that require low amounts of input data may have increased bias, and therefore uncertainty at the site scale (Ball et al., 2023).

In addition to long-term datasets from research experiments, model improvements require field-scale, spatiotemporally explicit information about agricultural management practices. Even given the explosion in availability of remotely sensed datasets, this is not always easy. As an example, it is difficult to verify the adoption of tillage practices in an area with diverse cropping systems. Ongoing work to classify regional scale tillage practices in eastern Washington through model development with satellite imagery is under development (Kandelati et al., submitted). The developed model incorporates satellite imagery, environmental variables, and ground-truthed data for tillage practices. The research project offers a scalable tool for verification of tillage practices for diverse crops like grains, legumes, and canola.

Over time, these experiments and efforts will improve models and yield data that can support better estimates of the impacts of particular management practices on the long-term storage of carbon in agricultural soils.