CLIMATE CHANGE SOLUTIONS IN CALIFORNIA AGRICULTURE

Agriculture has much to lose if the state does not avoid the worst impacts of a changing climate. A 2018 literature review by the University of California predicted that by the year 2100 climatic changes such as temperature and precipitation will dramatically reduce the production of walnuts, apricots, peaches, kiwis, avocados, almonds, table grapes, and other crops. More extreme and frequent droughts and floods also put our agricultural industry at great risk.

California's farms and ranches contribute eight percent of the state's total greenhouse gas (GHG) emissions. With sufficient resources, farmers can reduce potent greenhouse gas emissions, store carbon in soil and woody plants, and produce renewable energy. In consultation with several academic experts in the field, this review summarizes primarily California-based peer-reviewed scientific literature on the most powerful farming practices available to reduce GHG emissions and sequester carbon.

The focus of our review is on methods to reduce GHG emissions and sequester carbon on farmland, pasture and rangeland. Many of these solutions also bolster agricultural resilience to climate change, providing additional environmental and health benefits for farmers and rural communities.

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HEALTHY SOILS

Healthy soils are the foundation of long-term agricultural sustainability. As defined in the code that established California's Healthy Soils Program, healthy soils "enhance their continuing capacity to function as a biological system, increase soil organic matter, improve soil structure and water- and nutrient-holding capacity, and result in net long-term greenhouse gas benefits."[1]

Properly managed soil has the potential to serve as a carbon "sink" through a process called soil carbon sequestration, in which atmospheric carbon dioxide is converted by photosynthesis in plants to organic forms of carbon and stored in soils. Practices that increase soil organic matter also support carbon sequestration. Building healthy soils that can sequester carbon provides an important opportunity for agriculture to both mitigate and adapt to climate change.[2,3]

More than one-quarter of all land in California is used for farming, offering a large area for carbon sequestration, especially for locations where agricultural practices have depleted soil carbon. The ability of farms and rangelands to sequester carbon depends on soil type, current levels of soil carbon, regional climate, choice of crop systems, and management practices.[4,5,6]

Many practices available to farmers and ranchers can increase soil health. Studies show that using several practices in combination has the greatest potential for building soil organic matter, sequestering carbon, reducing nitrous oxide emissions and maintaining yields.[7,8,9,10,11] The most promising practices include planting cover crops, reducing or eliminating tillage, using diversified crop rotations that keep soil covered, improved grazing management, applying organic soil amendments such as compost and manure, and reducing and properly timing the application of nitrogen fertilizer inputs.[12,13,14,15,16,17]

Several soil management practices that can increase soil carbon sequestration (e.g., cover cropping and the application of composted manure and green waste) also lower nitrous oxide emissions[18,19,20] when synthetic fertilizer inputs are reduced at the same time.[21] The effect of these soil health practices alone on the emissions of nitrous oxide (which is 300 times more potent than carbon dioxide) depends on the rate and timing of manure amendments, and whether a legume or non-legume cover crop is used.[22]

Complex interactions among plants and soil microbes help provide plant nutrients and defend against diseases.[23] Keeping soil covered with cover crops or plant residues and minimizing or eliminating tillage will reduce soil erosion and supply the resources that soil microbes need to grow and persist.[24,25] Reducing soil disturbance by decreasing tillage intensity and frequency also helps keep carbon in soil by reducing the disruption of soil structure and the stimulation of microbial decomposition, both of which convert carbon in soil to atmospheric carbon dioxide.[26]

Perennial plants such as hedgerows, trees, orchard crops and grapevines can store carbon and nitrogen in their above and belowground biomass and in soils.[27,28,29] Perennials often have much deeper roots than annual crops, increasing their carbon sequestration potential.[30]

Though it can take years to build healthy soils, farmers can reap long-term benefits such as improved water penetration and retention, decreased need for chemical inputs, and greater resilience to drought, flooding and pest infestations. Studies show that healthy soils are able to support higher crop yields and can increase profit for farmers by more than $125 per acre.[31,32]

Soils high in organic matter are able to store and cycle water and nutrients more effectively, making them more resilient to extreme and variable weather.[33,34] Soil health practices also positively impact water quality. Organic nitrogen from cover crops has longer residence times in soil[35] and releases nitrogen more slowly compared to single or just a few applications of synthetic fertilizer.[36] This can more closely match plant demand for nitrogen and its availability in the soil,[37] and can minimize nitrogen leaching into groundwater and/or volatilizing as nitrous oxide. The use of cover crops can reduce nitrate contamination in groundwater by as much as 83 percent.[38] Replacement of fallowed fields with cover crops can dramatically reduce leaching of nitrate into surface and groundwater by up to 70 percent.[39,40,41]

RANGELAND MANAGEMENT

Rangelands in California cover more than 60 percent of the state. Most of this land—approximately 40 million acres—is actively grazed.[42,43] Rangelands in California vary widely in their characteristics and composition. While some rangelands are mostly annual and perennial grasses, others are mostly scrub or woodlands.[44,45]

Preventing conversion of rangelands to more intensive irrigated agricultural systems or urban development will avoid increased GHG emissions and maintain ecosystem services such as biodiversity and wildlife habitat.[46]

Although soil carbon sequestration in rangelands is typically low on a per-acre basis, the total carbon mitigation potential of using improved grazing is significant over California's vast acreages of rangeland.[47,48,49] Compared to forests, grasslands store more carbon belowground and are more resilient to wildfires and drought, potentially making them more reliable carbon sinks.[50] Carbon sequestration in rangeland soils has many benefits, including reduced erosion and increased water infiltration and storage in soils.[51] Applying compost can also bolster carbon sequestration because many rangelands are nutrient-deficient, so compost can increase plant productivity and, in turn, soil carbon.[52,53,54,55]

Avoiding livestock overgrazing by using rotational systems can increase forage productivity, soil carbon sequestration, water infiltration and storage, above- and belowground biodiversity, and resilience to climate change.[56,57,58,59] Adaptive grazing management strategies employ flexible timing, duration, and grazing intensity to balance animal stocking density with impacts on forage and can improve environmental outcomes as California rangelands face climate change.[60]

The perennial grasses and oaks of California's rangelands store carbon in their tissue and also draw carbon into the soil to feed belowground microbes associated with their extensive root systems.[61,62] Increasing carbon sequestration by these plant species can be done by managing grazing intensity, using silvopasture techniques that integrate livestock, trees and forage, and restoring previously wooded rangelands.[63,64,65]

LIVESTOCK AND METHANE

While GHG emissions from crop production have been declining, methane emissions from California dairies and livestock have been increasing and now account for more than half of the state's on-farm methane emissions.[66] Methane is what is called a "short-lived climate pollutant," meaning it decomposes more readily than carbon dioxide. However, it is more potent, with an impact approximately 84 times higher over a 20-year period.[67] For this reason, the state has set its sights on reducing methane emissions from dairy and livestock (the source of 60 percent of California's total methane) by 40 percent of 2013 levels by 2030.[68]

Methane emissions from livestock operations are significant and come from two sources in approximately equal parts.[69] The first is the emissions from the animals themselves generated by methane-producing bacteria in their rumen (known as enteric fermentation). The second is from the anaerobic decomposition of manure in ponds and manure lagoons found on most dairy and livestock operations where large volumes of water are used to flush out barns and stalls.

Installing anaerobic digesters to capture methane produced from manure lagoons can provide the dual benefit of reducing methane and producing energy, offsetting the use of fossil fuels.[70,71] However these systems are highly technical (usually requiring dedicated operators), very expensive, and only affordable on the largest confined-animal operations with their high volumes of manure slurry.[72]

Switching from flush water lagoon systems to drier manure management strategies can significantly reduce methane production and provide numerous co-benefits.[73,74] Compared to liquid manure lagoons, dry manure management systems reduce groundwater contamination by nitrates, pathogens, and antibiotics. They also improve air quality by reducing ammonia emissions, and reduce noxious odors that can impact nearby residents.[75,76,77,78] Additionally, dry manure management can reduce water use.

Compost pack barns—where large amounts of bedding are added to manure and composted underneath the livestock—not only reduce methane emissions but also protect livestock from the rain and create valuable compost which can be applied to soils, adding organic matter and reducing GHG emissions.[79]

Pasture-based dairy and livestock systems can be an important tool for mitigating manure-based methane emissions because manure is deposited directly to the grazed rangeland, avoiding anaerobic decomposition.[80,81,82] However conflicting studies indicate possible increases in enteric methane production in grass-fed livestock. Transitioning completely to pasture-based systems may not be feasible for larger dairies, but even modest increases in the time animals spend on pastures could reduce methane emissions and increase carbon sequestration.[83]

Improved grazing management designed to promote optimal forage communities can improve the digestibility and nutrient composition of grazed lands, reducing the methane generated by enteric fermentation. This will offset some of the methane emitted by sequestering carbon in the soil.[84,85,86,87] Some feed additives are being examined for use in conventional livestock systems for their potential in improving feed digestibility and therefore reducing enteric methane emissions.[88,89]

FARMSCAPING AND BIODIVERSITY

Increasing on-farm biodiversity using farmscaping can mitigate climate change by increasing carbon sequestration in woody shrubs, trees and soil. Farmscaping involves a range of practices such as increasing crop diversity with rotations and intercropping (planting two or more crops together), integrated crop-livestock systems, reforestation, establishing riparian areas, silvopasture (combining trees and grazing land) and planting hedgerows (shrubs and trees along farm margins and roadways).[90,91,92] In addition to the climate benefits, these practices increase on-farm biodiversity, promote biological pest management, and provide other environmental benefits such as wildlife habitat.[93,94]

Hedgerows and flowering plants attract beneficial insects, like pollinators and natural predators of crop pests. This then improves yields in pollinator-dependent crops and reduces the need for pesticides that have human and environmental health impacts.[95,96,97,98] Using biodiversity to manage pests, rather than pesticides, can increase farm profits by lowering pesticide costs and pest-related yield losses.[99,100] Hedgerows, riparian corridors and other types of vegetative buffer strips can also reduce the flow of sediment and fertilizers into surface waters, thereby improving water quality.[101,102]

Increasing crop diversity with rotations and intercropping builds resilience and limits the economic risk of major crop losses that are more likely in monocrop systems. Such systems are vulnerable to pests or weather events like drought,[103,104] early frost, or extreme heat which are all predicted to become more frequent, intense and unpredictable with climate change.[105,106]

Restoring riparian areas between cropland and rivers or streams can create additional opportunities to sequester carbon. One California study showed that riparian areas stored almost 30 percent more carbon than adjacent cropland, and this increased to 100 percent on rangeland.[107] Other ecosystem services provided by planting trees, shrubs and other woody deep-rooted plants include reduced soil erosion, improved pest control, and enhanced water quality.[108,109] Grass strips and restored riparian areas can catch agricultural runoff, reducing nitrate water contamination by up to 69 percent.[110]

WATER CONSERVATION

Agriculture in California accounts for 40 percent of all water use.[111] While many farmers continually strive for improved water conservation, opportunities remain for further efficient use of water and energy related to pumping, which will reduce associated GHG emissions and costs.

Switching from flood irrigation to drip systems allows water to be applied in smaller, more precise quantities, increasing the crop yield per unit of water.[112, 113] In addition, switching to drip irrigation from flood irrigation in tomato, corn, and lettuce systems was found to be one of the most consistent ways to reduce emissions of nitrous oxide from soils, since high soil moisture can increase nitrous oxide emissions.[114]

Micro-irrigation technologies that precisely target water application—such as sub-surface drip irrigation—can provide additional benefits such as increased crop yield and quality, increased profitability, and up to 20 percent water savings compared to drip irrigation.[115,116,117] However, these benefits must be weighed against potential tradeoffs such as the high investment costs of establishing sub-surface irrigation and slightly higher energy requirements compared to surface irrigation. There may also be tradeoffs related to soil health: micro-irrigation systems have a smaller wetting pattern in the soil and may compromise healthy microbial activity throughout the soil profile.

Researchers have recently suggested that use of flood or furrow irrigation may support groundwater recharge compared to sub-surface irrigation and other efficient practices—an important consideration as the state faces the diminished water availability predicted with climate change.[118] Some irrigation experts are beginning to recommend dual irrigation systems that enable the use of both surface water (when it is available) and groundwater, as well as combinations of flood irrigation and drip or micro-irrigation.

Soil management practices, such as compost and mulch application, can improve water conservation by increasing soil organic matter content, which boosts aggregate stability and soil structure. These changes typically lead to improvements in infiltration and water-holding capacity and also reduce water loss via evaporation—all of which give plants greater access to the available water.[119,120] As a general guideline, the Natural Resources Conservation Service states that every one percent increase in soil organic matter has the potential to store an additional 20,000 gallons of water per acre.[121]

Techniques like combining crop-residue retention with reduced tillage may decrease soil-water evaporation by four to five inches annually.[122] Cover crops and organic amendments can also reduce evaporation and increase infiltration, although cover crops must be carefully managed to minimize transpiration losses prior to cash-crop planting.[123] For more on strategies for increasing soil organic matter, see the Healthy Soils section.

Another water conservation tool is dry farming, which takes advantage of residual soil moisture from the rainy season without requiring any additional irrigation. This method involves the use of drought-tolerant, native, and/or regionally adapted crop breeds.[124,125] Also, on-farm ponds collect precipitation and excess surface irrigation, reducing runoff, recharging groundwater, providing a water source for dry-season irrigation, and contributing to regional flood management efforts.[126]

RENEWABLE ENERGY & ENERGY EFFICIENCY

Renewable energy is a growing sector in California agriculture. Wind turbines, solar panels, geothermal and bioenergy projects can increase the state's production of renewable energy. These projects also generate income for farmers and ranchers through the sale of excess energy. Between 2009-2012, the number of farms reporting on-farm energy generation through renewables tripled.[127]

Energy audit services, such as those offered through California's electric utilities and the Natural Resources Conservation Service, assist farmers to reduce unnecessary energy use prior to installing renewable energy.[128] These audits help maximize energy efficiency in lighting, packing, cooling, and packaging to reduce GHG emissions and costs for farmers. Agricultural irrigation also consumes enough energy to power 1.5 million residences each year.[129,130,131] Water conservation strategies to support conservation of on-farm energy use are covered above.

FARMLAND CONSERVATION

Approximately 50,000 acres of California's agricultural land on average is lost every year—the vast majority to urban development—with negative impacts on climate change mitigation and adaptation.[132,133,134]

Research suggests that conserving farmland at the urban edge slows the spread of sprawl and reduces transportation-related GHG emissions.[135] A case study in Yolo County found that an acre of urban land emits 70 times more GHG emissions compared to an acre of irrigated, conventionally managed cropland.[136,137] The conversion of rangelands to more energy intensive uses such as urbanization, rural ranchette development or irrigated agriculture results in the loss of soil carbon storage over large acreages in California.[138]

Conserving farmland is also a climate adaptation strategy in the face of rising temperatures.[139,140] Agricultural lands reflect solar radiation and thereby can provide a cooling effect when the fields are adjacent to cities that absorb solar radiation and intensify heat.

California agriculture provides many important services in addition to climate mitigation and adaptation. The state produces over half of the country's fruits, vegetables and nuts and is the leading dairy producer—all products necessary in a healthy diet.[141,142] California leads the country in the production of on-farm renewable energy, with future opportunities for growth. Agriculture is also an economic driver in the state, maintaining rural livelihoods as well as providing other ecosystem services such as groundwater recharge areas,[143] biodiversity and wildlife habitat.[144,145]

ORGANIC AGRICULTURE

California is the nation's leading producer of organic agricultural products, covering over one million acres[146] and representing 38 percent of the country's organic products.[147] Organic systems integrate ecologically based practices to boost fertility, build soil organic matter, conserve natural resources, and mitigate GHG emissions.[148,149] Organic farmers are prohibited from using fossil-fuel based fertilizers, herbicides, and pesticides. Instead, they use a variety of methods including cover crops, plant and animal based fertilizers, crop rotations, and biological pest control—practices also used by many conventional farmers. As a result, these systems can have smaller carbon footprints per acre than their conventional counterparts when all energy inputs are considered, with up to 30 percent less embedded energy and therefore lower net GHG emissions.[150,151]

While there is considerable variation between farms, seasons, soils, and other conditions, studies have found that soils under organic management sequester more carbon than conventionally managed soils. A survey of soil samples from across the country found improved soil organic matter content in organic systems, which is often correlated to higher rates of soil carbon sequestration.[152]

Data from UC Davis's Long-Term Research on Agricultural Systems study showed that after 13 years, organic plots under standard tillage sequestered 14 times more carbon than conventionally managed plots; under conservation tillage, organic sequestered 27 times the carbon as conventional.[153] A 12-year study in California showed a 36 percent increase in carbon sequestration with the use of organic practices like green manures and animal manures, despite increased tillage compared to the conventional system.[154] Research on 13 organic farms in California identified several farms with an optimal combination of high crop yields, available nitrogen for plant growth, and minimal nitrogen loss, suggesting potential for farmer-to-farmer knowledge sharing to improve management and outcomes on other farms.[155] USDA research shows that organic agriculture, even when using tillage, can sequester more carbon than no-till conventional agricultural systems.[156]

In addition to the climate benefits, there are many other advantages to organic systems:

- Avoiding the use of herbicides and pesticides promotes on-farm biodiversity and can encourage pollinator and beneficial insect populations
- Using crop rotations, cover crops, and diversified cropping systems increases on-farm biodiversity, enhancing biological pest control
- Avoiding synthetic fertilizer inputs can reduce nitrous oxide emissions and nitrogen leaching into waterways
- Premiums in the marketplace reward farmers and ranchers for the enhanced environmental benefits associated with agricultural production

CONCLUSION

Farmers and ranchers contribute important climate solutions for California and the nation as a whole. Encouraging sustainable agricultural practices such as those summarized here can reduce GHG emissions, enhance on-farm capacity for carbon sequestration, and provide numerous environmental and health co-benefits.

The projected changes in climate create a novel set of challenges that are outside the experience of even the most experienced farmers and ranchers. The situation creates an imperative to provide research and monitoring, technical assistance and financial resources for farmers and ranchers to both mitigate and adapt to climate change.

As shown in the sidebar, California has launched a suite of grant programs using revenue from the state's cap-and-trade program to incentivize many of agriculture's climate solutions. These programs are vital for capitalizing and reducing the risks of changing practices on the state's farms and ranches. With resources such as these, we can ensure that California agriculture is a leader in mitigating and adapting to climate change. We can make certain that California farms will remain viable, innovative, and ecologically and economically sustainable for years to come.

CLIMATE SMART AGRICULTURE PROGRAMS

The state of California launched the first of its innovative Climate Smart Agriculture programs in 2014, funded with proceeds from the state's cap-and-trade program. These grant programs—the first of their kind in the country—provide unique resources for farmers and ranchers to adopt transformative management practices that reduce potent GHG emissions, increase carbon storage in soils and woody plants, and protect at-risk agricultural lands, all while providing multiple benefits that improve the health and resilience of our farms, ecosystems and communities.

CalCAN and numerous partners have been champions for the funding and continual improvement of these trailblazing programs. For more information on California's Climate Smart Agriculture programs, see CalCAN's website: http://calclimateag.org/agpolicyclimatesolutions/.

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The California Climate and Agriculture Network (CalCAN) is a statewide coalition that advances policy reforms to realize the powerful climate solutions offered by sustainable and organic agriculture. Since 2009, we have cultivated farmer leadership to face the challenges of climate change and to serve as the sustainable agriculture voice on climate change policy in California.

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