

LINKING CLIMATE-FRIENDLY FARMING PRACTICES TO SAN DIEGO COUNTY'S CLIMATE ACTION PLAN:

An Opportunity Analysis of Carbon Farming
in the Unincorporated County

MARCH 2018



Prepared by



BATRA ECOLOGICAL
STRATEGIES

Puja Batra, Ph.D.

ACKNOWLEDGMENTS

We greatly appreciate the San Diego Foundation's generous support. We are also grateful for the insights shared by numerous stakeholders and advisors in the preparation of this report, including teams and individuals from:

- San Diego's Farming and Ranching Communities
- California Department of Fish and Wildlife, Rancho Jamul Ecological Reserve
- Carbon Cycle Institute
- Checkerboard Studios/Geoffrey Plagemann
- County of San Diego Agriculture, Weights & Measures
- County of San Diego Air Pollution Control District
- County of San Diego Department of Public Works, Solid Waste Planning and Recycling
- County of San Diego Department of Public Works, Watershed Protection Program
- County of San Diego Health & Human Services
- County of San Diego Land Use and Environment Group, Live Well Food System Initiative
- County of San Diego Planning & Development Services
- Dr. Bronner's
- East Stanislaus Resource Conservation District
- Ecology Artisans/ Montado Farms
- Energy Policy Initiatives Center, University of San Diego
- Jena and Michael King Foundation
- Marin Agricultural Land Trust
- Marin Carbon Project
- Marin County Community Development Agency, Sustainability Team
- Mission Resource Conservation District
- Natural Resources Conservation Service
- Natural Resources Defense Council
- New Farmer's Guild
- Resource Conservation District of Greater San Diego County
- San Diego County Farm Bureau
- San Diego Roots: Victory Gardens San Diego + Wild Willow Farms
- San Diego State University, Department of Geography
- Solana Center
- Sonoma County Regional Climate Protection Authority
- The Conservation Fund
- The San Diego Foundation
- U.S. Fish and Wildlife Service, Partners for Fish and Wildlife

EXECUTIVE SUMMARY

The intentions of this report are to estimate the potential of climate-smart agriculture, or “carbon farming” to help the County of San Diego reach its GHG reduction goals while also building climate resilience; to identify synergies in which carbon farming can address multiple challenges; to identify existing and new funding sources by leveraging resilience, and propose ways to create incentives for carbon farming; and more broadly, to recommend overall strategies by which the County can partner with agriculture to advance mutually beneficial climate solutions.

The County of San Diego has developed its Climate Action Plan (CAP) for reducing greenhouse gas (GHG) emissions for the unincorporated areas of the county. Agriculture is estimated to contribute 163,696 MTCO₂e, or 5% of the total emissions, which accounts for livestock, fertilizer, and agricultural machinery emissions, but methodologies do not yet enable estimating net carbon sequestration in agricultural lands. In addition to climate mitigation needs, the region faces several resilience challenges that affect the county as a whole, and will be felt strongly by agriculture. Among the most important of these are increased average temperatures and prolonged heat waves, which will result in plant evaporative stress. Rising water costs are already a major barrier to farm profitability, so any measures that can alleviate water stress and/or water pricing will act to stabilize farm incomes and farming in the region.

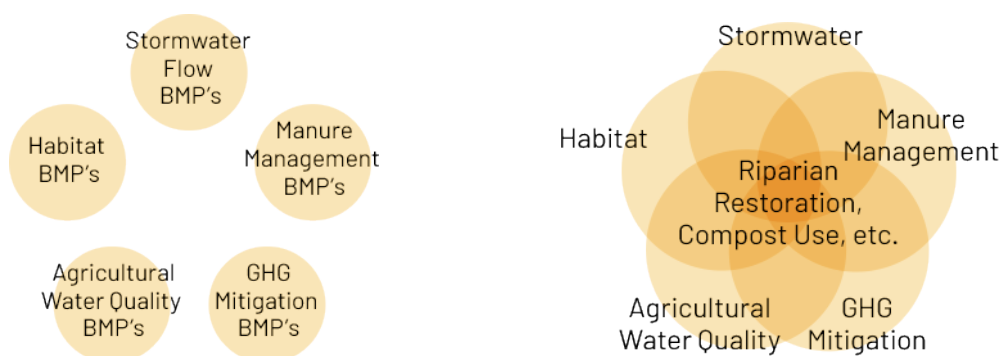
A suite of farming and ranching practices, collectively called “carbon farming” hold the potential for delivering multiple benefits: 1) reducing GHG’s 2) building soil health, and 3) strengthening climate resilience. They include numerous practices that sequester stable soil carbon, sequester carbon in living vegetation, and reduce emissions from conventional practices such as fertilizer application. Practices include composting, riparian restoration and other perennial plantings, cover cropping, reduced tillage, silvopasture, and several others that are already well-known as part of Natural Resource Conservation Service (NRCS) list of conservation practices. Compost application on cropland and rangeland has high GHG removal potential (1.5 – 4 MTCO₂e /acre/year), and has resulted in remarkable increases in plant growth, and water holding capacity improvements, among several other co-benefits. Similarly, riparian restoration has GHG reduction potential of 1 MTCO₂e/acre/year, and several important co-benefits including water quality improvements and habitat conservation.

Our region’s agriculture already currently utilizes some important carbon farming practices, due to a large amount of acreage in orchards. However, during 2000-2015, an estimated 1 million orchard trees were taken out of production, largely due to rising water costs. The resulting lost storage and sequestration value is estimated to be more than 300,000 MTCO₂e over the 15-year period. Investments in recycled water distributed to

agriculture at reduced rates will preserve our existing orchard carbon sinks and allow for further sequestration to occur, boost the agricultural bottom line, and result in increased availability of freshwater for non-agricultural purposes.

Compost application on crop and rangelands, and riparian restoration of eligible areas could deliver GHG reductions of over 234,000 MTCO₂e/year. Implementation of carbon farming on County lands would begin the processes, monitoring, and demonstration needed to scale up practices by the farming community, while also helping achieve GHG reductions needed for climate action.

Programs whose goals can be met by the same climate-friendly practices represent opportunities to pool resources and optimize existing funds in ways that result in GHG mitigation. However, attention must be paid to address any contrary regulations that deter farmers from employing those practices. For example, riparian restoration and planting of perennial vegetation are carbon farming practices that are also best management practices for improving agricultural water quality, manure management, habitat connectivity, groundwater recharge, and stormwater management. By combining resources across agencies, easing regulatory hurdles associated with habitat creation, and incentivizing these specific practices, several resilience issues can be addressed holistically using existing resources, while also mitigating GHG's.



* BMP = Best Management Practices

Other such synergistic opportunities exist, for example, in scaling up the application of compost on crop and rangelands. Facilitating the production and use of compost, including specific attention toward composting of manure, will achieve multiple benefits: reduce landfill methane emissions, as estimated by the County's new organic waste management plan; increase soil moisture, thereby reducing plant water stress; increase water infiltration, aiding groundwater recharge; manage nutrient pollution caused by manure runoff; add new economic possibilities of on-farm income and compost-associated businesses; and finally, achieve even further GHG reduction benefits through soil carbon sequestration. Appropriate attention must be given to regulation associated with

compost production, and results after application should be monitored for effects on vegetation growth, nitrate leaching, and native species in order to find locally optimal application rates and methods of rangeland management. This will enable the county to optimize multiple climate and soil health benefits of compost application.

Early investments in carbon farming will continue to sequester carbon over several decades. A number of possible financial incentives and funding mechanisms are discussed. The CAP strategy of direct investments in GHG reductions projects can also be cost effective investments in resilience if streamlined, local carbon farming protocols are developed and approved as eligible recipients of these direct investment funds. Approval of carbon farming as CEQA GHG mitigation can help to finance the process of carbon sequestration in soils, and may be more cost effective than developing a local offsets registry. An optional affirmative component to the PACE program is also discussed.

The region's farmers, at an average age of 62, are being succeeded by an incoming generation of first-time farmers predisposed to sustainable farming methods. By facilitating the success of this younger generation of farmers, focusing on training and financing of carbon farming practices, the County can shift the region toward climate-friendly farming practices over the longer-term.

We make several specific recommendations, organized under four broad strategies.

1. Convene a task force on carbon farming whose role will be to engage with different stakeholders to develop and advance climate friendly agricultural strategies in the region.
2. Conserve the existing agricultural carbon storage and sequestration by addressing root drivers behind the decline in orchard crops.
3. Synergize among relevant agencies to facilitate and incentivize key carbon farming practices that have resilience co-benefits, such as composting and riparian restoration, and several others such as cover cropping, mulching, and planting of perennial vegetation.
4. Seize the opportunity for climate mitigation that lies with new generation of farmers and ranchers by helping them to succeed in carbon farming and regenerative agriculture.

As San Diego County begins the undertaking of climate mitigation, it is the ideal moment to recognize farmers and ranchers who provide ecosystem services to our county. With the region's agricultural strengths already providing a strong foundation for carbon farming, a forthcoming demographic shift in farming, and the knowledge and technology to address major barriers, the County is presented with an opportunity to partner with agriculture as a key ally in building a climate positive and more resilient region.

TABLE OF CONTENTS

Background	8
Rationale	8
San Diego County climate resilience challenges	10
The San Diego region's agricultural context	11
What is carbon farming?	14
High impact carbon farming practices	15
The Potential Carbon Sink Of San Diego County's Agricultural Lands.....	19
Emissions impacts of orchard tree loss.....	19
How much net GHG reduction can be achieved through carbon farming?	21
<i>Compost application to rangelands and croplands.....</i>	<i>21</i>
<i>Compost availability.....</i>	<i>22</i>
Which State And Local Policies, Programs, & Regulations Have Potential Synergies With Carbon Farming?	27
Resilience planning in General Plan Update	27
Short-lived climate pollutants.....	27
Sustainable Groundwater Management Act	27
Healthy Soils Program.....	27
County of San Diego General Plan	28
County of San Diego Strategic Plan to Reduce Waste	28
County of San Diego Board of Supervisors policy I-133: Support and Encouragement of Farming in San Diego County	28
Water quality regulations (County Watershed Protection, Regional Water Quality Control Board).....	28
The Multiple Species Conservation Plan	29
Purchase of Agricultural Conservation Easements.....	29

Funding For Carbon Farming..... 30

What funding mechanisms exist?.....30

What financial incentives can be developed to scale up carbon farming? 31

Creating water savings32

Purchase of Agricultural Conservation Easements (PACE).....32

Crediting systems.....33

CEQA mitigation funds34

Building the compost value chain35

Reducing regulatory barriers for habitat creation35

New farmer capacity building and apprenticeship programs.....36

Access to credit for new farmers36

Carbon funds and revolving loan fund.....36

Conclusion, Challenges & Recommendations 39

Works Cited 43

Appendices 49

 Appendix A: Carbon Farming Practices50

 Appendix B: Estimating the impact of net loss of orchard acreage
on CO2e reductions.....54

 Appendix C: Estimating acreage of compostable rangelands and orchards56

BACKGROUND

Rationale

The County of San Diego¹ has developed the Climate Action Plan (CAP) for the unincorporated areas for reducing greenhouse gas (GHG) emissions which cause climate change (San Diego, 2018.) In keeping with Senate Bill 32 of 2016, the CAP identifies strategies to reduce unincorporated county emissions to 40% below their 1990 levels by the year 2030. The CAP estimates current GHG emissions originating in several sectors, uses models to project how emissions under the current trajectory are expected to increase over the coming decades, and finally proposes specific strategies and target amounts by which they will reduce emissions so that the emissions trajectory takes a downward path to reach overall state targets. While the major contributors to unincorporated county GHG emissions are the transportation and electricity sectors, at 45% and 24% respectively, agriculture in our county, as is the case worldwide, is also currently considered a net source of GHG emissions. However, a suite of farming and ranching practices, collectively called “carbon farming” hold the promise of multiple benefits: 1) reducing GHG’s 2) building soil health, and 3) strengthening climate resilience. The soils and resilience benefits can also make measurable improvements to the agricultural bottom line. With County engagement, a commitment to recognizing the “ecosystem services”² that carbon farmers provide to the county as a whole could also help to boost the region’s declining farming sector.

The intentions of this report are to estimate the potential of carbon farming to help the County reach its GHG reduction goals; to identify synergies where carbon farming can address multiple challenges; to identify existing funding sources, and propose avenues to incentivize carbon farming; and more broadly, to recommend overall strategies by which the County can partner with agriculture to advance mutually beneficial climate solutions. Throughout this report, we use the terms “carbon farming,” “climate smart agriculture,” and “climate friendly agriculture” interchangeably.

The San Diego County Climate Action Plan (2018) estimates that of the 3,211,505 MTCO₂e estimated total unincorporated county emissions³, five percent – or 163,696 MTCO₂e – comes from the agricultural sector, and more specifically fertilizer use, livestock, and farm equipment. In fact, actual agricultural emissions are likely to be very different due to the

1 The focus of this report is the unincorporated County of San Diego, unless noted otherwise. Below, the capitalized word “County” refers to County of San Diego government, and lower case “county” is a general reference to the unincorporated area and/or population as a whole. The phrases “greater San Diego” and “San Diego region” refer to the entire county, including its 18 municipalities and the unincorporated area.

2 Ecosystem services are the quantifiable benefits that society receives from functioning ecosystems. Here, we refer to healthy agricultural soil ecosystems., with benefits such as carbon sequestration, and others.

3 Metric tonnes of carbon dioxide equivalents (MTCO₂e) are a standardized measure of the global warming potential of different greenhouse gases, all of which have different levels of severity. This “common currency” allows a side-by-side comparison of how different activities, producing different types of emissions, affect the climate.

fact that baseline emissions associated with agricultural soils, land management practices, and agricultural carbon sequestration cannot yet be modeled efficiently, nor can emissions associated with conversion of agricultural lands to other uses be efficiently estimated.

While we do not currently have full accounting of emissions associated with agricultural soils, we do know that carbon farming practices directly decrease the agricultural GHG footprint that may come, for example, from fertilizer use, and specific types of machinery use. In addition to reducing its own footprint, carbon farming can reduce levels of carbon dioxide in the atmosphere overall. Applied at large-scale, carbon farming can transform the agricultural sector into a net carbon sink, while building climate resilience at the same time.

The CAP (2018) recognizes that carbon farming can add value to achieving enforceable targets in multiple ways; for example, as an overall support measure in agricultural strategies:

In addition to quantifiable measures, the CAP also includes supporting efforts related to carbon farming and availability of locally grown and raised food. The County recognizes the importance of promoting sustainable agricultural practices and innovative carbon sequestration solutions to achieve continued GHG reductions. (p.3-78)

And, as a support measure for a sprawl-reduction strategy (T-1.2) under transportation:

Collaborate with agricultural stakeholders and the University of California Cooperative Extension to develop conservation and sustainable agricultural farming practices, carbon farming methods, and other climate beneficial practices on agriculture lands and rangeland, including practices and incentives that reduce the impact and use of synthetic fertilizer. (p.3-13)

It must be stated at the outset that carbon farming is not a panacea for high GHG emissions. Emissions reductions at their source are critical in slowing, and ultimately stopping climate change. Nonetheless, carbon sequestration in soils and vegetation is one of the few ways in which communities can simultaneously address climate mitigation and climate resilience. In a community in which agriculture is the 5th largest contributor to the economy (San Diego, 2018), we cannot afford to ignore an opportunity to reduce our climate impacts in ways that strengthen food security, regenerate natural resources, and boost our agricultural sector.

Early investments in carbon farming can continue to pay climate dividends for decades to come, as the effects of several practices actually increase over time. It is important not to wait until methods for estimating soil baselines have been perfected before making a commitment to partner with agriculture to benefit the quality of life across our entire region.

San Diego County climate resilience challenges

While tackling the causes of climate change at their sources, we must also build resilience to the changes that are already occurring and which will continue through this century. Using California Energy Commission's climate change scenarios tools⁴, the Climate Change Vulnerability Assessment included in the County's CAP (San Diego, 2018) identified several challenges facing the region which will be felt across the community, and will have profound impacts on agriculture. Using different GHG emissions scenarios, the Vulnerability Assessment findings suggest that by the end of the century, our region will experience several changes:

- **Higher average temperatures:** Average maximum temperatures are projected to rise between 5–10°F, and average minimum temperatures between 6–10°F.
- **Extreme temperatures and heat waves:** Annually, between 29–67 more days on which maximum temperature exceeds 96.3°F may occur, spread over a longer duration of the year.
- **Water reliability:** Precipitation locally is projected to increase between 1–5 inches annually, and is likely to become more erratic, with intense downpours that can result in flooding. Decreased snowpack feeding the headwaters of our primary sources of water, i.e., imports from the Colorado River and the State Water Project, are projected to decrease water availability. Changing snowmelt patterns will also lead to irregularity in the timing of water availability.
- **Wildfire:** Currently, an average of 21,000 acres burn annually in San Diego County. This figure is projected to increase by an additional 4000–9000 acres.
- **Sea level Rise:** Projected to rise by 31–55 inches during this century, direct effects on the unincorporated county are not anticipated due to its minimal exposure to coastline. However, it should be noted that one inland effect of rising sea level is seawater intrusion into aquifers which have a coastal connection, especially those that are overdrawn, such as has occurred in past decades in the San Luis Rey basin (Regional Water Management Group, 2013). Therefore, the indirect effects of sea level rise and the coastal-inland relationship must be considered when planning groundwater management efforts, enabling actions that contribute to positive outcomes in our water stressed area.

Several of these resilience challenges will further exacerbate GHG emissions, defying our ability to reach our GHG reductions targets. For example, during the last decade the region experienced catastrophic wildfires which resulted in sharp peaks of GHG emissions released from burning vegetation and other materials (Hahn and Tyner, 2008.) Similarly, studies have recently reported a positive feedback cycle between temperature and GHG's emanating from soils (Crowther, et al. 2016), thereby accelerating climate

⁴ cal-adapt.org

change's impacts to agriculture, natural ecosystems, and the ecosystem services that rely on soil carbon.

Of the above projections, all of the temperature-related impacts are expected to ensue over the next two decades with relatively high certainty, and precipitation changes also are expected to occur in the short-term. In the foreseeable future, the implications for agriculture of increases in heat and irregularity of rainfall will be profound: increased agricultural water demand, and plant and livestock stress will increase vulnerability to crop losses, pest infestations, and disease outbreaks. Therefore, focusing on carbon farming measures that can alleviate agricultural water stress will help to build a more resilient agricultural sector and address increasing regional water needs as well. Increased wildfire risk is projected as a medium-term concern with a mid-level of certainty, but its impacts can be rapid, widespread, and can significantly reverse progress on GHG reductions in a single catastrophic event. Therefore, any measures that may decrease this risk while also reducing GHG's should receive significant consideration.

The San Diego region's agricultural context

Currently valued at \$1.7 billion in sales, the agricultural economy in the greater San Diego region is in the top 20 counties in the United States. The region is home to the greatest number of small farms, and the greatest number of certified organic farms of any county in the U.S. It is also the top avocado-producing county, and even is anecdotally reputed to have among the largest number of horses per capita of any county in the nation. Distinct from other parts of the state, San Diego agriculture's unique characteristics present unique strengths, challenges, and opportunities to scale up carbon farming in ways that address some of the greatest obstacles facing farmers in our region today.

Important opportunities for linking climate action and agriculture lie in the composition of farming in the region⁵ (Agricultural Weights and Measures, 2015). The region's 250,000+ acres of agriculture include irrigated croplands, and non-irrigated field crops such as hay, oats, and rangeland. Orchard crops, primarily avocados and citrus, which occur on almost 35,000 acres, dominate the irrigated croplands. Orchard trees sequester and store carbon, and as such, our region's dominant croplands already represent an extremely effective carbon farming practice. That is, planting perennial woody vegetation such as orchard trees has among the highest GHG reduction potential of any cropping systems (Tonsmeier, 2016). Ensuring their continued presence is an important climate mitigation strategy, which yields more benefits and is less costly to maintain than the new tree planting at a later date.

Second in acreage, but highest in economic gains (Agricultural Weights and Measures,

⁵ Here we refer to trends in the region as a whole, as reported in San Diego County Crop Reports, which aggregate statistics across the entire county.

2015) are nursery and ornamental plants. Many of these products are grown in containers using non-soil media, so their productivity may not benefit from soil building practices. However, some of the co-benefits still may assist on-farm requirements for water quality management. For products such as cut flowers grown in the soil, carbon farming will result in the same benefits as would other crops.

Row crop agriculture comprises just over 3800 acres of croplands (Agricultural Weights and Measures, 2015), about 2% of total agricultural acreage. This implies a relatively low occurrence of methods such as soil tillage and large machinery usage that result in erosion and soil degradation.

Finally, rangelands cover almost 200,000 acres, though it is not known how much of this area is actively being grazed at present. Currently, cattle ranching yields the lowest dollar value per acre, when compared to other agricultural activities (Agricultural Weights and Measures, 2015), and the number of full-time ranchers is believed to be fewer than 25 (Farley, et al, 2017.) The large area of land and currently low economic productivity of rangelands presents an opportunity to enhance ranching livelihoods through climate-smart practices.

Notably, with 385 certified organic farms (Agricultural Weights and Measures, 2015), and many additional farmers practicing uncertified organic methods (San Diego Food System Alliance, 2017), it is clear that many San Diego farmers are already well-informed about soil building practices. In summary, with an abundance of perennial agriculture, relatively low incidence of soil tillage and annual row cropping, large acreage of non-irrigated rangelands, and the predisposition of many toward building soil health, San Diego County's agricultural sector is well poised to make major contributions toward combating climate change and strengthening regional resilience.

The region's agricultural context also includes several challenges. Rising land values, along with the escalating cost of water, shortages of labor, and complex regulations increasingly hinder the livelihood viability of farming. Trends during 2000–2015 illustrated in Figure 1 show overall agricultural acreage in the greater San Diego region declining over the last decade, and more rapidly so in recent years, paralleling the changes in field crops (i.e., rangeland). During the same period, the acreage of vegetables and orchard crops declined, with the latter dropping precipitously between 2007–2011, corresponding to a loss of around 10,000 acres of trees (San Diego, 2000–2015), the climate implications of which are discussed in a later section of this report. Nursery croplands have increased steadily over the past few years, indicating a transition away from food crops and those that have high carbon sequestration potential toward non-food products that generate a relatively steady agricultural income.

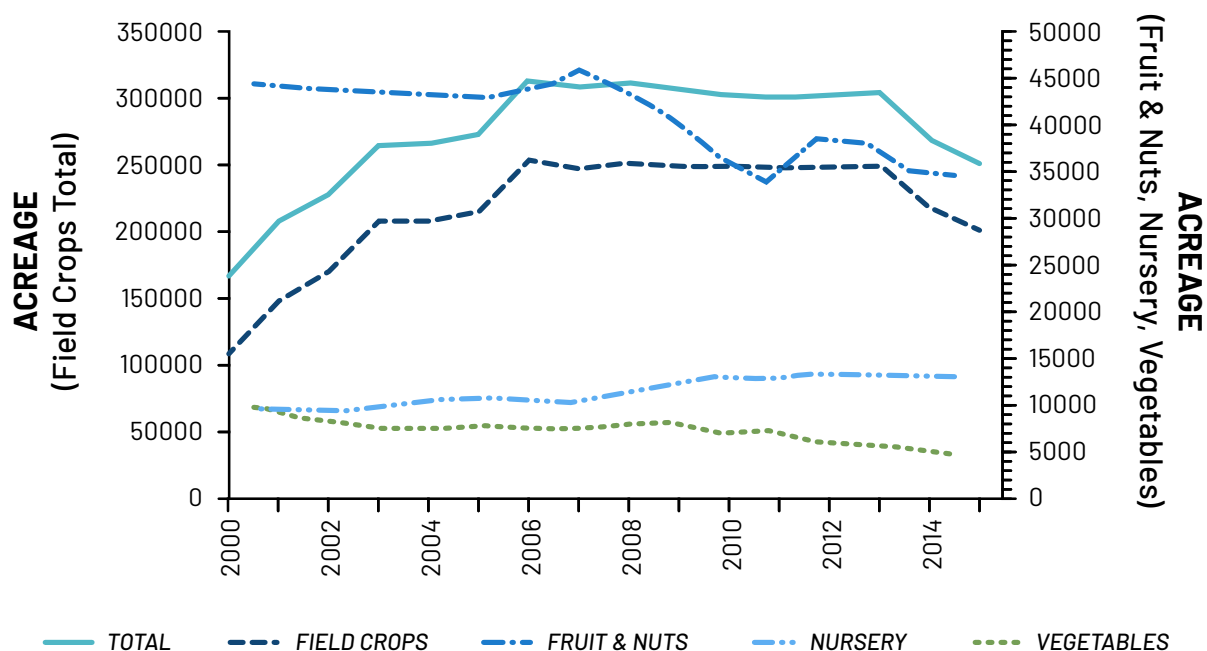


Figure 1. Agricultural acreage trends from 2000–2015. Note different axes for different crop types.
 (Data source: County of San Diego Statistics and Annual Crop Report, 2000–2015)

The average size of a farm in the region is 79 acres, while the median size is 4 acres⁶ indicating a wide range of farm size, with a majority of them being extremely small. Agricultural management companies, rather than a full-time owner or tenant farmer, often manage the latter. Farmers with different levels of engagement in their farms face different economic challenges. They will constitute different target groups when developing incentives and technical support for carbon farming.

A key feature of farming in the county is the farmers themselves. There is a demographic transition occurring in farming, as the average age a farmer in the region is 62 years old (United States Department of Agriculture, 2012) with fewer multi-generational families staying in the profession. This poses troubling uncertainty about the future of agriculture in the region; however, it also may present opportunities to train the incoming generation of first-time farmers in practices that can address the increasing need to build climate resilience. Initial surveys of emerging farmers conducted by the San Diego Food System Alliance (2017) suggest that a majority of them are predisposed to organic farming methods, many of which are also carbon farming practices. Providing them with early-stage training, support, and incentives to establish climate-friendly practices will help to transition the region to climate-smart agricultural practices, and ideally, establish them as the norm over the next few decades.

⁶ E. Larson, pers. comm.

With these defining characteristics, San Diego County is well positioned to partner with agriculture to make great strides towards climate mitigation, and climate resiliency. Simultaneously facilitating improvements in the agricultural bottom line will go a long way towards reducing risks that cause skilled and committed farmers and ranchers to leave the profession. Agriculture has preserved a quality of life in the region in both intangible and tangible ways. Now, the multi-faceted challenge of climate change presents a new opportunity to engage and recognize the valuable role that farmers and ranchers can play in providing much needed climate-related ecosystem services.

What is carbon farming?

It is widely recognized that the health of the soil ecosystem, in which carbon plays a key role, is directly related to food and nutritional security (Lal, 2016). As soil organic carbon increases in crop and rangelands, crop yields, plant nutritional content, and livestock production also increase (Tonsmeier, 2016, and references cited therein.) For these reasons, a suite of agricultural practices which build and conserve soil organic carbon – collectively called “carbon farming” – are gaining global momentum as potentially transformational solutions to our current climate change and food security crises (Chambers, et al, 2016; Hawken, 2017; Lal, 2016). In California, as well as in several other U.S. states⁷ the suite of practices is gaining the attention of scientists (Byrd, et al 2015; Flint, 2016), legislators (Donlon, 2017), and communities alike because of their multiple benefits: improving soil health and reducing GHG levels, while building climate resilience in the process.

While a full explanation of soil carbon is beyond the scope of this report, it is useful to point out that soils contain multiple types of organic carbon⁸, which vary in the rate at which they enter the soil carbon cycle. The active or labile pool of carbon is made up of leaf litter, crop residues, and smaller particulate organic carbon, and may take between a few hours to a few years to break down and begin to cycle through living organisms in the soil. The recalcitrant pool of carbon contains humus, formed through chemical interactions between soil microbes and plant roots, and may persist in a stable form for decades up to centuries, and some components such as charcoal may last for millennia. The objectives of carbon farming are to reduce GHG’s while increasing the amount of carbon locked in the recalcitrant pool and in long-lived vegetation. These effects occur in multiple, interrelated ways.

First, carbon farming practices result in GHG reductions through the avoided emissions that would otherwise come from conventional practices such as intensive tillage or synthetic fertilizer use (Tonsmeier, 2016. DeLonge, et al 2013). Secondly, plants sequester

⁷ Currently, state legislatures of California, Hawaii, Maryland, Massachusetts, New York and Vermont have committed resources toward promoting carbon farming.

⁸ Organic carbon is carbon of biological origin.

CO₂ by pulling it out of the atmosphere and building plant tissue, i.e., above-ground wood, stems, and leaves, and below-ground roots. By increasing the labile carbon pool and soil nutrient availability, carbon farming practices can enhance this plant growth. Most of this carbon stays locked into the plant biomass for the life of the plant, so perennial plants can store this carbon for several decades. Thirdly, those healthy plants exude carbon rich compounds through their roots, which foster the growth of soil fungi and bacteria. This leads to the aggregation of humus, a stable, recalcitrant humus form of sequestered carbon that can be several feet deep in the soil, and which can persist for hundreds of years – in the absence of disturbances like tilling. The increase in water holding capacity that comes with increased soil organic carbon facilitates even more plant and microbial growth, creating a positive feedback cycle. “Carbon farming” practices are those that facilitate sequestration and long-term storage of soil and plant-based carbon (Tonsmeier, 2016).

While there are numerous carbon farming methods (Tonsmeier, 2016), a shorter list of practices is recognized and eligible for funding by California Department of Food and Agriculture’s (CDFA) new Healthy Soils Program (Appendix A). They are a subset of conservation practices included in the Natural Resource Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP). The carbon farming practices are already supported by NRCS, so there is EQIP cost-share funding available for them, and their methods are well-known and widely supported by NRCS and other technical experts across the country.

We focus our analyses at a broad scale on a few key practices, based on their applicability in our region, their GHG removal potentials, and the importance of their resilience co-benefits in San Diego County. On an individual farm, however, a grower might choose one or many from the full list of possibilities. A “carbon farm plan,” similar to the NRCS conservation plan, is based on the farm’s bio-physical properties, and the farmer’s economic and personal considerations (Schembre, 2017). In California, the NRCS offices and/or Resource Conservation Districts (RCD) are working with farmers to develop farm plans specifically designed to meet farmer needs and optimize carbon sequestration.

High impact carbon farming practices

One well-known carbon farming practice that is gaining new attention is compost application. Composted organic matter has long been used by organic farmers to build soil structure, provide slow-release fertilization, increase soil water holding capacity, maintain pH levels, and control soil-borne diseases, among numerous other benefits (Rodale Institute, n.d.). Climate benefits of compost include reduction of atmospheric carbon through sequestration in soil and plant matter, avoided nitrous oxide (N₂O) emissions from conventional fertilizers, and avoided landfill methane emissions from organic waste disposal (Ryals and Silver, 2013). In addition to its value for croplands, the practice of

compost application has gained attention across California because of its potential to restore rangeland soils, degraded over the last century of grazing, while having the same climate benefits.

In Marin County, ongoing studies by researchers at UC Berkeley and the Marin Carbon Project report that a single ½" application of compost to rangelands resulted in average carbon sequestration rates of 1.5 MTCO₂e /acre/year⁹ (Marin Carbon Project, n.d.; Ryals and Silver, 2013), and grassland forage increases of between 40–75% (Ryals and Silver, 2013). The carbon sequestration benefits from this one-time application have been projected to continue for over a decade (Sullivan, et al. 2006; Walton, et al., 2001; Zhai, et al, 2014.) In addition, the researchers have measured significant increases in water holding capacity, in some cases of up to 25% (N. Scolari, pers.comm.)¹⁰

Closer to home, in a test plot in Santa Ysabel, preliminary results¹¹ show that forage production was almost triple that of the control, six months after an application of ½" compost, and following abundant rainfall in the 2016–17 winter. While the dramatic growth response seen initially in the Santa Ysabel test plot may not continue at the same rate over successive sampling periods, it does indicate that San Diego County's soils and climate mitigation efforts will benefit from rangeland composting. One rancher we spoke to expressed that forage yield improvements during the growing season would reduce the need to purchase supplemental hay in fall and early winter, resulting in significant cost-savings for ranchers.

Practices which enhance rangeland forage yield must also be accompanied by managed grazing. Managed grazing — often referred to as "rotational" grazing — is a carbon farming practice itself in which the rancher actively manages the vegetation by managing the location, duration, and intensity of grazing in any given area of the rangeland. It will be important to incentivize and build capacity for these strategies in order to optimize among the benefits such as increased forage and higher soil moisture, and potential risks such as fire fuel accumulation that may result from additional standing dry vegetation. Research on the effects of rangeland compost application is ongoing and management strategies must be tailored to local conditions.

The importance of increased soil water holding capacity cannot be overstated. As we enter an era of rising temperatures, more heat waves, and unpredictable precipitation, it is crucial to take actions that increase and preserve soil moisture and reduce plant evaporative stress. Enhancing soil water holding capacity in areas of groundwater is the first step in natural aquifer recharge, a resilience necessity as our region's growing demand for freshwater increases our reliance on groundwater.

9 Results reported are 1 Mg C/hectare/year = 1.4 MTCO₂e /acre/year

10 N. Scolari presentation to California Resource Recovery Association

11 Unpublished data, J. Borum, East Stanislaus RCD.

The benefits to avocado growers of compost are also substantial. They include decreased fertilizer needs, and progressively greater yield improvements and water holding capacity as soil carbon increases. At application rates of an inch or more in which compost effectively acts as both fertilizer and mulch, water holding capacity improvements and reduced evaporation from the soil surface results in at least a 10% decrease in water demand¹². One farmer who uses this quantity of compost reported that his annual water use is around 2.25 acre-feet/acre¹³, compared to the more typical water use of 4 acre-feet/acre (Bender, 2014). This dramatic water savings of almost 40% may be due to a combination of practices, and not solely attributable to compost, but at current pricing, even the more modest 10% decrease in water use would reduce costs to avocado farmers by \$800/acre/year.¹⁴

There are additional benefits and considerations related to compost. In a later section we evaluate the GHG reduction potential of compost application at a large scale on range-lands and croplands. The County is currently at the beginning stages of implementing an organic waste reduction plan that has the potential to result in new economic benefits through compost-related income streams, both on-farm and off-farm. While the benefits of compost application are numerous, there is currently attention on biogenic volatile organic compounds (VOC), which contribute to ozone formation, and are released during the production of compost. This concern may result in regulation of compost production facilities to manage and minimize VOC's.

Another climate-smart practice that yields multiple resilience benefits is riparian zone restoration. Restoring native perennial vegetation along streams and rivers is a recommended best management practice for storm water reduction, manure management, habitat connectivity, agricultural water quality management, and groundwater management. These are current challenges which are projected to become even more challenging in the future. In a later section we highlight ways agencies engaged in these issues can jointly facilitate and incentivize riparian restoration to meet multiple goals.

Table 1 lists selected carbon farming practices, their estimated annual sequestration potential in the region, and their resilience co-benefits for the county.

12 S. Murray, pers. comm.

13 An acre-foot is the volume of one foot depth of water covering an area of one acre, equaling 325,851 gallons.

14 Based on the upper range of current water pricing of \$2000/acre-foot in some water districts of the county. (Valley Center Municipal Water District, 2017, Escondido Utilities Department, 2017.)

TABLE 1:**Carbon farming practices: GHG reduction benefits and co-benefits**

Carbon Farming Practice	GHG Reduction (MTCO ₂ e/acre/yr)*	Co-benefits
Compost (C:N >11) on grazed grassland (rangeland)	4	Improved forage yields and nutritional content; increased soil water holding capacity, infiltration, & percolation; improved drought tolerance; reduced agricultural runoff; reduced landfill
Compost (C:N >11) on perennial cropland (orchards)	5	Yield improvements; increased soil water holding capacity, infiltration & percolation; reduced storm water & agricultural runoff; reduced landfill
Riparian Restoration	2	Decrease storm water and agricultural runoff, nutrient pollution, stream erosion; improve stream water quality; increase groundwater recharge; increase nutrient cycling; attract pollinators & natural pest control; provide native species habitat connectivity.
Mulch (orchard, row crops)	.2	Reduced irrigation demand; orchard fungal disease reduction ¹⁵ ; increased drought resistance; increase infiltration & percolation; reduced erosion; reduce storm water runoff
Cover cropping with legumes (row crops)	.5	Improve surface water quality through reduced soil erosion; loosen compacted soil; increase soil porosity and infiltration; increase soil nutrients; reduce pests; biodiversity habitat; livestock feed
No-till or strip-till (row crops)	.2	Improve surface water quality through reduced soil erosion; reduce evaporation, water demand;
Silvopasture (rangelands)	.7	Improve nutrient cycling; increase infiltration; moderate microclimate for livestock; additional fodder; biodiversity habitat

Sequestration estimates use standardized online tools developed and/or approved by California Department of Food and Agriculture's Healthy Soils Program: www.compost-planner.com for compost application (accessed July 2017) and www.comet-planner.com & www.comet-planner-cdfahsp.com for all other practices (accessed April – Aug 2017). Except for grazed grassland and silvopasture, all estimates refer to irrigated land.

¹⁵ Bender, G. 2012.

THE POTENTIAL CARBON SINK OF SAN DIEGO COUNTY'S AGRICULTURAL LANDS

Emissions impacts of orchard tree loss

The practices that have the highest GHG reduction potential are those that use perennial woody vegetation (NRCS, 2017; Tonsmeier, 2016.) Indeed, the County CAP recognizes the value of tree planting to achieve GHG reductions and lists tree planting as one of the key strategies in achieving GHG reductions for agriculture (San Diego, 2018), setting a target of approximately 84,000 new trees to be planted by 2030. San Diego's native ecosystems are not dominated by trees, but our agriculture is, with tree crops comprising almost 70% of the region's irrigated cropland area¹⁶ (Agricultural Weights and Measures, 2015) amounting to millions of trees currently in orchards, silently sequestering carbon as they produce food.

Planting new trees will bring many climate benefits, but it is of even greater importance to climate mitigation and resilience to maintain the trees that already exist. Larger, older trees have more stored carbon than younger trees, and according to recent findings, as trees age, the rate at which they sequester carbon actually continues to increase (Stephenson, et al., 2014.) This means that older trees are more valuable to climate mitigation than younger trees. When a tree is removed or left to die in place, this contributes to higher GHG emissions in two ways: first, the carbon stored as wood is lost as CO₂ once the wood is destroyed or decomposed; and second, the sequestration that the tree would have performed in subsequent years does not occur.

From 2000–2015, approximately 10,000 acres of orchards, estimated to contain one million trees, were taken out of production by farmers in the greater San Diego County (Figure 2), decisions largely attributed to rising, prohibitive water costs, along with some fire losses (Rivard, 2016; E. Larson, pers. comm.). We estimate the GHG emissions value of these losses to amount to a total 375,125 MTCO_{2e}, which is the sum of lost carbon stored in the trees, and the foregone cumulative sequestration over a 15-year period (Table 2, and Appendix B).¹⁷ In a single year snapshot of 2014, tree losses amounted to 89,321 MTCO_{2e}, which is over half of the entire estimated agricultural emissions for the unincorporated county that year (Appendix B.)

16 Here, orchards are assumed to be the "Fruit & Nuts" category, and irrigated cropland is assumed to be the total of all acreage except "Field Crops," as listed in the 2015 Crop Report.

17 This is likely an underestimate, due to the assumptions about size of the trees which only account for above ground biomass, and assumption that the sequestration rate is constant over time. Additionally, we did not account for nitrous oxide or methane releases that would result from any burning of tree biomass.

TABLE 2.
GHG effects of orchard tree removal, 2000–2015

Lost Orchards	9969 acres
Lost Trees	996,900 trees
Released Stored Carbon (MTCO _{2e})	243,468
Lost Sequestration Potential (MTCO _{2e})	131,657
TOTAL EMISSIONS (CO₂e)	375,125

These numbers are noteworthy for several reasons. First, the contributions of sequestration in orchards, and the loss thereof, are significant. Secondly, the economic pressure of changing climate conditions are apparently already resulting in accelerated GHG emissions. And most importantly, investments in halting the attrition of existing perennial croplands will have significant impacts on climate mitigation for decades to come. This is addressed in further sections, but the clear signal in discussions with the agricultural community is that reducing costs of irrigation will be the most important way to prevent the loss of orchard tree cover, and the sequestration potential it carries.

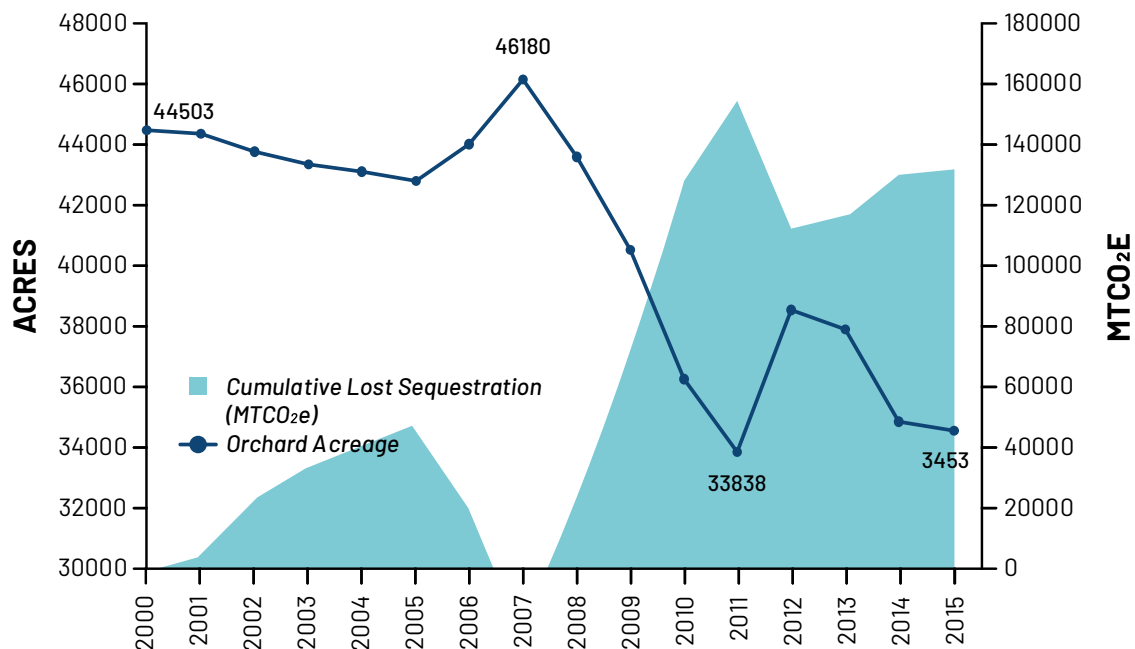


Figure 2. 15-year historical trends of cumulative lost carbon sequestration associated with the changes in orchard cover. (Data source: County of San Diego Crop Statistics and Annual Report, 2000–2015.)

How much net GHG reduction can be achieved through carbon farming?

Carbon sequestration by soils and vegetation is a complex process that varies with numerous bio-physical factors. Thus, estimates of the GHG removal potential of carbon farming is best done when tailored to the region of interest. Here, we estimate the potential of the unincorporated county's agricultural lands to act as a carbon sink, focusing on selected carbon farming practices.

Compost application to rangelands and croplands

Compost application, with a multitude of promising benefits, is not feasible on highly sloping land, which comprises much of the unincorporated county's rangelands and orchards, particularly avocados. In order to estimate the GHG benefits of compost, we first calculated the area of rangeland and orchard land that falls within two recommended slope limits¹⁸ (Appendix C). We assumed all row crop area to be level and amenable to compost application. Table 3 lists the range of GHG reductions that could be achieved with compost application to eligible acreage.

TABLE 3.
GHG removals from compost application

Land Use	Acres Eligible for Compost Application*	GHG Reductions (MTCO _{2e} /year)#
Rangeland	3,665 – 46,883	16,220–207,100
Orchards	14,500 – 27,140	64,750 – 121,170
Row Crops ¹⁹	3,837	16,300
TOTAL	22,002 – 77,860	97,283 – 344,583

* Acreage of < 15% and < 25% slope

Estimated using CDFA tool compost-planner.com for compost C:N >11. Accessed Sept, 2017.

These figures, estimated using California Department of Food and Agriculture's (CDFA) online modeling tool developed for use by the Healthy Soils Program, indicate GHG reductions that, at the high end of the range, could neutralize the entire annual agricultural

18 CDFA guidelines restrict compost to land whose slope < 15%, while Carbon Cycle Institute recommends < 30% (P. Alvarez, pers. comm.) We used available SANGIS data of <15%, and <25% slope, yielding more conservative estimates.

19 Row crop acreage as reported in 2015 Crop Report is for the entire region, as opposed to rangeland and orchard, which is for the unincorporated area only.

emissions of the unincorporated county, estimated at 163,696 MTCO_{2e} /year (San Diego, 2018). There are some caveats requiring further investigation of how best to utilize this opportunity. CDFA recommends annual compost application rate of approximately 7 tons/acre – about 25% of the amount used by the Marin Carbon Project researchers, whose estimates are modeled to continue over several decades following a single heavy application of 1/2", or about 30 tons/acre, and whose water holding capacity improvements are quite high. Annual application will require more resources, and result in higher emissions from transportation. However, the CDFA rate is deliberately conservative in order to minimize possible impacts that heavy compost nitrogen additions may have on native plants and on groundwater nitrate levels. These differences in application rate point to the need to take a tailored approach that addresses the concerns of different areas, and to monitor local conditions in pilot projects.

Compost availability

Compost must be readily available from local sources in order to maximize its carbon sequestration potential and minimize GHG emissions associated with delivery. Current local regulations limit composting of organic matter in small-scale facilities, resulting in valuable compost feedstock instead being sent to landfills and producing methane, a particularly potent GHG. The Department of Public Works' (DPW) Strategic Plan to Reduce Waste (2017) includes a proposed rule change that would encourage small to mid-scale composting practices on farms in adherence with all state requirements governing quality and safety. Once enacted, anticipated benefits and co-benefits are 1) reduction of GHG's that result from hauling and landfilling organic waste, 2) downstream carbon sequestration and soil building through compost application, and 3) creation of new on and off-farm compost-related income streams.

Using DPW's estimates for current green waste, Table 4 shows the GHG impact if all of the region's current organic waste, excluding food waste, were composted and applied to agricultural lands. At compost application rates recommended by CDFA of 7 tons per acre (Gravuer, 2016), current compost production can be applied to 51,264 acres, yielding over 227,000 MTCO_{2e} in sequestration benefits alone. When avoided landfill methane emissions are included, the benefits total over 700,000 MTCO_{2e}. Methane reductions are accounted for already in the County CAP, but we list the figures here to demonstrate the magnitude of impact that lies in the full compost value chain. These figures indicate that compost production and application to agricultural lands has the potential to offset over 20% of the unincorporated county's total annual emissions of 3.2 million MTCO_{2e}.

TABLE 4:**Estimated compost production and GHG benefits of San Diego region's current green waste capacity**

Compost Production & Use	
Diverted organic waste, excluding food waste ²⁰ #	1,435,400 tons
Compost Yield [#]	358,850 tons
Acreage fertilized (7 tons/acre)*	51,264 acres
GHG BENEFITS**	
C-sequestration from compost application to: 20287 acres rangeland, 27,140 acres orchard, 3837 acres row crops ²¹ (MTCO ₂ e/year**)	227,152
Avoided landfill methane (MTCO ₂ e/year)^	473,682
TOTAL MTCO₂e/year	700,834

* CDFA recommended rate of application

Estimates from County of San Diego DPW Solid Waste Planning & Recycling Section

** Estimated using CDFA tool compost-planner.com. Estimate accounts for reduced methane in soils, and emissions of nitrous oxide in soils

^ Estimated using Carbon Balance Calculator, based on CARB Compost Emission Reduction Analyses, acquired from C. R. Ostrander

Riparian restoration with trees and shrubs

Riparian restoration is another practice that has relatively high carbon sequestration value, and high co-benefits value (Lewis, et al, 2015). Each acre of restored riparian zone has the potential to sequester almost 2 MTCO₂e /year (COMET-Planner, 2017), and bring with it numerous co-benefits. If one quarter of the unincorporated county's riparian miles were restored, it would result in sequestration of over 7000 MTCO₂e /year.

20 We restricted this analysis to green waste, wood, manure, and excluded food waste because of concerns expressed regarding minimize plastic and glass contamination that inevitably ends up in composted food waste, and which ranchers would be hesitant to apply to lands grazed by animals.

21 We calculated GHG reductions by assuming that the 51,264 acres would encompass the entirety of row crop agriculture, entirety of orchards within the slope limit of 25%, and around half the eligible rangeland area.

22 Horse population is a conservative estimate based on consultations with local equine professionals. Assumptions are 50 lbs manure/horse/day, and 50% weight reduction from feedstock to compost.

BOX 1: COMPOSTING OF EQUINE MANURE

San Diego County is reputed to have among the highest number of horses per capita in the U.S. Here we estimate the GHG reductions associated with horse manure-based compost only, in order to highlight the potential of this single valuable feedstock. Manure is currently largely unutilized for compost, but is a source of nutrient pollution in surface waters in some cases, and a source of landfill methane in others. Using this conservative estimate of manure-based compost applied at modest rates to rangelands, it is clear that if a fraction of this potential compost feedstock is utilized, it would have significant climate benefits, and could reduce nutrient pollution in our county's waterways.

Estimated GHG reductions from composted manure

COMPOST PRODUCTION & USE ²²	
Estimated number of horses in San Diego County	50,000
Manure feedstock	456,250 tons
Composted manure	228,125 tons
Rangeland application (7 tons/acre [^])	32,589 acres
GHG BENEFITS	
C-sequestration*	144, 010 MTCO ₂ e
Avoided landfill methane (MTCO ₂ e)**	150,563 MTCO ₂ e
TOTAL GHG Reductions	294, 573 MTCO₂e

[^] CDFA recommended rate of application

* Estimated using CDFA tool compost-planner.com. Estimate accounts for reduced methane in soils, and emissions of nitrous oxide in soils

** Estimated using Carbon Balance Calculator, based on CARB Compost Emission Reduction Analyses, acquired from C. R. Ostrander

Table 5 summarizes the selected carbon farming practices and their annual GHG removal potential, focused on compost use and riparian restoration. We focus on these practices for three reasons. First, they have relatively high GHG reduction potentials and therefore demonstrate the magnitude of the potential carbon sink in the unincorporated county's agricultural soils. Secondly, the County CAP agricultural baseline accounts for GHG's

from fertilizer use, but it does not include a strategy for its reduction. Compost provides an alternative to synthetic fertilizer that both reduces nitrous oxide emissions of fertilizer and also sequesters carbon. It may represent a useful CAP strategy for reducing agricultural emissions. Thirdly, early implementation of these particular practices will have cumulative and increasing benefits over several decades. Therefore, in initial years of CAP implementation, as more complex CAP strategies in other sectors are put into effect, early direct investments in key carbon farming practices will help to offset the emissions as these sectors' strategies ramp up. Moreover, initial implementation will help to demonstrate and test the practices. We recommend that the County set a target to neutralize baseline agricultural emissions by implementing and monitoring demonstration sites on County lands.

TABLE 5.
Summary of selected carbon farming practices and their GHG reduction potential

Land Use	Carbon Farming Practice	Acreage	GHG Reduction Potential (MTCO ₂ e/year)
Rangeland	Compost application	20,287*	89,700
Fruit & Nut (Orchards)	Compost application	27,140*	121,170
Vegetables (Row Crops)	Compost application	3,837	16,300
Riparian	Restoration with woody plants	7,264** ²⁴	7,230
TOTAL			234,400

* Unincorporated county acreage under 25% slope limit for composting

Estimated using CDFA online tool: compost-planner.com, accessed Sept 2017

**Estimated using USDA online tool: comet-planner.com, accessed Oct 2017

²³ We have not listed avoided landfill emissions here because that is already accounted for in the CAP waste reduction measures.

²⁴ San Diego County has close to 7000 stream/river miles of riparian area, which with a buffer of 35 feet recommended by NRCS to capture water quality benefits (cite), translates into 29,056 acres. Data on stream miles acquired from SDC GIS, sourced from National Hydrology Dataset. In absence of data on what portion of the total is actually available for restoration, we have taken 25% of total as a feasible amount of riparian restoration

The focus on only two practice types is not meant to suggest that they are suitable in all cases, nor that other carbon farming practices are not viable, useful, or desirable. In fact, the decision of which practices to use on any farm or ranch will be suited to individual preferences and abilities, and to biophysical features of the land. There are several factors that influence decisions about farming methods, including cost and ease of implementation, economic incentives, technical support, regulatory constraints, and current market demands. Below, we discuss possible ways that the County can recognize these considerations and incentivize farmers and ranchers' to provide essential ecosystem services of soil building, GHG mitigation, and resilience building through climate smart agriculture.

WHICH STATE AND LOCAL POLICIES, PROGRAMS, & REGULATIONS HAVE POTENTIAL SYNERGIES WITH CARBON FARMING?

In addition to the state legislation that underpins GHG reductions targets, several state and local policies, programs, and regulations present a strong framework for optimizing the co-benefits of carbon farming. Programs whose goals can be met by the same climate-friendly practices represent opportunities to combine and optimize existing funds in ways that also result in GHG mitigation. However, attention must be paid to addressing any regulatory hurdles that prevent or deter farmers from adopting those practices, and to perverse incentives that may reward practices which run contrary to climate goals.

Resilience planning in General Plan Update

SB 379 requires local governments to include resilience and adaptation plans in the safety elements of General Plan Updates made after January 1, 2017. These plans must be based on identified climate change vulnerability of the region.

Short-lived climate pollutants

SB 1383 requires 50% reduction of organic waste disposal in landfills by 2020, and a 75% reduction by 2025. This will result in avoided landfill methane emissions from compostable materials, which can be used instead to catalyze carbon sequestration and GHG reductions.

Sustainable Groundwater Management Act

Three related bills mandate local and regional sustainable groundwater management by the year 2042, and require development and implementation of local Groundwater Sustainability Plans. San Diego County's four groundwater basins are all designated as medium priority. Groundwater recharge is facilitated by increases in soil carbon (Byrd, 2015). Because of the increase in water holding capacity of carbon-rich soils, deep infiltration of water increases, thereby increasing the potential for recharge to occur. Additionally, the carbon farming practices of riparian zone restoration and other perennial vegetation planting are also beneficial for facilitating infiltration of water into the soil. Areas of San Diego County in which groundwater is a concern may be of particular interest for scaling up practices that increase soil carbon.

Healthy Soils Program

The California Department of Food and Agriculture program to build soil carbon and reduce GHG's includes a grant program for carbon farming implementation.

County of San Diego General Plan

The County General Plan lists among its Guiding Principles the importance of maintaining environmentally sustainable communities, slowing the causes of climate change, and preserving agriculture.

County of San Diego Strategic Plan to Reduce Waste

In keeping with the state targets, the plan sets a target of 75% organic waste diversion by 2025. GHG mitigation benefits from this plan are included in the County CAP.

County of San Diego Board of Supervisors policy I-133: Support and Encouragement of Farming in San Diego County

The County has made a commitment to “identify, secure, and implement incentives that support the continuation of farming as a major industry in San Diego.”

Water quality regulations (County Watershed Protection, Regional Water Quality Control Board)

Agricultural runoff including fertilizer nutrients, chemical pesticides, and eroded soil can have negative downstream impacts on water quality. For this reason, all commercial farmers on irrigated land are required to manage, monitor, and rectify agricultural water runoff (San Diego Regional Water Quality Control Board, 2016). such that all irrigation water, and the chemical and nutrient pollution that it may contain, is prevented from entering waterways and the storm drainage system. For greenhouses and nurseries, additional municipal storm water restrictions, known as MS4, also apply (University of California Cooperative Extension (a), n.d.). In either case, if high pollutant levels cause a water body to be deemed “impaired” according to federal standards, as is currently the case with nutrient pollution in Rainbow Creek watershed of the Santa Margarita River (Project Clean Water, n.d.), stricter measures and oversight are put in place to reduce pollutants of concern to a specific numerical level, called a Total Maximum Daily Load (TMDL).

Compliance requires that farmers choose from an extensive set of best management practices (BMP) to prevent pollutant-laden excess water from entering waterways. The lists of BMP’s for irrigated lands, MS4, and TMDL water quality regulations include planting of vegetation, such as riparian buffers, filter strips, and cover crops (University of California Cooperative Extension (b), n.d.), strategically placed to intercept runoff before it flows into surface waters. Riparian restoration and other forms of perennial vegetation are also carbon farming practices. Monitoring and managing water quality is costly to implement – for agencies as well as farmers, but the overlap of water quality BMP’s with carbon farming practices represents an opportunity to combine resources to emphasize use of those water quality measures that also reduce GHG’s. While these measures are

not applicable to every property, incentives in cases where they are appropriate will help to achieve multiple objectives and streamline costs. One farmer expressed trepidation about utilizing riparian restoration to meet water quality requirements due to additional regulatory burdens that may come from creating protected species habitat. This is discussed further below and in the section dealing with incentives, but the comment highlights the interrelated nature of regulatory issues that affect farmers, suggesting that efforts to mitigate climate change and build resilience will be most effective with an integrated approach.

The Multiple Species Conservation Plan

San Diego's Multiple Species Conservation Plan (MSCP) is an important tool in conserving natural ecosystems and ecosystems services of the region. Using a fund paid into by developers to meet their habitat mitigation requirements, the MSCP protects pre-designated areas of habitat for dozens of protected native species. Connectivity, scale, and habitat diversity are key to the success of the MSCP, so the pre-designated area essentially delineates a map for intended habitat protection, and this map includes some existing farmland. Existing active farms inside the MSCP are exempt from restrictions resulting from habitat creation, and may be a good initial group to focus incentives efforts on so that ecological soil management practices are encouraged inside the MSCP. Among farmers outside the MSCP there is apprehension that creating connectivity and riparian habitat that attracts protected species will result in future farming restrictions. Therefore, while they may yield multiple climate benefits, riparian buffers currently represent a risk for farmers. In the section on incentives, we discuss how riparian restoration may be incentivized by multiple agencies.

Purchase of Agricultural Conservation Easements

The Purchase of Agricultural Conservation Easement (PACE) program is a County incentive program focused on keeping land in the path of development in agriculture. Landowners enrolled in PACE agree to maintain agriculture on the property in perpetuity; thus, the easement restricts their development rights, and those of any future buyers. The County pays farmers the price difference between the appraised value of their restricted agricultural land and the unencumbered fair market value of the land, currently about a 25% difference (E. Schoppe, pers. comm.) The County CAP (San Diego, 2018) recognizes the value that keeping land in agriculture can have for climate mitigation, and proposes expansion of the PACE program as one of its transportation strategies, with carbon farming mentioned as a support measure. Though it is impossible to mandate any specific farming practice on an easement "in perpetuity," in later a section we discuss possibilities for PACE to scale up its climate benefits through incentivizing carbon farming.

FUNDING FOR CARBON FARMING

What funding mechanisms exist?

Climate action plans are challenged with raising the finances to implement their strategies. The multiple benefits of carbon farming present multiple ways to make use of existing funds and find new resources, by leveraging the co-benefits. Funding is needed both for direct implementation of carbon farming by the County, and also for developing and financing incentives and training for farmers, which is discussed in the following section.

Table 6 lists some existing funding sources which address problems that climate-friendly agriculture can help address.

TABLE 6:
State funding for carbon sequestering agricultural practices

Source	Funding type and Purpose
USDA NRCS Environmental Quality Incentive Program (EQIP)	Technical assistance and approximately 50% cost-share to farmers for implementation of soil, water, air and other natural resource conservation practices.
CDFA Healthy Soils Program	Funding to farmers for implementing carbon farming practices. Currently requires 1/3 match.
Sustainable Agriculture Lands Conservation Program	Funds permanent easements on crop and range lands, and/or policy and land use planning to reduce GHG's by conserving agriculture.
State Water Efficiency and Enhancement Program (SWEEP)	Funds water efficiency equipment, including sensors, etc. Water efficient practices are not funded, per se, but can earn applicants extra points.
Non-Point Source Grant Program, Water Resources Control Board	Funds for implementing non-point source pollution prevention measures in areas with TMDL requirements
Proposition 1 Integrated Regional Water Management	Funds projects for water systems to adapt to climate change, build collaborative regional water management systems, and improve local water self-reliance

What financial incentives can be developed to scale up carbon farming?

Incentives that recognize the contributions of those who provide environmental benefits to the wider public, is being recognized as a useful mechanism to scale up change, especially with carbon sequestration. While carbon credit markets for land management have not yet proven to be profitable, other types of incentives are gaining attention. California's Healthy Soils Program (HSP) will provide grant funding for farmers to implement carbon farming, and several other U.S states are in the process of developing incentive mechanisms aimed at scaling up carbon farming (Donlon, 2017.)

The HSP funding demonstrates California's commitment to carbon farming, but it is limited in its ability to scale up the practices because the grants are given on an individual basis, and state budget allocations for the program may vary from year to year. However, HSP has developed a strong framework, standardized carbon accounting models and tools, and standards that can be applied to local efforts without having to reinvent the wheel.

Effective incentives to recognize the value of carbon farming will be most effective if they help to alleviate difficulties that farmers are currently facing, and will differ across different groups and areas. While investigating these nuances is beyond the scope of this report, we did have numerous conversations with individuals in the farming community, and the common theme was that the cost of water is becoming prohibitively high. Therefore, anything that can reduce this cost may gain the attention of farmers.

New farmers face several entry barriers that must be addressed if agriculture is to have a significant presence in the unincorporated county a decade from now. A preliminary survey conducted by San Diego Food System Alliance (2017) suggests that this group is philosophically aligned with the idea of carbon farming and soil regenerative practices. Thus, there is an opportunity to transition agriculture in San Diego County towards climate-friendly practices over the next decade by tailoring carbon farming incentives to address the primary barriers that new farmers face:

1. Access to affordable land
2. Access to capital/credit
3. Business skills
4. Water availability
5. Farming education/training

Below we discuss several potential incentives and financing mechanisms that can be applied in San Diego County to build a carbon farming program. Some of these mechanisms are being used elsewhere in California for funding climate action, others have been developed to compensate providers of other ecosystem services.

Creating water savings

In the decade between 2006–2015, almost one quarter of orchard trees were taken out of production due to the rising cost of water. Removing trees not only releases stored carbon dioxide, it also removes the “machine” of future carbon sequestration, thereby slowing the rate of GHG removal. These emissions are not currently accounted for in the agricultural baseline, but having removed living trees, any other land use – even open space, initially – will result in higher emissions and reduced sequestration. Accounting aside, it must be recognized that there is a direct link between water pricing and GHG emissions that originates in the economic necessities of farmers. Investments in win-win measures such as recycled water specifically distributed to agricultural areas at lower cost than fresh water, could have enormous implications for water pricing and the agricultural bottom-line, which ultimately could act to stem the tide of orchard tree loss and the carbon sequestration that goes with it. Measures that act to stabilize the agricultural economy and reduce attrition rates will ultimately have effects similar to anti-sprawl strategies such as agricultural conservation easements, one of the County CAP transportation strategies for reduction of vehicle miles travelled (VMT).

BOX 2: RECYCLED WATER FOR AGRICULTURE

Substantial water savings in an era of increasing drought and rising water demand can mean the difference between orchard trees staying in the ground or being taken out of production. The City of Escondido was faced with an impending cost to replace the pipe infrastructure that carries treated wastewater to the ocean to be released (Escondido Grapevine, 2016). Recognizing the increasingly high cost of irrigation, they have instead opted to recycle the treated water, first polishing it further to remove excess salts, and to build the infrastructure needed to deliver it to the community’s agricultural operators. The City will save \$300–400 million in costs, and farmers will pay \$700/ acre-foot for recycled water, approximately one-third the cost of freshwater. Moreover, by supplying agriculture with a new and separate source of water, there will be significantly less demand on limited freshwater supplies, and water that was previously being treated as a waste product is now being “upcycled” for food production.

Purchase of Agricultural Conservation Easements (PACE)

The County CAP recognizes that agricultural easements help to avoid emissions associated with sprawl and development. PACE also presents an opportunity to add real GHG

reductions to the “avoided emissions” strategy of passive land preservation. The PACE program does not currently include any affirmative requirements, and requiring management practices such as carbon farming would restrict the flexibility of the farmer, and be impossible to enforce in perpetuity. However, certain carbon farming practices have long-term carbon sequestration implications, and are impossible or undesirable to intentionally reverse, such as rangeland compost application or riparian restoration. Adding an optional carbon farming component for implementing select practices or maintaining existing features such as perennial riparian buffers with an additional payment may provide an incentive to the landowner, and would result in long-term carbon sequestration and soil fertility improvements on lands that will never be converted by development.

Crediting systems

In the United States, California has led the way in developing a cap-and-trade market that recognizes that carbon sequestration in forests and rangelands can be financed by selling offsets (or “carbon credits”) for GHG emissions to entities that exceed their emissions limits. The practice of rangeland compost application is an approved protocol for generating carbon offsets by both the American Carbon Registry (2014) and the California Air Pollution Control Officers Association Greenhouse Gas Reduction Exchange (CAPCOA, 2015). While the possibility of carbon crediting holds promise for incentivizing carbon sequestration in our rangeland soils, so far the process has not proven to be profitable. There are high transaction costs of monitoring and verification, as well as from the risk management strategies needed to insure against carbon losses that may arise, for example, from natural disasters. With transaction costs, it currently costs about \$38 to produce one rangeland carbon offset²⁵, which will sell at a price of \$14–15²⁶ (California Carbon Dashboard, 2017). As these costs are streamlined, and/or as the price of carbon rises, offsets on the state exchanges may prove to be an attractive incentive for ranchers in the future.

The County of San Diego CAP has recognized the need for a flexible adaptive management tool such as direct investments by the County to meet GHG reductions of over 175,000 MTCO_{2e}, and has suggested that it will buy and retire locally generated credits whose protocols have been approved for the state wide registries. Generating credits from carbon farming protocols must have leaner implementation costs if they are to be cost effective, which can be done through local approval by the San Diego Air Pollution Control District (SDAPCD). These local credits could result in substantial cumulative GHG reductions over several decades, and also act as an investment in resilience.

25 C. R. Ostrander, pers comm.

26 August 2017 price of carbon

BOX 3: DIRECT PAYMENTS FOR ECOSYSTEM SERVICES

Besides cap and trade systems, other types of payments for ecosystem services (PES) can have different degrees of structure in which a “provider” (e.g., a farmer or rancher) receives compensation for delivering a “service” needed by the larger public, which comes from healthy ecosystems, such as carbon sequestration, or water filtration.

Ecological systems are complex and results of changes in farming practices are not easily measured, so instead of directly monitoring the ecosystem service of interest, proxy measures are sometimes used. For example, instead of directly measuring gas flux from the soil, measuring changes in soil carbon and vegetation allows us to estimate, based on certain assumptions, the amount of CO₂ that has been removed. However, even this type of monitoring can be time consuming, expensive, and is not always possible on working lands.

Because of this complexity, and because many of the factors that influence ecosystem services, such as rainfall, are out of the control of farmers who provide the service, some PES arrangements are structured by modeling the expected benefits of certain land management actions. This is similar to developing a carbon farm plan that models the expected GHG reductions of carbon farming practices. Those practices, and not the actual GHG reduction, would be the object of monitoring and the basis for payment. Payments are based on whether the farmer’s practices are in compliance with a contract, and not the actual measured levels of ecosystem services. (e.g., Lynch and Shabman, 2011.)

In the case of carbon farming, because many important co-benefits come from implementing certain practices, such as compost application, riparian restoration, or cover cropping, funding for payments could come from direct investment funds by the County, CEQA GHG mitigation funds, or combining existing resources among different agencies that recommend the same “best management practices.”

CEQA mitigation funds

The County has ample experience with successfully developing mitigation funds tied to CEQA requirements. For example, property developers meet their species habitat mitigation obligations by paying into the MSCP fund that is then used toward the protection of large, connected tracts of habitat. Similarly, the PACE program’s mitigation fund allows developers to meet their CEQA requirements for impacts to agricultural resources by purchasing credits in a mitigation bank (Planning and Development Services, 2014). This fund

brings additional funds into the PACE program for purchases of agricultural easements and associated costs.

In any CEQA mitigation measures, there must be a nexus that links the impact (i.e., GHG emissions) to the mitigation, and there must be rough proportionality between the impact and the mitigation measure. Because GHG's are considered a global pollutant, a project in any sector that needs to mitigate its GHG emissions may use any approved compensatory mitigation measure, whether or not the activity is the same. By paying fees that finance implementation of the mitigation measure, the project developer can meet its GHG requirements.

GHG mitigation could be a source of significant resources for carbon farming implementation, and warrants consideration by the County. The CAP proposes to develop a local offsets registry. Instead, approving carbon farming practices as CEQA GHG mitigation measures may be more cost effective than 3rd party verification and credit development. This could be done, for example, by utilizing the carbon farm planning process and the state's approved models for the Healthy Soils Initiative to estimate sequestration benefits, and developing a project tracking process that utilizes existing institutions such as the RCD's. This will amount to a payments system that relies on modeling the benefits, and monitoring and compensating the actions, explained in the box below.

Building the compost value chain

Compost must actually find a market if it is to have the anticipated benefits. Once enacted, the County's proposed ordinance enabling tiered permitting can generate additional on and off-farm income streams if attention is put towards facilitating the value chain of compost.

Greater San Diego County has a high horse population whose manure, if improperly stored, can be a serious contributor to nutrient pollution and eutrophication in surface waters (Watershed Protection Program, 2013). Disposal in landfills costs the horse farmer labor and hauling fees, and generates GHG's in transport and landfilling. Similarly, installing some of the County Watershed Protection Program's BMP's that prevent nutrient runoff also cost horse farmers space, labor, and materials. However, composting is one of the BMP's recommended by the County Watershed Protection program (WPP), with the caveat that it may require additional permitting. Particular attention toward facilitating composting of horse manure can have co-benefits towards watershed protection, while also saving the farmer the costs of other forms of manure management.

Reducing regulatory barriers for habitat creation

Carbon farming practices such as riparian restoration have the potential to create habitat and connectivity on farmland, and add co-benefits such as water quality, groundwater management, and stormwater reduction, but there must be assurances that farmers will

not lose the flexibility to farm if protected species do expand into the area. An example of such an assurance is NRCS' Working Lands for Wildlife program, which offers cost-share and training to farmers to create riparian and wetland habitat for the endangered Southwestern Willow Flycatcher. The program guarantees that enrolled farmers have 'incidental take' coverage for 84 species that benefit from restoration of these habitats, for as long as the practices are maintained. Climate change has increased our need to find ways to maximize habitat connectivity and species' dispersal ability, and the County can foster win-win-win situations for agriculture, climate, and biodiversity by creating clear legal assurances that habitat creation will not end up restricting farming decisions.

New farmer capacity building and apprenticeship programs

A key barrier experienced by new farmers is in training opportunities. Survey results (San Diego Food System Alliance, 2017) suggest that this group of farmers is philosophically aligned with the principles of organic and/or regenerative agriculture. Training, capacity building and apprenticeship programs that allow new farmers to receive mentorship and guidance around healthy soils practices will be an investment in the future carbon sink of San Diego County agricultural soils.

Access to credit for new farmers

New farmers expressed that one of the primary barriers they face is access to capital and/or credit (San Diego Food System Alliance, 2017). One farmer expressed that amounts above \$5000 can be difficult to raise from family and friends. Assistance with implementation of carbon farming practices through low interest loans may help to cover the costs, for example, of the farmer's cost-share component to implement an EQIP carbon sequestering practice, or purchase of equipment.

Carbon funds and revolving loan fund

Some of the above measures to incentivize carbon farming can be implemented with relatively modest funding. Developing a fund linked to climate mitigation, and targeted specifically for implementation of carbon farming will communicate a commitment to partnering with agriculture. Local governments across California are using innovative strategies to develop and capitalize carbon funds to finance aspects of their climate action plans.

For example, the City and County of San Francisco's Carbon Fund, administered by the Department of the Environment, was established in 2009 through an ordinance that adds a mandatory 13% fee on municipal air travel (San Francisco Board of Supervisors, 2009). Voluntary mitigation contributions are also made by others, such as organizers of conferences held in the city. Originally envisioned as funding to develop a local off-sets program, the fund operates now as a grant program that invests more broadly in

local projects that reduce GHG's and create a greener city. (San Francisco Department of the Environment, 2016).

BOX 4: CROP INSURANCE FOR RESILIENCE

Nationwide, farmers of major commodities rely on the Federal Crop Insurance Program (FCIP) to stabilize farm revenues in the event of market fluctuation or weather-related crop losses. A dust-bowl era program, the FCIP operates as a public-private partnership in which the government sets non-competitive pricing for insurance policies, which are then sold by private companies. Farmer premiums, as well as insurance company losses from high indemnity payments, are subsidized by US taxpayers. Farmers purchase a policy that insures them to receive indemnity payment if they lose a selected percentage of their crop yield, based on historical average yields, but they receive only a fraction of the per acre price. As their average yields drop, their premiums increase and so does the cost to taxpayers.

Nationwide, over the last several years, indemnity payments have been increasing due to weather anomalies that have impacted farm yields. Currently, FCIP premium pricing is not structured around market-based risk factors that would reward farmers for engaging in risk reducing practices, such as those that improve soil health, disease resistance, or drought tolerance. In fact, the policies are structured in a way that incentivizes riskier practices in order to be eligible for indemnity payments. Thus, short-term insurance gains lead, over time, to long-term losses. Natural Resources Defense Council and other organizations are advocating that the USDA to create insurance policies that will incentivize true risk reduction practices, thereby reducing the cost to taxpayers for practices that lead to runaway losses (O'Connor, 2013.)

Most farmers and ranchers in SDC do not utilize crop insurance, as there are few options available for small or diverse cropping systems. Many who do maintain insurance do so only to meet the minimum requirements of lenders. Developing a locally useful insurance product may be one way that SDC can incentivize climate smart agriculture. FCIP allows organizations to propose and develop locally relevant insurance packages. This warrants further consideration as a long term strategy in San Diego County.

The City of Santa Cruz developed a carbon fund through solar and energy efficiency rebates from city improvements, and uses the funds towards GHG reducing projects

consistent with its Climate Action Plan. They are now reportedly exploring ways to diversify the income stream by, for example, implementing a fuel surcharge for city vehicular travel, among other possibilities (Brown, 2017).

The City of Sacramento has developed a revolving loan fund used for capitalizing energy and water efficiency improvement projects within city departments (Sacramento City Council, 2011). Originally seeded by a federal block grant, it now continues to grow through savings, and energy rebates. Departments pay back the loan and 3% interest through energy cost savings. A similar low interest revolving fund for new farmers to finance implementation of carbon farming practices will catalyze practices that ultimately result in cost savings and/or yield improvements for them, enabling re-payment.

CONCLUSION, CHALLENGES & RECOMMENDATIONS

As San Diego County begins undertaking climate mitigation, it is the ideal moment to recognize the farmers and ranchers who provide ecosystem services to our county. With the region's agricultural strengths already providing a strong foundation for carbon farming, a forthcoming demographic shift in farming, and the existing knowledge and technology to address major barriers, the County is presented with an opportunity to partner with agriculture as a key ally in building a climate positive and more resilient region.

Our area is extremely amenable to carbon farming practices. Given that orchards play a dominant role in agriculture here, preserving carbon sequestration that already exists is vitally important. We found that almost 25% of orchard trees were taken out of production between 2000–2015, resulting in carbon storage and sequestration losses amounting to over 375,000 MTCO₂e. We did not make forward projections of the impacts of continued losses, but it is clear that any future net loss of existing trees will have implications for climate mitigation.

Focusing on only selected carbon farming practices which have multi-decadal benefits – compost application to cropland, compost application to rangelands, and riparian restoration – we found that there is significant opportunity in county unincorporated agricultural lands to sequester carbon and move toward County CAP targets. By committing to utilizing carbon farming to at least neutralize baseline agricultural emissions by 2020, the County of San Diego will reduce emissions, build resilience, and build the institutional knowledge, support, and financial incentives mechanisms that can catalyze even more action. Use of appropriate County-owned lands to implement practices will provide important demonstration of the practices, and regionally sound monitoring data on benefits and risks required for scaling up. Ultimately reaching this target will require consultation with farmers and ranchers from different geographic, demographic, and production groups to structure meaningful incentives.

Large-scale implementation of climate-smart agricultural practices is not without its challenges. The heterogeneity of natural resource and resilience issues across the county is itself a challenge, and requires heterogeneity of approaches and stakeholders. This heterogeneity also presents opportunities, however, for pooling or raising the funds needed for GHG mitigation by making use of dollars that are put towards activities that provide locally-specific resilience benefits.

Implementation costs, especially for large-scale measures such as recycled water, are likely to be significant. However, given the long-term nature of the problems we are facing, they may prove to be cost-effective investments and may be amenable to climate-related financing, especially when considering their value for both GHG reductions

and resilience. Economic modeling that examines the co-benefits alongside carbon modeling is a necessary next step in examining the feasibility of solutions such as recycled water, which require significant investments in infrastructure.

Regulatory and other concerns about unanticipated impacts of practices should be met with rigorous initial monitoring to understand how practices such as compost application perform in our region, what the trade-offs may be, and how best to manage and minimize risks. Use of County lands for initial implementation and monitoring will provide useful demonstration and monitoring sites while also developing the necessary process templates for scaling up, e.g., ensuring compost quality, availability, efficient transportation, and so forth.

The County CAP direct investments vehicle for achieving targets is an opportunity to fund climate smart agriculture early in the CAP process. However, challenges exist around cost-effectiveness of carbon farming if the County is restricted to projects that use only protocols that have been approved on the state registries. Instead, local development and approval of carbon farming protocols will provide a cost effective option for the County's direct investments as well as provide the basis for local CEQA mitigation.

Understanding opportunities and overcoming the challenges presented by carbon farming requires inclusive processes that involve a broad coalition of stakeholders.

Recommendations on moving forward and addressing challenges fall into four broad strategies, along with a few key actions listed for each based on our analysis of this opportunity.

Convene a task force on carbon farming whose role will be to engage with different stakeholders to develop and advance climate friendly agricultural strategies in the region.

- The task force should include County of San Diego officials; agricultural operators, agricultural extension, advocacy, and trade associations; organizations involved in water, climate, food policy, climate finance, ecosystem services and habitat conservation; and private sector representatives knowledgeable about sustainable sourcing.
- Map the geography of resilience needs and resources, how co-benefits might best be incentivized, and who the relevant stakeholders are. (For example, in areas of the county where groundwater recharge is a concern, practices that show high increases in soil water holding capacity and infiltration would be valuable. Thus, it may be appropriate to engage the Groundwater Sustainability Agency authorities in those areas to identify relevant regulations, policies, and resources needed for implementation.)
- Convene farmer groups with different concerns to develop useful and practical incentives programs.

Conserve the existing agricultural carbon storage and sequestration by addressing root drivers behind the decline in orchard crops.

- Make investments in recycling treated wastewater and distributing it to agricultural areas, to be priced at lower rates than freshwater. GHG benefits and co-benefits include: 1) Avoiding the continuing loss of carbon storage and sequestration potential of orchard trees that is being driven by the rising cost of irrigation 2) Re-use water that is currently treated as a waste product to be disposed of 3) Increased availability of freshwater for non-agricultural purposes.

Synergize among relevant agencies to facilitate and incentivize key carbon farming practices that have resilience co-benefits, such as composting, riparian restoration, and several others such as cover cropping, mulching, and planting of perennial vegetation.

- Work with SDAPCD to develop and approve carbon farming protocols for CAP direct investments. The goal of this is to ensure that investments are cost effective for mitigation while also recognizing the resilience and economic value that carbon farming can bring.
- In place of a local offsets registry, resources should be put towards developing a mechanism for CEQA GHG mitigation to be achieved through carbon farming.
- Support the proposed ordinance of the County's Strategic Plan to Reduce Waste for tiered composting operations by: subsidizing the purchase and distribution of local compost to farmers and ranchers; education about its use and benefits; assistance and capacity building for certification of compost production. GHG benefits and co-benefits of compost production and application include: 1) Reduced GHG emissions from transporting organic waste to distant facilities 2) Reduced landfill methane emissions of organic waste 3) Long-term carbon sequestration in soils and perennial vegetation 4) Reduced GHG from fertilizer use 5) Increased soil water holding capacity, reduced runoff, and increased water infiltration 6) Reduced plant water demand, yield improvements, disease resistance 7) Reliable market for locally produced compost
- Partner across agencies for water quality improvements by developing the manure compost value chain. GHG benefits and co-benefits include: 1) Reduced nutrient pollution in streams from manure runoff 2) Reduced costs to horse farms for manure hauling and/or runoff management measures 3) New economic opportunities along the compost value chain.
- Demonstrate rangeland compost application practices on County-owned land leased for grazing, focusing only in areas that do not harbor sensitive habitats or patches of rare ecosystems. Partner with multiple agencies and local organizations

to monitor effects on soil moisture, soil temperature, forage production, nutrient runoff, nitrate leaching, and fire-related parameters, and to build capacity about grazing and rangeland vegetation management practices specific to our region.

- Encourage riparian restoration and planting of other perennial vegetation on agricultural land by supporting development of an incidental take permit for farmers who employ these practices.
- Build partnerships among multiple agencies concerned with agriculture, water conservation, water quality, and habitats to pool and/or raise new resources for significant riparian restoration in agricultural areas. GHG benefits and co-benefits include: 1) Long-term carbon sequestration in perennial vegetation 2) Water quality improvements 3) Storm water flow reduction 4) Reduced erosion 5) Terrestrial habitat connectivity 6) Freshwater habitat improvements 7) Farmer compliance with water quality BMP's 8) GHG benefits from existing program funds
- Amplify the climate mitigation value of the PACE program by adding an affirmative option that incentivizes carbon farming practices. Specify practices that are not easily reversed and will result in long-term carbon storage and sequestration, such as rangeland compost application or riparian restoration.
- Work with farmers and insurance experts to develop locally-relevant insurance products that incentivize practices that reduce risk through building healthy soils.

Seize the opportunity for climate mitigation that lies with new generation of farmers and ranchers by helping them to succeed in carbon farming and regenerative agriculture.

- Develop a carbon farming revolving low interest loan fund (through fees on VMT's, for example) to fund capacity building and implementation of carbon farming related practices among new farmers.
- Partner with local organizations to develop training and apprenticeship programs that will help a new generation of farmers to succeed in soil-healthy, climate-friendly, agricultural practices.

WORKS CITED

- Agricultural Weights and Measures, Department of. 2015. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
- 2014. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2013. Crop Statistics and Annual Report. County of San Diego. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2012. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2011. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2010. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2009. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2008. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2007. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2006. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2005. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2004. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2003. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2002. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
 - 2001. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html

- 2000. Crop Statistics and Annual Report. County of San Diego. Retrieved from http://www.sandiegocounty.gov/awm/crop_statistics.html
- American Carbon Registry, 2014. Methodology for Compost Additions to Grazed Grasslands. Accessed March 2017. <http://americancarbonregistry.org/carbon-accounting/standards-methodologies/methodology-for-greenhouse-gas-emission-reductions-from-compost-additions-to-grazed-grasslands>.
- Bender, Gary (ed.). 2012. *Avocado Production in California: A Cultural Handbook for Growers, Book 1* (2nd edition). University of California Cooperative Extension, San Diego & The California Avocado Society.
- Brown, Karalee. 2017, July. California cities create carbon funds to support climate action. Western City. Accessed July 2017. <http://www.westerncity.com/Western-City/July-2017/California-Cities-Create-Carbon-Funds-to-Support-Climate-Action/>
- Byrd, K.B., Flint, L.E., Alvarez, P., Casey, C.F., Sleeter, B.M., Souland, C.E., Flint, A.L., Sohl, T.L., (2015), Integrated climate and land use change scenarios for California range-land ecosystem services: wildlife habitat, soil carbon, and water supply. *Landscape Ecology*, 30(4): 729-750. 10.1007/s10980-015-01597 <https://ca.water.usgs.gov/pubs/2015/ByrdEtAl2015.pdf>
- California Carbon Dashboard. Accessed August 2017. <http://calcarbodash.org/>
- California Water Science Center, United States Geological Service. Seawater Intrusion. <https://ca.water.usgs.gov/sustainable-groundwater-management/seawater-intrusion-california.html> Accessed September 2017.
- CAPCOA. 2015, January 6. <http://www.capcoa.org/wp-content/uploads/2015/01/CAPCOA%20Press%20Release%202014%20GHG%20Protocol%201-6-2015.pdf>
- Chambers, A., R. Lal, K. Paustian. 2016. Soil carbon sequestration potential of US croplands and grasslands: Implementing the 4 per thousand initiative. *Journal of Soil and Water Conservation* 71(3):68A-74.
- COMET-Planner. 2017. Accessed March – Sept 2017. <http://www.comet-planner.com/>
- Crowther, T., Todd-Brown, K., et al. Quantifying global soil carbon losses in response to warming. *Nature* 540: 104-108.
- DeHaan, D., & L. Tyner. 2008. San Diego County greenhouse gas inventory: An analysis of regional emissions and strategies to achieve AB 32 targets. Agriculture, forestry, and land use report. Energy Policy Initiatives Center, University of San Diego.
- Department of Public Works. 2017. Strategic Plan to Reduce Waste. County of San Diego.
- DeLonge, M., Rebecca Ryals, and Whendee L. Silver. 2013. A Lifecycle Model to Evaluate

- Carbon Sequestration Potential and Greenhouse Gas Dynamics of Managed Grasslands. *Ecosystems* 16 (6): 962-979
- Donlon, D. (2017, July 12). 6 states tapping into the benefits of carbon farming: Soil solutions. Retrieved from <https://soilsolution.org/2017/07/6-states-tapping-into-the-benefits-of-carbon-farming/>
- Escondido Grapevine, 2016, January 18. Three Escondido projects awarded \$7.5 million in state water grants. Accessed August 20, 2017. <http://escondidograpevine.com/2016/01/18/three-escondido-projects-awarded-7-5-million-in-state-water-grants/>.
- Escondido Utilities Department. 2017. Rates and fees schedule. User rates for potable water. Accessed October 2017. <https://www.escondido.org/Data/Sites/1/media/pdfs/Utilities/UtilitiesRatesAndFeesSchedule6.pdf>
- Farley, K. A., K. Walsh, and A. S. Levine. 2017. Opportunities and obstacles for rangeland conservation in San Diego County, California, USA. *Ecology and Society* 22(1):38. <https://doi.org/10.5751/ES-09077-220138>
- Flint, Loraine. 2016. Increasing Soil Organic Carbon to Mitigate Greenhouse Gases and Increase Climate Resiliency for California. Project description. United States Geological Service. Accessed September 2017. https://ca.water.usgs.gov/projects/reg_hydro/projects/soil-carbon-greenhouse-gases.html.
- Gravuer, 2016. Compost application rates for California croplands and rangelands for a CDFA Healthy Soils Incentives Program. Retrieved from https://www.cdfa.ca.gov/oefi/healthysoils/docs/CompostApplicationRate_WhitePaper.pdf.
- Hawken, Paul, ed. 2017. *Drawdown—The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*. Penguin Books, NY.
- Lal, Rattan. 2016. Global food security and nexus thinking. *Journal of Soil and Water Conservation* 71(4):85A-90A.
- Lewis, D.J., M. Lennox, A. O’Geen, J. Creque, V. Eviner, S. Larson, J. Harper, M. Doran, and K.W. Tate. 2015. Creek carbon: Mitigating greenhouse gas emissions through riparian restoration. University of California Cooperative Extension in Marin County. Novato, California.
- Lynch, S, and L. Shabman. 2011. Designing a payment for environmental services program for the Northern Everglades. *National Wetlands Newsletter* July-Aug 2011: 12-15.
- Marin Carbon Project, n.d. Can Land Management Enhance Soil Carbon Sequestration? Accessed April 2017. <http://www.marincarbonproject.org/science/land-management-carbon-sequestration>.
- Morton, J. 1987. Avocado. p. 91-102. In: *Fruits of warm climates*. Julia F. Morton, Miami, FL.

- In https://www.hort.purdue.edu/newcrop/morton/avocado_ars.html
- Natural Resources Conservation Service, n.d. Conservation Practices. https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/cp/ncps/?cid=nrcs143_026849#A. Accessed September 2017.
- Natural Resources Conservation Service, 2017. GHG and Carbon Sequestration Ranking Tool. Accessed August 2017. <https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/air/?cid=stelprdb1044982>
- O'Connor, Claire. 2013. Soil matters: How the Federal Crop Insurance Program should be reformed to encourage low-risk farming methods with high reward environmental outcomes. Natural Resources Defense Council Issue Paper IP: 13-04-A.
- Planning and Development Services. n.d. About the Multiple Species Conservation Plan. County of San Diego. Accessed August 2017. <http://www.sandiegocounty.gov/content/sdc/pds/mscp/overview.html>.
- Planning and Development Services. 2014. Purchase of Agricultural Conservation Easement (PACE) Program. County of San Diego. Accessed August 2017. <http://www.sandiegocounty.gov/content/dam/sdc/pds/advance/PACE/PACEGuidelines.pdf>
- Project Clean Water. n.d. Santa Margarita Water Management Area. <http://www.project-cleanwater.org/santa-margarita-wma/>. Accessed July 2017.
- Rodale Institute, n.d. Compost Overview. <https://rodaleinstitute.org/our-work/compost/>. Accessed September 2017.
- Regional Water Management Group. San Diego Regional Integrated Water Management Plan. 2013. http://www.sdirwmp.org/pdf/SDIRWM_05_Watersheds_Sep2013.pdf
- Sacramento City Council, 2011. Resolution no. 2011-650 Authorizing actions related to establishing the energy reinvestment program capital improvement project. (C13001900) Accessed Sept 2017. http://sacramento.granicus.com/MetaViewer.php?view_id=22&clip_id=2847&meta_id=377226
- San Diego Regional Water Quality Control Board. 2016. Accessed August 2017. Commercial Agriculture Regulatory Program: General Agricultural Orders. Accessed Sept 2017. http://www.waterboards.ca.gov/sandiego/water_issues/programs/commercial_agriculture/commercial_ag_wdr.shtml
- San Francisco Board of Supervisors. 2009. Ordinance 172-09 establishing carbon mitigation program. Accessed Sept 2017. <https://sfgov.legistar.com/LegislationDetail.aspx?ID=483777&GUID=E255D688-69B7-4332-B9D1-09BB8750E1D6&Options=&Search=>
- San Francisco Department of the Environment. 2016. San Francisco Carbon Fund.

- Accessed August 2017. <https://sfenvironment.org/carbon-fund>
- Rivard, Ry. (2016, May 23). San Diego's Losing Its Grip on the Avocado Market - Voice of San Diego. Accessed Sept 2017. <http://www.voiceofsandiego.org/topics/science-environment/san-diegos-losing-its-grip-on-the-avocado-market/>
- San Diego, County of. 2018. Climate Action Plan Final. SCH#2016101055. Accessed March 2018. http://www.sandiegocounty.gov/content/sdc/pds/ceqa/Climate_Action_Plan_Public_Review.html
- San Diego, County of. 2011. San Diego County general plan: A plan for growth, conservation, and sustainability. Accessed Sept 2017. http://www.sandiegocounty.gov/pds/gpupdate/docs/GP/Cover_Intro_Vision.pdf
- San Diego Food System Alliance. 2017. *Research Brief: San Diego County New and Young Farmers Needs Assessment*. <http://www.sdfsa.org/barriers-to-farming/>
- Schahczenski, J, and H. Hill. 2009. Agriculture, Climate Change and Carbon Sequestration. ATTRA - National Sustainable Agriculture Information Service. <http://www.attra.ncat.org/attra-pub/carbonsequestration.html>
- Schembre, C. 2017. Huichica Creek Sustainable Demonstration Vineyard Carbon Farm Plan. Accessed Sept 2017. <http://calclimateag.org/wp-content/uploads/2017/03/Carbon-Farm-Planning.pdf>. Accessed 6 September, 2017.
- Stephenson, N. L., A. J. Das, R. Condit, et al. 2014. Rate of tree carbon accumulation increases continuously with tree size. *Nature* 507, 90-93.
- Sullivan, T.S., M.E. Stromberger, M.W. Paschke, and J.A. Ippolito. 2006. Long-term impacts of infrequent biosolids applications on chemical and microbial properties of a semi-arid rangeland soil." *Biology and Fertility of Soils*. 42(3):258-66.
- Tonsmeier, Eric. 2016. *The Carbon Farming Solution: A Global Toolkit of Perennial Crops and Regenerative Agriculture practices for Climate Change Mitigation and Food Security*. Chelsea Green Publishing, White River Junction VT.
- United States Department of Agriculture. 2012. Census of Agriculture: San Diego County Profile. Washington D.C.
- University of California Cooperative Extension (a). n.d. Agricultural Water Quality Research and Education. Accessed September 4, 2017. http://ucanr.edu/sites/agwaterquality/Grower_Resources/
- University of California Cooperative Extension (b). Best Management Practices. Accessed September 4, 2017. <http://ucanr.edu/sites/agwaterquality/files/121815.pdf>.
- Valley Center Municipal Water District. 2017. Schedule of rates. Accessed October 2017.

<http://www.vcmwd.org/Portals/0/PDF/Finance/ScheduleOfRates.pdf>

Walton, M., J.E. Herrick, R.P. Gibbens, and M.D. Remmenga. 2001. Persistence of municipal biosolids in a Chihuahuan desert rangeland 18 years after application. *Arid Land Research and Management* 15(3): 223–32.

Watershed Protection Program, 2013. Equine facilities best management practices. County of San Diego. Accessed August 2017. http://www.sandiegocounty.gov/dplu/advance/WPP_Equine_Facilities_BMPs.pdf.

Watershed Protection Program. n.d. Equine Best Management Practices Implementation Manual. County of San Diego. Accessed August 2017. http://www.sandiegocounty.gov/content/dam/sdc/dpw/WATERSHED_PROTECTION_PROGRAM/watershedpdf/sw_equine_bmp_tech.pdf.

Zhai, W., D. J. Moschandreas, G.Tian, D. Venkatesan, K. E. Noll, 2014. Degradation rate model formulation to estimate soil carbon sequestration from repeated biosolids application. *Soil Sci. Soc. Am. J.* 78:238–247.

APPENDICES

Appendix A: Carbon Farming Practices

Practice Standard	Beneficial Attributes
Conservation Cover	Establishing perennial vegetation on land retired from agriculture production increases soil carbon and increases biomass carbon stocks.
Residue and Tillage Management, No Till/Strip Till/Direct Seed	Limiting soil-disturbing activities improves soil carbon retention and minimizes carbon emissions from soils.
Anaerobic Digester	Biogas capture reduces CH ₄ emissions to the atmosphere and provides a viable gas stream that is used for electricity generation or as a natural gas energy stream.
Roofs and Covers	Capture of biogas from waste management facilities reduces CH ₄ emissions to the atmosphere and captures biogas for energy production. CH ₄ management reduces direct greenhouse gas emissions.
Combustion System Improvement	Energy efficiency improvements reduce on-farm fossil fuel consumption and directly reduce CO ₂ emissions.
Multi-Story Cropping	Establishing trees and shrubs that are managed as an overstory to crops increases net carbon storage in woody biomass and soils. Harvested biomass can serve as a renewable fuel and feedstock.
Windbreak/Shelterbelt Establishment	Establishing linear plantings of woody plants increases biomass carbon stocks and enhances soil carbon.
Silvopasture Establishment	Establishment of trees, shrubs, and compatible forages on the same acreage increases biomass carbon stocks and enhances soil carbon.
Forage and Biomass Planting	Deep-rooted perennial biomass sequesters carbon and may have slight soil carbon benefits. Harvested biomass can serve as a renewable fuel and feedstock.

Nutrient Management	Precisely managing the amount, source, timing, placement, and form of nutrient and soil amendments to ensure ample nitrogen availability and avoid excess nitrogen application reduces N ₂ O emissions to the atmosphere.
Feed Management	Diets and feed management strategies can be prescribed to minimize enteric CH ₄ emissions from ruminants.
Tree/Shrub Establishment	Establishing trees and shrubs on a site where trees/shrubs were not previously established increases biomass carbon and increases soil carbon. Mature biomass can serve as a renewable fuel and feedstock.
Forest Stand Improvement	Proper forest stand management (density, size class, understory species, etc.) improves forest health and increases carbon sequestration potential of the forest stand. Managed forests sequester carbon above and below ground. Harvested biomass can serve as a renewable fuel and feedstock.
Contour Buffer Strips	Permanent herbaceous vegetative cover increases biomass carbon sequestration and increases soil carbon stocks.
Riparian Forest Buffer	Planting trees and shrubs for riparian benefits also increases biomass carbon sequestration and increases soil carbon stocks.
Vegetative Barrier	Permanent strips of dense vegetation increase biomass carbon sequestration and soil carbon.
Windbreak/Shelterbelt Renovation	Restoring trees and shrubs to reduce plant competition and optimize planting density increases carbon sequestration.
Alley Cropping	Trees and/or shrubs are planted in combination with crops and forages. Increasing biomass density increases carbon sequestration and enhances soil carbon stocks.

Riparian Herbaceous Cover	Perennial herbaceous riparian cover increases biomass carbon and soil carbon stocks.
Range Planting	Establishing deep-rooted perennial and self-sustaining vegetation such as grasses, forbs, legumes, shrubs and trees improves biomass carbon sequestration and enhances soil carbon.
Herbaceous Wind Barriers	Perennial herbaceous vegetation increases biomass
Residue and Tillage Management, Ridge Till	Ridge planting promotes organic material accumulation that increases soil carbon. Reconstruction of ridges in the same row year after year will maximize organic matter buildup in the row. Shallow soil disturbance maintains soil carbon in the undisturbed horizons.
Solid/Liquid Waste Separation Facility	Removal of solids from the liquid waste stream improves the efficiency of anaerobic digesters. CH ₄ generation is maximized within the digester by separating solids from the liquid feedstock. Proper management of the solid and liquid waste streams increases CH ₄ .
Critical Area Planting	Establishing permanent vegetation on degraded sites enhances soil carbon and increases carbon sequestration by adding vegetative biomass.
Residue Management, Seasonal	Managing residue enhances soil carbon when crop residues are allowed to decompose on a seasonal basis, increasing soil organic matter and reducing soil disturbance.
Residue and Tillage Management, Mulch Till	Soil carbon increases when crop residues are allowed to decompose, increasing soil organic matter and minimizing soil disturbance.
Forest Slash Treatment	Woody plant residues managed (chipped, scattered, etc.) on-site will increase soil carbon and soil organic matter. Forest slash that is removed can serve as a renewable fuel and feedstock.

Field Border	Permanent vegetative field borders sequester carbon and increase soil carbon content.
Filter Strip	Herbaceous vegetation in filter strips has slight carbon sequestration benefits and enhances soil carbon.
Grassed Waterway	Perennial forbs and tall bunch grasses provide slight carbon sequestration benefits.
Hedgerow Planting	Woody plants and perennial bunch grasses increase biomass carbon stocks and enhance soil carbon.
Land Reclamation Abandoned Mined Land	Establishment of permanent trees, shrubs, and grasses on abandoned and unmanaged lands increases biomass carbon stocks and enhances soil carbon.
Land Reclamation Currently Mined Land	Establishment of permanent trees, shrubs, and grasses increases biomass carbon stocks and enhances soil carbon. Pre-mining baselines are important to establish prior to evaluating any carbon benefits.
Cross Wind Trap Strips	Perennial vegetative cover increases biomass carbon stocks and enhances soil carbon. Minimized soil disturbance also enhances soil carbon.
Wetland Restoration	Establishment of vegetation, particularly woodland and forest vegetation, increases biomass carbon stocks. Soil organic carbon is increased by incorporating compost as a physical soil amendment.

Appendix B: Estimating the impact of net loss of orchard acreage on CO₂e reductions

A	B	C	D	E	F	G
Year <i>i</i>	Fruit & Nuts (acres)	Lost acreage	Lost trees	Released stored carbon (MTCO ₂ e)	Lost sequestration (MTCO ₂ e/yr)	Cumulative Sequestration lost from the removal of year <i>i</i> 's trees from year <i>i</i> – 2015 (MTCO ₂ e)
2000	44503	-	-	-	-	-
2001	44363	140	14000	3419	308	4620
2002	43791	572	57200	13970	1258	17618
2003	43374	417	41700	10184	917	11926
2004	43127	247	24700	6032	543	6521
2005	42815	312	31200	7620	686	7550
2006	44028	-1213	-121300	-29624	-2669	-26686
2007	46180	-2152	-215200	-52557	-4734	-42610
2008	43624	2556	255600	62424	5623	44986
2009	40532	3092	309200	75514	6802	47617
2010	36239	4293	429300	104846	9445	56668
2011	33838	2401	240100	58638	5282	26411
2012	38535	-4697	-469700	-114712	-10333	-41334
2013	37910	625	62500	15264	1375	4125
2014	34811	3099	309900	75685	6818	13636
2015	34534	277	27700	6765	609	609
SUM TOTAL		9969	996900	243468		131657

Column A: Year_i

where $i = 0-15$, corresponding to 16-year period

Column B: Total Fruit and Nut acreage

Assumptions & Sources:

- Fruit and Nut acreage assumed to be orchards
- Data from San Diego County Crop Reports (2000–2015)

Column C: $B_{i+1} - B_i$

Column D: $C_i * 100$

Assumptions & Sources:

- All removed trees are Avocado.
- Planting density = 100 trees/acre (Bender, 2012.)

Column E: $D_i * .24 \text{ MTCO}_2\text{e}$

Assumptions & Sources:

- All trees are the same size, whether removed or added. In years in which trees were added, this overestimates their sequestration value (i.e., too large a negative number) thereby underestimating net removals.
- All stored carbon from removed/destroyed trees is released as CO₂.
- Average tree biomass of 133.09 kg estimated using data from Rosecrance, et al. 2001. Carbon content = 50% of biomass = 66.05 kg.
- 1 kg C = .001 metric ton C = .00367 MTCO₂e.
- 66.05 kg C/tree * .00367 MTCO₂e/kg C = .24 MTCO₂e/tree

Column F: $E_i * .022 \text{ MTCO}_2\text{e}$

Assumptions & Sources:

- Tree diameter (dbh) = 20 inches (Morton, J. 1987)
- Sequestration rate = 48 lbs/year = .022 MTCO₂e /year, estimated using National Tree Benefit Calculator for 20 inch dbh Avocado tree planted in open space in SD region. <http://treebenefits.com>. Accessed Aug 2017.

Column G: $F_i * (16-i)$

Appendix C: Estimating acreage of compostable rangelands and orchards

To get acreage of rangeland and orchards on slopes amenable to compost application, we used publicly available SANGIS data files (<http://www.sangis.org/>) and extracted categories within them:

SANGIS Data	Categories Extracted
Municipal_Boundaries.shp	San Diego Unincorporated
Slopes_CN.shp	<15%, <25%
Landuse_Current.shp	Orchard or Vineyard, Field Crop

We created independent layers for the extracted categories, and used “join” and “intersect” functions in ArcGIS to determine area in which slope categories overlapped with each selected land use category within San Diego unincorporated. Area in square feet was converted to acres. (1 acre = 43560 square feet)

Land Use	Slope <15% (acres)	Slope <25% (acres)
Orchard or Vineyard	14,500	27,140
Field Crops	3665	46,883