## COLLABORATIVE SOLUTIONS FOR CALIFORNIA'S CLIMATE-RESILIENT AGRICULTURE:

# HARNESSING THE WATER-RELATED BENEFITS OF SOIL

Sustainable Conservation

Sustainable Conservation is a California-based nonprofit advancing collaborative stewardship to meet the water needs of California's environment, people, and economy for current and future generations – with particular focus on advancing sustainable groundwater management and accelerating the stewardship of natural and working lands and waterways.

**Soil health has the potential to play an outsized role in conserving and protecting California's valuable water resources, which is at the core of our work. The following report represents an analysis of the barriers preventing California's growers from implementing soil health practices and solutions to address them.**

Sustainable Conservation would like to express our thanks and appreciation to the 60+ people who generously shared their time, knowledge and expertise. Without them, this report would not have been possible.

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# INTRODUCTION

California's agricultural regions are experiencing significant burdens associated with climate change. Multi-decadal drought, periods of extreme heat, and intense flooding are already threatening the productivity and profitability of California farmland. Overapplication of agricultural fertilizers and overpumping of groundwater have compromised California's water resources. As a result, our communities are burdened with degrading environmental conditions and a lack of clean and affordable drinking water. Sustainable water management at all scales – from farms to basins – is critical to addressing these impacts to California's people, land, and ecosystems.

**ADDRESSING THESE CHALLENGES MEANS WE MUST CHANGE THE WAY WE USE WATER.**

Soil health is at once the foundation of productive farmland and one tool that can help with California's water challenges. By bolstering soils' natural ability to capture and store precipitation and increasing the efficiency of applied water, we can make better use of our limited water resources. By employing agricultural practices that reduce excessive nutrient inputs, we can prevent further groundwater pollution. And yet, California growers face a complex landscape of barriers preventing the implementation and expanded adoption of soil health practices. Measures to proactively address these barriers are essential to expanding adoption and increasing climate resilience on California's farmland. Moving this work forward requires working collaboratively to build strong multi-sector partnerships, seek innovative solutions, and continuously incorporate new learnings to our approaches.

**THROUGH OUR SOILS, WE CAN BUILD A MORE RESILIENT WATER AND CLIMATE FUTURE.**

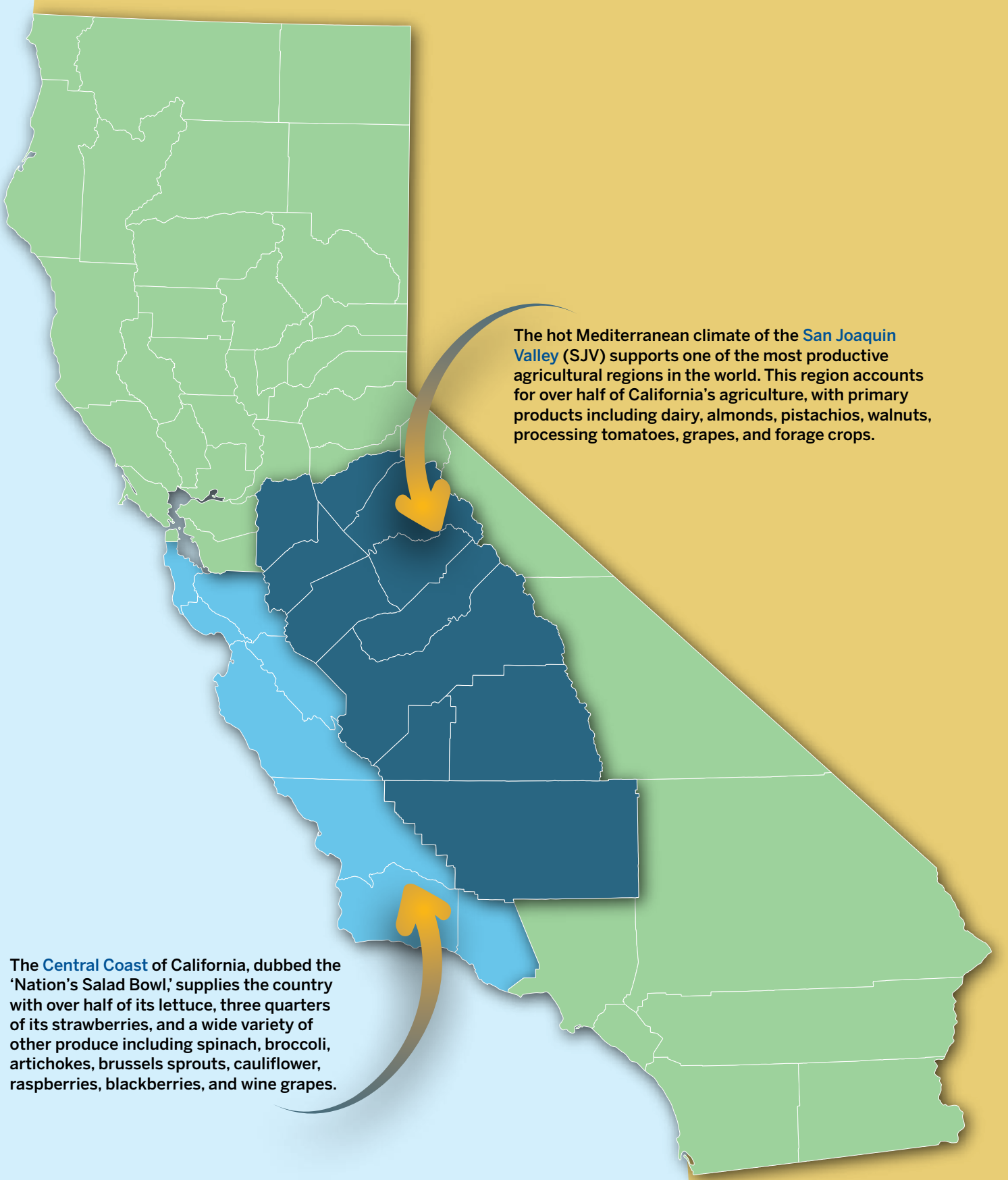
# GOALS OF OUR WORK

Soil health practices that provide water-related benefits have the potential to help address California's regional water challenges, yet practice adoption has been slow to scale relative to other parts of the country (US Department of Agriculture, 2019; LaRose & Meyers, 2019). This short report represents the findings of an effort to understand barriers to adoption for California growers and to deepen our understanding of how and when soil-health-promoting management practices provide benefits to California's agricultural watersheds.

**Our premise is that given the current and projected future of water extremes – prolonged droughts punctuated by intense flooding – articulating the water-related benefits of sustainable agricultural practices will help to expand adoption in water-limited regions and across California.**

Our approach to this inquiry was two-fold. We aimed to better understand the obstacles deterring widespread grower adoption of three of the most common soil health practices – **cover cropping, compost application, and conservation tillage** – that hold promise for improving on-farm sustainable water management. We also sought to understand the water-related outcomes California researchers have documented regarding these soil health practices. Our intent was both to inform Sustainable Conservation's programmatic actions around soil health and to share our learnings with the broader community. To follow, we outline prevalent barriers growers face to adopting these agricultural management practices, and we provide key takeaways for accelerating adoption on California farmland.

# REGIONAL CONTEXT



The hot Mediterranean climate of the San Joaquin Valley (SJV) supports one of the most productive agricultural regions in the world. This region accounts for over half of California's agriculture, with primary products including dairy, almonds, pistachios, walnuts, processing tomatoes, grapes, and forage crops.

The Central Coast of California, dubbed the 'Nation's Salad Bowl,' supplies the country with over half of its lettuce, three quarters of its strawberries, and a wide variety of other produce including spinach, broccoli, artichokes, brussels sprouts, cauliflower, raspberries, blackberries, and wine grapes.

## Central Coast

Dubbed the 'Nation's Salad Bowl', the Central Coast supplies the country with fresh produce (e.g., lettuce, spinach, broccoli, artichokes, brussels sprouts, cauliflower), berries (e.g., strawberries, raspberries, and blackberries), and wine grapes. Central Coast agriculture relies exclusively on groundwater and winter rainfall. Due to its geographic location, water is not imported into the region, except in some small geographically distinct zones, and thus protecting and preserving groundwater resources is critically important. The region's water quality has been severely impacted by a legacy of fertilizer overapplication and the leaching of nutrients and harmful agricultural chemicals to groundwater and runoff to surface water bodies. Although water availability pressures are currently less severe relative to other parts of the state, overpumping groundwater has caused seawater intrusion and salt contamination to groundwater supplies. These impacts to water quality are of significant consequence because over 80% of Central Coast residents rely on groundwater for drinking. As a result, many communities in this region cannot reliably access clean and affordable drinking water.

Because of the highly intensive agricultural practices and a climate that allows for three crop rotations per year, soil carbon has been degraded across the Central Coast's diverse soil types. Agricultural lands that are managed conventionally to keep soils bare in winter months are prone to soil erosion and sediment loss to surface waterways, especially during periods of heavy precipitation. Moreover, growers in this region struggle with a myriad of different soil-borne disease pressures resulting from the continuous cultivation of agricultural lands.

## San Joaquin Valley

One of the most productive agricultural regions in the world, the San Joaquin Valley (SJV) accounts for over half of California's agricultural production. The region's dominant crops include perennial orchard crops (e.g., almonds, pistachios, and walnuts), vineyard crops (e.g., wine and table grapes), and lesser acreage of annual row crops (e.g., dairy silage, processing tomatoes, and cotton). This semi-arid basin, with its limited winter rainfall, relies on surface flows from the adjacent Sierra Nevada Mountains, water conveyed from other parts of the state, and groundwater pumped from dwindling aquifers. Persistent drought conditions have led to regional water shortages, increasing pressure on groundwater pumped for agricultural uses and leaving aquifers in a state of critical overdraft. These drought conditions are punctuated by short, intense rainstorms or snowmelt runoff that flood communities and farmland, but can also provide water managers more flexibility in meeting demands. As water rapidly becomes the greatest constraint to agricultural production, concern for the livelihoods of farmers, farm workers, and communities in this region is growing.

While highly diverse, soils in the SJV are characteristically low in their organic matter, and thus generally have lower water holding capacity. Growers deal with various soil-related water issues including low infiltration rates and poor drainage due to soil surface crusting and cracking, compaction, and poor soil structure. On the west side of the SJV, where water is scarcer, soils are characterized by their high salinity due to a legacy of irrigation and drought.

### IMPACTS TO COMMUNITIES RELIANT ON GROUNDWATER

In both regions, the high agricultural productivity has come at a significant cost to communities. The impacts of groundwater overdraft and legacy of past farming activities are particularly acute for communities relying on groundwater. Tens of thousands of Californians are expected to lose some or all primary water supplies in the coming decades (The Water Foundation, 2020). Moreover, these agricultural regions experience the highest rates of drinking water contamination in the state, and over 1 million people lack access to safe and affordable drinking water statewide (California State Auditor, 2022). The Sustainable Groundwater Management Act (SGMA), which took effect in 2020, regulates groundwater overdraft and has meant that groundwater use will be progressively more restricted. In the SJV alone 500,000 acres of land are estimated to come out of intensive irrigated production in the next two decades due to a lack of water (Ayres et al., 2022).

As clean drinking water increasingly becomes an issue for agricultural communities, additional regulations have been put in place to curb agriculture-related groundwater pollution. Thus, nitrate pollution is a leading regulatory target of the Dairy General Order (Dairy GO), Irrigated Lands Regulatory Program (IRLP), and the Central Valley Salinity Alternative for Long-term Sustainability (CV-SALTS). The recently updated Central Coast Ag Order (v 4.0) limits application of nitrogen (N) fertilizer and the discharge of waste, including nitrate from excess fertilizer, from irrigated lands into surface- and groundwaters.

## ENHANCING SOILS' INHERENT WATER FUNCTIONS

Both regions' chief water challenges relate to the protection of groundwater resources. Effectively leveraging winter precipitation and increasing the efficiency of applied water is critical to reducing agriculture's consumptive use of groundwater. Meanwhile, minimizing nutrient loading and leaching below the rootzone can preserve and improve groundwater quality.

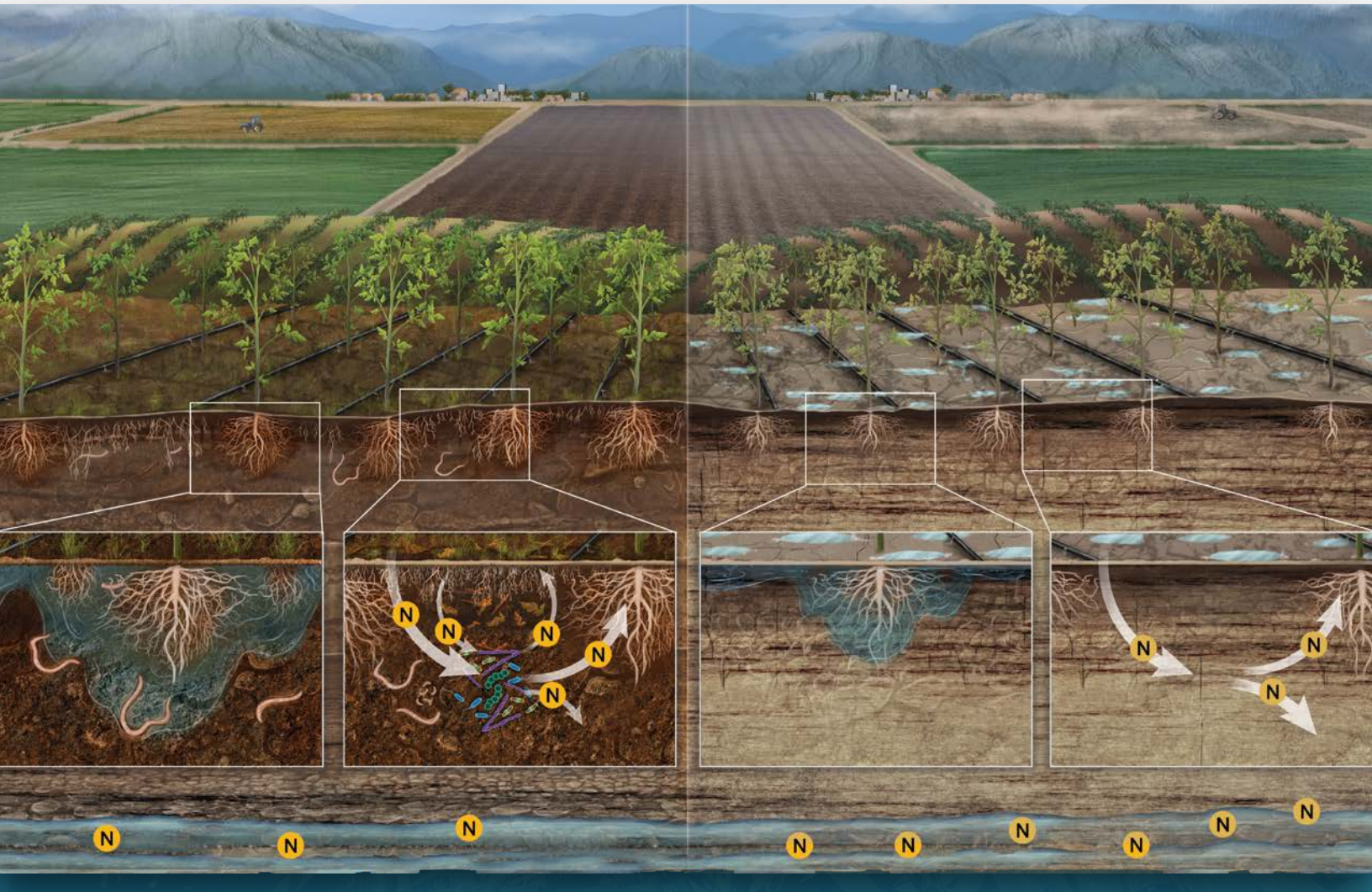
By bolstering the inherent functions of farmland soil, we can help California capture and store more water and improve the quality of water returned to aquifers and waterways. Soil health can help growers continue to produce, reduce inputs, and even increase yields (American Farmland Trust, 2019, 2020), while reducing their impacts to water supplies and quality.

Often viewed as the gold standard of soil health, organic matter, a common soil health indicator, is a component of soil made up of living and decomposed plant and animal materials. In most cases, as organic matter increases so does soil *water holding capacity*, bolstering soils' ability to hold and store water in the rootzone,[1] although this is not always the case.[2] More soil organic matter also means better soil structure, fertility, and more active and diverse soil biology. While soil organic matter may take many years to accumulate, there are also important water-related soil health benefits that may be realized over the short-term.

As depicted in the illustration below, practices that keep more live roots in the ground, reduce compaction, and build soil structure allow water to infiltrate deep in the soil profile. Practices that keep the soil surface covered with vegetation or residue, protect the soil surface and slow the movement of water which reduces soil crusting and soil loss via erosion. And soil health practices that improve nutrient cycling, including those that use live roots or soil microbes to scavenge nutrients, also protect water quality by reducing the amount of nutrients, including nitrogen (N) that leave the root zone.

[1]Footnote: A 1% increase in soil organic matter helps soil hold 20,000 gallons more water per acre. Source USDA-ARS.

[2]Footnote: Increasing organic matter may reduce water holding capacity in very fine textured soils (silty clay or clay soils). Source Flint et al., 2018.



# COMMON WATER-BENEFICIAL SOIL HEALTH PRACTICES

1

**Cover Cropping** is an on-farm management practice where non-harvested or partially harvested crops – which can include resident vegetation, native, or non-native plants – are integrated into a grower's crop rotation or are grown between rows or along field edges. For California's annual and perennial crops, cover cropping is mostly used during the cool season to take advantage of winter precipitation, and to give the soil a break from intensive warm season management. California growers cite pollinator habitat and belowground soil biodiversity as benefits to implementing the practice. **Across the state, cover crops have been known to increase water infiltration and reduce runoff, erosion, and surface evaporation. Cover crops are also an effective strategy for recovering soil nutrients that might otherwise leach into groundwater.**

2

**Compost** is a type of soil amendment comprised of organic material that has been decomposed in a controlled process. Common compost feedstocks in California are food waste, green waste (grass clippings, leaves, branches, etc.), animal manure, and agricultural by-products. Growers apply compost to improve soil structure, increase soil organic matter content, and enhance populations of beneficial microorganisms in the soil. California's conventional growers historically haven't viewed nutrient content – which is low when compared to synthetic fertilizers – as a primary benefit of compost, but this may change with increasing fertilizer prices. **Due to compost's high organic matter content, additions may increase soil carbon and water-holding capacity in California's agricultural soils.**

3

**Conservation Tillage** is a suite of tillage regimes referring to how the farmer tills, preps, or seeds the field to reduce soil disturbance, decrease tractor passes, and protect the soil surface with crop residues. This can be achieved by either reducing the frequency of passes or reducing the area of the field tilled per pass. Growers cite benefits including economic savings from reduced labor and diesel fuel. **Water-related benefits to California soils may include reduced erosion and sediment loss, and increased nutrient retention, infiltration, and soil water storage.**

# SUSTAINABLE CONSERVATION'S APPROACH

**An eye on the data:** We examined results from California-based field studies, peer-reviewed studies, and research reports to understand how these practices impact water-related soil physical and chemical metrics like infiltration, runoff, water-holding capacity, soil organic carbon, aggregation, soil biology, and nutrient leaching and scavenging. These data points are critical for understanding how practices perform on California's diverse agricultural landscapes and provide important context for interpreting adoption barriers and grower perceptions. Though not covered in our inquiry's scope, soil health practices can provide important co-benefits including reducing and offsetting agricultural greenhouse gas (GHG) emissions and improving air quality, which have been well documented (Horwath et al., 2008).

**An ear to the ground:** Our 60+ unstructured interviews with growers and the agricultural support community from the San Joaquin Valley to the Central Coast shed light on obstacles to soil health practice adoption in California. We interviewed both adopters and non-adopters from a wide range of cropping systems, spanning 10+ cropping systems (e.g., tree nuts, dairy silage, berries, leafy greens). From these interviews, we identified and ranked adoption barriers based on how frequently they were reported. Our findings corroborate recently published social science literature on farmer behavior and soil health adoption in California (Esquivel et al., 2021; Carlise et al., 2022; Khalsa et al., 2022, Rudnick et al., 2021; Mitchell et al., 2007).

# CALIFORNIA-RELEVANT RESEARCH

We examined the California-based research for evidence of specific soil health practices impacting the water-related functions of soils (i.e., increased infiltration, reduced runoff, etc.). For these key agricultural regions, published research results show potential opportunities to improve on-farm water management through the adoption of practices like cover cropping, compost application, and conservation tillage.

In the San Joaquin Valley, cover crops have generally been observed to improve water infiltration (Mailapalli et al., 2012; Mitchell et al., 2017) and reduce runoff (Miyao & Robins, 2001) which are important for effectively capturing winter rainfall. Other studies in the SJV have shown that cover crops both deplete soil water (Mitchell et al., 2015) and have minimal impacts (DeVincentis et al., 2022). Thus, there is a critical need for research examining the net impacts of cover crops on water use and the conditions under which cover cropping is most effective. Compost or organic amendment applications have been shown to increase the soil water holding capacity (Lepsch et al., 2019) and soil organic carbon (Villa et al., 2021). Similarly, conservation tillage practices coupled with surface residue have been shown to, over time, improve soil structure and aggregate stability which help reduce evaporative losses (Mitchell et al., 2012). Furthermore, combining multiple practices like conservation tillage and cover cropping could yield additional benefits (White et al., 2020; Mitchell et al., 2017).

On the Central Coast, cover crops have been shown to effectively reduce agricultural impacts to surface water including runoff and sediment loss (Daugovish et al., 2020) and for non-legume cover crops, reduce nitrate leaching (White et al., 2022; Daugovish et al., 2020; Heinrich et al., 2014). Cover crops have also been shown to increase soil organic matter (Smith et al., 2008). High carbon amendments have also been shown to increase nutrient cycling efficiency, immobilize nitrate, and prevent leaching to groundwater (Muramoto & Smith, in preparation).

Although tremendous efforts have already gone into adapting these practices in California, more research is needed to understand their net impacts on water use in California agriculture. Efforts should focus on adapting and developing best management practices for implementing soil health approaches in California's diverse agricultural contexts; taking into account its distinct climates, soil types, landforms, and varied cropping systems. Ultimately, the degree to which these practices contribute to water capture, storage capacity, and help improve water quality is dependent on the agricultural and environmental context of the farm (Devine et al., 2021, 2022).

# INTERVIEW FINDINGS

We explored the benefits and barriers to adopting the three most common soil health practices – cover crops, compost, and reduced tillage – from the perspectives of growers and the agricultural support network. To gather these insights, we hosted informal interviews with more than 55 growers, technical assistance providers, researchers, food companies, and government agency personnel. An analysis of these conversations indicated that growers share perspectives on the benefits of each of the practices but face different barriers to implementation that are specific to the practices, crops, and regions. Throughout the process, six consistent barriers were identified:

1. Lack of information and research
2. Opportunity costs
3. Buyer contract requirements
4. Inconsistent materials
5. Equipment Costs
6. Suitability for specialty crops

Some of these barriers were viewed to be more prevalent for specific soil health practices than for others.

**To follow is a discussion of the two most commonly cited barriers to adoption for each of the three practices, based on our interviews.**

# COVER CROPPING

## WATER BENEFITS:

- Increased infiltration
- Reduced runoff and erosion
- Increased surface shading
- Diverse and active soil biology
- Nutrient scavenging

### Barriers to Adoption

For the SJV and other water-limited regions of the state, uncertain water supply – winter rainfall, surface water deliveries, and groundwater use restrictions – is one of the greatest pressures faced by growers. As the Sustainable Groundwater Management Act (SGMA) goes into effect and Groundwater Sustainability Agencies (GSAs) establish limits on groundwater pumping, some growers will face challenging decisions around how to use their limited water allocations. Thus, the lack of knowledge and information around cover crop water use was cited as the leading barrier to adoption, particularly in regions like the SJV that are facing significantly reduced water availability. Cover crops, like all plants, require water to grow, and while there are well-documented water-related benefits to cover cropping (e.g., increased infiltration, reduced on-field runoff), the net impact of cover crops on water budgets is unclear. What is missing are local examples illustrating whether the water benefits (increased infiltration, etc.) outweigh the water use of cover crops and if this impacts the water available for cash crops. Although recent research has suggested that cover crops do not cause notably greater water losses relative to fallowed ground (DeVincentis et al., 2022), further clarifying this is critical for successful SGMA implementation in water scarce agricultural regions.

For both growing regions, opportunity, equipment, and operational costs were cited as barriers to planting and managing a cover crop. For annual crop growers who farm year-round, just one benefit of California's Mediterranean farming climate, taking land out of cash crop production to plant cover crops represents a significant opportunity cost. Likewise, delayed cover crop termination may delay cash crop planting and harvesting schedules with implications for buyer contract deadlines, crop yields, and grower revenue. This is particularly relevant for warm season annual row crops like processing tomatoes. Moreover, the short winter fallow period doesn't allow for much time for cover crop residue to decompose causing issues for the establishment of direct-seeded crops like spinach or high-density baby greens.

Seeding, mowing, and terminating a cover crop require tractor passes, and thus additional operating expenses in terms of labor, fuel, equipment, and cover crop seed. Additional specialized equipment may also be necessary, depending on the cropping system and cover crop, such as an orchard drill or a specialized seeder to fit between tree or vine rows.

"Winter cover crops are nature's sponges. Without them, we have soil erosion and water runoff. With them, we create an environment that sustains soil health, water infiltration, and increased soil carbon and organic matter. It's a no-brainer to incorporate this practice into farming systems."

AMY SILIZNOFF, MADERA/CHOWCHILLA RESOURCE CONSERVATION DISTRICT, EXECUTIVE DIRECTOR

# COMPOST APPLICATION

## WATER BENEFITS:

Increased organic matter
Increased water holding capacity
Reduced synthetic fertilizers

Our interviews revealed that food safety is the chief barrier limiting the use of compost or other recycled organic amendments on California's orchard and fresh produce farmland. While the use of incompletely composted materials can pose a risk to human health and food safety, there are well established best management practices to manage this risk. Specifically, high temperatures and appropriate wait times associated with proper compost management will destroy human pathogens such as E. coli, salmonella, and others. Despite its proven safety, the prospect of a violation or rejection of crops by buyers significantly deters the use of compost or other recycled organic amendments on California's orchard and fresh produce farmland (Khalsa & Brown, 2017; Esquivel et al., 2021).

Supply chains commonly take a zero-risk tolerance policy to agricultural practices that can impact food safety. While our interviews revealed that growers generally had interest in compost as a fertility source, applying compost posed a significant risk to their contracts and relationships with buyers.

Moreover, our interviews revealed growers' concerns around compost consistency and quality. Composted products can be highly variable in their nutrient content, organic matter, and carbon-to-nitrogen ratio (C:N) depending on the feedstock material (Koelsch et al., 2020). A lack of compost consistency means that the composition, quantity, and rate of nutrient release into the soil is also highly variable. Thus, growers utilizing compost may need to take additional measures to understand soil fertility and crop nutrition. Finally, some composted materials can have higher levels of contaminants (e.g., chemicals, plastics) and can introduce unwanted materials onto a growers' land.

"As climate smart agricultural practices are featured in retailer buying requirements – the conversation about the use of compost is coming back around. When coupled with current science, we can help more clearly define the risks and create best practices for use."

JOHN MCKEON, DIRECTOR OF FOOD SAFETY, TAYLOR FARMS

# CONSERVATION TILLAGE

## WATER BENEFITS:

**Increased infiltration**
**Reduced runoff and erosion**
**Increased water holding capacity**

Based on our interviews, we found that upfront equipment costs required for conservation tillage practices were a significant barrier to adoption (Mitchell et al., 2007; Bossange et al., 2016). Specialized equipment may be required not only for reduced tillage, but also for planting or drilling seeds into untilled land. Although there are cost savings associated with reduced tillage, the break-even for the equipment investment for growers that do their own planting and harvesting is heavily dependent on the size of the farm.

For growers who rely on third parties for planting and harvesting services, conservation tillage may not even be an available option. In many cases, third parties charge by number of tractor passes instead of the service provided, so there is little incentive for them to offer conservation tillage services that come with fewer passes.

Additionally, conservation tillage has not been optimized as a management practice for many of California's specialty crops. While some cropping systems see negative impacts, such as temporary yield reductions, others are incompatible with the practice. (Mitchell et al., 2007; Bossange et al., 2016). For example, shallowly rooted vegetable crops require loose soil structures that are achieved with tillage, while other cropping systems require that residue is removed or incorporated, neither of which are features of conservation tillage.

"Conservation Tillage (CT) provides tremendous benefits. However, it isn't something most small growers can afford. You see a return on investment from the reduction of tractor passes, savings on fuel and labor. If I farm 1000 acres, CT pays for itself in a few years. If I farm 50 acres, I don't think I would ever break even."

AARON WICKSTROM, MANAGING PARTNER, VALSIGNA FARMS, LLC

# WHAT IS NEEDED TO ADDRESS BARRIERS TO ADOPTION

Despite the potential agronomic, environmental, and water-related benefits of soil health practices, California growers must overcome significant barriers to the adoption of these practices, both on and off the farm. On-farm operational constraints include economic feasibility, resource limitations, and agronomic incompatibility. It is also critical to address the external barriers to grower adoption, such as a lack of technical support, complicated regulatory requirements, supply chain conflicts, and a lack of clear research outcomes and guidance around best practices on California farmland. Widespread adoption of soil health practices is unlikely unless these systemic barriers are addressed. The following are critical needs in addressing these barriers.

## 1. GREATER COORDINATION OF EFFORTS AND SHARING OF INFORMATION.

Efforts to expand the adoption of soil health practices and demonstrate the agronomic, environmental, and economic benefits of implementation are longstanding – and growing – in California. There are many stakeholders working to implement these practices, provide technical assistance, assess outcomes, and develop tools. Yet there is an unrealized opportunity to better coordinate and collaborate across these initiatives – to share learnings, build on the insights of others, and avoid duplication of efforts.

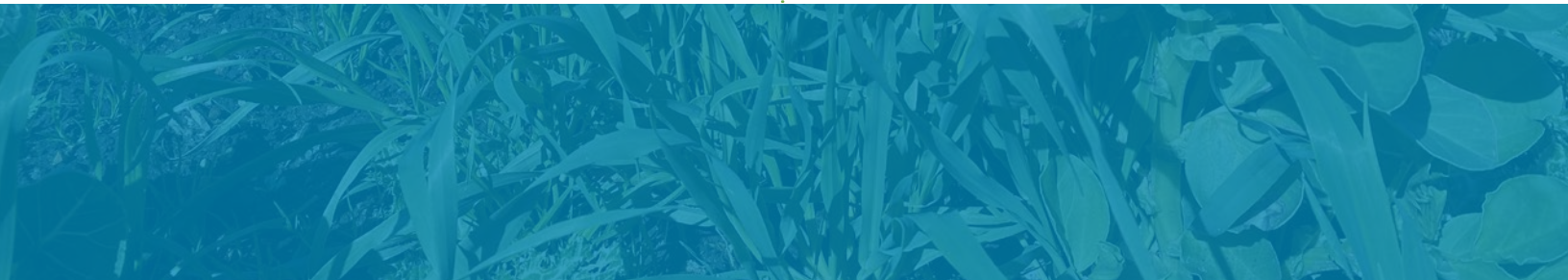
Existing sources of information, beyond being siloed across initiatives, remain difficult for users to access, understand, and apply. At present much of the available research is inaccessible to the groups who need it the most, including growers, technical assistance providers, policymakers, and regulators. In addition to improved access to information, there is a need to synthesize and translate the information for these different groups so that they can make informed decisions. This process must incorporate the lived experiences and on-the-ground knowledge of growers and others.

Greater collaboration will elevate knowledge sharing between growers, the agricultural support community, researchers, regional agencies, environmental nonprofits, environmental justice organizations, and communities – enabling each to engage more effectively. The many existing efforts can be harnessed in a strategic and coordinated way, resulting in a powerful force for advancing soil health practices that generate multi-benefit outcomes in California.

## 2. DEEPER UNDERSTANDING OF THE NET WATER BENEFITS OF SOIL HEALTH PRACTICES.

A major theme throughout our findings was the need for a more comprehensive understanding of the impacts of soil health practices on water in California agriculture. While there are many California-focused studies documenting the impacts of soil health practices on specific water-related soil metrics (soil organic carbon, infiltration, water holding capacity, etc.), there remain large information gaps owing to the diversity of cropping systems, soil types, and microclimates present in the San Joaquin Valley and Central Coast. Additionally, studies examining the net impacts of soil health practices on farm water budgets are currently lacking, and although this body of regional research is rapidly growing, particularly for cover crops, more is needed. Finally, the on-the-ground experiences of growers and technical assistance providers is critical to understanding how water benefits play out in practice and the practical constraints around implementing these practices. Anecdotal accounts related to water use, soil moisture, and the timing of first irrigation can help ground truth findings and steer new investigations.

The need to understand the net water benefits of



soil health practices is most pressing in California's arid regions, such as the San Joaquin Valley. This is especially true with the continued implementation of SGMA and its mandatory accounting of water use. While practices like cover cropping require water, some research shows that they may also have important benefits to getting more rainwater in the ground (DeVincentis et al., 2022). Other practices, like compost application, have been shown to increase soil water-holding capacity, but the net impacts remain unclear, especially in hotter, drier climates. Additionally, soil health indicators may be positively correlated with irrigation efficiency (Acevedo et al., 2022) and this area warrants further investigation. Until these benefits to the water budget are not only understood but quantifiable, growers in water scarce regions will continue to grapple with how to best use limited water resources.

## 3. IMPROVED GROWER GUIDANCE THAT ACCOUNTS FOR CALIFORNIA'S DIVERSE GROWING REGIONS AND CROPPING SYSTEMS.

California's heterogenous agricultural landscape, with its distinct climates, soil types, landforms, and diverse cropping systems, precludes a "one-size-fits-all" approach to soil health. The soil health practices and indicators – which were largely developed for the more homogeneous cropping systems of the Midwest – must be adapted. Although tremendous efforts have already gone into adapting these practices in California, more is needed due to the diversity of our agricultural systems and regions.

The California-based scientific research suggests real potential for certain practices to improve water-

related soil health benefits on farmland, though the efficacy of different practices can vary widely based on cropping systems and on-farm conditions. Growers who adopt these practices similarly report a range of observed soil health outcomes. Though variability in outcomes is not surprising, it must become part of the discourse around soil health and lead toward contextually relevant guidance.

California specific soil health benchmarks for different soil types (Devine et al., 2021), cropping systems, and climactic conditions are needed to be able to assess soil health outcomes, set realistic expectations for what outcomes growers can expect from soil health practice implementation, and avoid perceptions that practices 'aren't working'. For example, significant increases in soil organic matter (SOM) content - a common soil health indicator for its benefits to soil fertility and functions like water storage - may not be a realistic or attainable goal for some farms in water-limited regions like the SJV. In fact, maintaining SOM or abating losses over time may be a more appropriate management goal for some of these farms, due to factors including soil type, soil texture, and climate.

For these reasons, localized soil health guidance is key for growers to set realistic goals and, in turn, for expanding adoption on California farmland.

## 4. ELIMINATION OF CONFLICTS BETWEEN SUPPLY CHAIN SUSTAINABILITY GOALS AND GROWER CONTRACT REQUIREMENTS.

Increasingly, food and beverage companies are incorporating soil health practices and the quantification of their environmental benefits (carbon offsets, water savings, etc.) into their sustainability goals. As demand for sustainably sourced agricultural products (climate smart, regenerative, organic) rises, growers are being asked to meet both supply chain sustainability requests and their contract requirements. While it would make sense for contract requirements to reinforce sustainability requests, these two things are often not aligned. This misalignment creates a conflict for the grower: it doesn't make business sense for a grower to implement a soil health practice that puts their revenue or contractual relationships at risk.

One area of misalignment is the lack of flexibility in contract deadlines to accommodate delays that may occur as a result of implementing soil health practices. Cover crops are one example of a practice that is relatively attractive to brands for their multiple ecosystem benefits. For some growers (e.g., warm season annuals), cover cropping adds uncertainty to the timing of planting – and subsequent harvest – of the cash crop. Some cover crops require precise timing to adequately terminate the crop and prevent regrowth. Late winter rains are just one factor that could prevent a timely cover crop termination and the subsequent delay of cash crop planting and harvest. And with rigid contract deadlines, delays in a grower's production schedule could jeopardize their revenue, relationships, and contracts with their buyers. In cases such as this, where implementation of soil health practices could result in uncertainty for harvest, a lack of flexibility in grower contracts creates a conflict with their ability to respond to sustainability requests.

Another area of misalignment is contractual restrictions that go beyond what science and regulations have determined are necessary to mitigate food safety risks associated with on-farm practices. Sustainability programs often

encourage compost use because it can generate multiple benefits, including reducing waste by transforming byproducts into compost, reducing GHG emissions by increasing soil carbon, and reducing the use of synthetic fertilizers, among others. At the same time, growers of many crops are contending with significant pressure regarding food safety from state and federal regulatory agencies and sometimes to an even greater degree from their supply chains (including packers and shippers). Research shows that proper composting practices mitigate pathogens, and this is reflected in regulatory requirements, including the Food Safety Modernization Act (FSMA). Despite this, restrictions of compost use are common in supply chain requirements and contracts. These supply chain restrictions translate to grower reluctance to integrate compost into their farming operations. In our interviews with growers, we heard concerns about food safety violations which would result in the loss of marketable crops and rejection of crops by the supply chain. Grower and supply chain education around safe compost procurement and application could help address the misconceptions of food safety risk with properly treated compost products. Further, innovation around new practices for harvesting orchard crops and additional certifications around compost quality are other potential paths to increasing adoption.

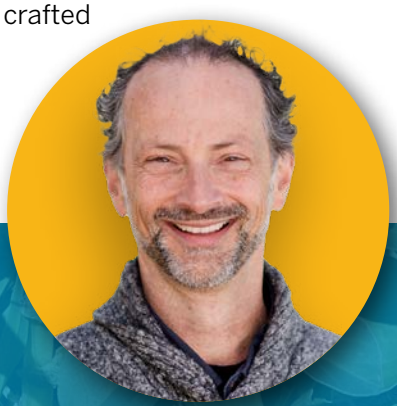
Our analysis indicates that there is a strong need for alignment within the supply chain around sustainable practices. Building awareness within the supply chain as to the challenges growers face is a step toward bridging this information gap between brands and their respective buyers, packers, and shippers, and could lead to greater alignment between sustainability goals and contract requirements.

## 5. MORE SHORT-TERM INCENTIVES TO SUPPORT LONGER-TERM OUTCOMES.

Soil health practices can provide economic benefits over time despite the costs associated with their implementation. Cost savings can come through reductions in water application, fertilizer, and other inputs (American Farmland Trust, 2019, 2020). However, many of the perceived cost savings of soil health practices are slow to accrue. Building soil organic matter and improving soil structure, for example, take years of continuous practice to manifest, while implementation costs are immediate (DeVincentis et al., 2020). Given already tight margins, many growers are reluctant or unable to make short-term investments for benefits they may not see for years. This dissonance can diminish incentives for growers and deter new adoption. Buyers and others looking to achieve these longer-term benefits should consider providing incentives that help growers feel confident their short-term investment will pay off.

This barrier to adoption is particularly challenging for non-landowners or tenant farmers, many of whom are underserved and marginalized. Tenant farmers may not have access to the capital, specialized equipment, or technical assistance needed to adopt a new practice. Further, these farmers often have short lease agreements with terms that may not allow for certain practices. Oftentimes, fields must be bare when leases end, and this may be well before a cover crop is terminated or before the mandatory waiting period for compost application. This barrier is particularly acute for incentives and credits that have requirements that don't align with lease dates and terms. Finally, soil health practices are an investment in improving the agronomic and environmental value in the land over time, which ultimately benefits the landowner and not a short-term tenant. Lease agreements often do not consider – let alone encourage – such improvements to the land.

Pathways to widespread adoption in California must include considerations of the mismatch of incentives, for both owner and non-owner farmers. For tenant farmers, the significant financial pressures, labor and equipment constraints, and short lease windows mean that incentivizing soil health requires special consideration and alignment with lease requirements. Any regulatory incentive programs must be carefully crafted to ensure access for small, minority, and historically underserved growers.



**"One of the best ways to help a grower invest in [soil-health] practices is to help them secure better [land] tenure."**

**BRETT MELONE, CHIEF BUSINESS STRATEGIES OFFICER, CALIFORNIA FARMLINK**

# RECOMMENDATIONS FOR INCREASING ADOPTION OF SOIL HEALTH PRACTICES

Soil health practices such as cover cropping, compost application, and conservation tillage have the potential to dramatically improve water quantity and quality outcomes on California farms.

In specific contexts, these practices have been demonstrated to improve water-holding capacity, infiltration, and soil organic matter, while reducing runoff and erosion.

Though improving soil health is a promising multi-benefit solution, California growers face a complex landscape of barriers preventing the expanded adoption of these practices.

Through a California-centric literature review and extensive informal interview process, we identified the most important systemic barriers and developed recommendations to address them.

The following activities have the potential to increase our knowledge about best practices, bridge communication gaps, realign incentives, and ultimately drive grower adoption of soil health practices, leading to more resilient farms across the state.

## Increase information access by translating and synthesizing findings for all audiences.

**Bridging the communication gap between researchers, growers, and policymakers, regulators, and communities will provide benefits to all in the interest of a better agricultural system.** Greater information sharing will build policy makers' and regulators' capacity to create and enforce effective evidence-based policy. Due to the urgency of some regulatory decisions, this may require the sharing of pre-publication research results through repositories and information hubs as they become available. Additionally, hearing evidence through on-the-ground experiences would help fill information gaps in the short-term and inform the iterative.

CLIMATE-SMART AGRICULTURE IN CALIFORNIA NECESSITATES BOTH FARMER CONTRIBUTIONS TO GREENHOUSE GAS REDUCTIONS AND FARMER RESILIENCY TO EXTREME FLOODS AND DROUGHTS.

## Support for research targeting highest priority information needs of growers and water users.

**Research on the impacts of soil health practices on on-farm water conservation is emerging, but due to the urgency, additional targeted research is needed quickly.** Growers and water managers need to be able to measure the impacts of soil health practices on water use and water quality easily and accurately. Additional research should target the areas of greatest need and outstanding operational, agronomic, and economic (cost/benefit) questions around the adoption of soil health practices on California farmland. Likewise, funding needs to be in place to support these high priority research efforts (e.g., cover crop impacts on on-farm water budgets; cover crop and high carbon amendment benefits to water quality). One short-term opportunity is to include water-related research and demonstration as fundable activities in existing climate-smart programs, which currently are restricted largely to carbon outcomes. Doing so would reflect the fact that climate-smart agriculture in California necessitates both farmer contributions to greenhouse gas reductions and farmer resiliency to extreme floods and droughts. In addressing this gap, adding water-related measurements to existing soil research and demo sites from the outset is a critical need. Activities should also include expanding demonstration projects focused on climate and water smart practices, harnessing grower participation in research design, and fostering peer-to-peer learning.

## Grower tools to spur adoption of soil health practices.

**Soil health has gained increasing interest in the academic, agency, and non-profit spheres, and as such there is a wealth of information across disparate efforts, case studies, and decision-making tools.** What is needed is a synthesis of this information to provide growers with data to inform when and how soil health practices may realistically improve soil carbon and water-related outcomes for varying on-farm conditions. This includes both the development of new materials and the incorporation of the water-related benefits into existing initiatives. One example of the latter is the cover crop selection tool developed by the Western Cover Crops Council to help growers identify appropriate cover crop species or mixes based on desired agronomic goals (i.e., pollination, soil compaction reduction), growing region, and cropping system. Including guidance relevant to water quantity and quality outcomes (e.g., crop water requirements and water-related desired agronomic outcomes such as drought tolerance) into efforts like this would fill an important information gap.

## Elimination of supply chain barriers.

**Increased collaboration between brand procurement and sustainability teams and between brands and their suppliers is a first step toward resolving conflicts within supply chains.** Grower and supply chain education around safe compost procurement and application could help address the misconceptions and identify best practices for integrating compost safely. Working with growers, packers, shippers, and brands to build flexibility into contract deadlines could help remove the financial risks of practices like cover cropping for growers.

## Incentives that support grower transition.

**The right incentives are needed to support grower short-term investments for longer-term soil health benefits.** Examples of voluntary incentives include the California Department of Food and Agriculture's (CDFA) Healthy Soils Program (HSP) and the Natural Resource Conservation Service's (NRCS) Environmental Quality Incentive Program (EQIP) and Conservation Stewardship Program (CSP). These programs provide funding and technical assistance to support producers in adopting soil health practices, and this support is particularly important for practices that have unclear or longer payback periods. However, these programs have funding limitations and require growers to submit applications. This creates several barriers. For example, even if farmers invest the resources to complete an application, they may not receive funding and thus face a potential sunk cost. This risk is less acceptable for smaller operations, and leads many growers to avoid applying in the first place. Additionally, not all growers have access to the information or the resources to know about the programs and submit applications in the first place – a barrier that disproportionately impacts farmers that are small, disadvantaged, beginning, and/or non-native English speakers. CDFA and NRCS acknowledge and are reducing the latter barrier, but the challenge remains given the structural limitations of these types of programs.

**SUPPLY CHAINS PROVIDING DIRECT INCENTIVES TO FARMERS IS PERHAPS THE MOST EFFECTIVE WAY TO INCREASE ADOPTION OF SOIL HEALTH PRACTICES.**

To address these limitations, additional support systems, technical assistance, and funding opportunities that are tied to core business operations are needed. For example, regulatory "carrots" based on the best available scientific and technical information and grower experiences can be an effective way to increase adoption of soil beneficial practices. One example is the Central Coast's Ag Order 4.0 which incentivizes growers to use practices like cover cropping and high carbon soil amendments to reduce excess nitrate leaching to surface and groundwater, while improving soil health, increasing moisture retention, and sequestering carbon and nitrogen.

Most importantly, supply chains providing direct incentives to farmers is perhaps the most effective way to increase adoption of soil health practices. Farmers are just like any business – they respond to what their customers pay for. These incentives could include preferential contracting, financial premiums, risk sharing, or technical assistance, among others. One example is Blue Diamond® Growers' Orchard Stewardship Incentive Program, which establishes several tiers of farmer sustainability performance – including soil practices – and provides increased financial incentives at each tier. Developing direct farmer incentive programs can be challenging in many of today's agricultural supply chains, but it should be prioritized, particularly when the products made from those crops are being marketed as more sustainable.

# CONCLUSION

The future of California agriculture depends on our ability to adapt to our changing climate. Soil health can help all California growers to be more resilient to drought and flood extremes while protecting communities and the environment. Though our farming is diverse, there are ways to incorporate these practices across a variety of crops and regions. However, to meaningfully scale adoption across the state we need to reduce the barriers faced by growers.

Doing the work of addressing these barriers requires engaging in broad collaborative coalitions, sharing information, cultivating trust, and developing understanding among growers, researchers, and policymakers. We also need coordination among groups to organize around addressing specific barriers. All parties must have access to the best available scientific and technical information, and observations that come from the on-the-ground experience of growers.

Solving this issue is bigger than the efforts of Sustainable Conservation or any single organization. There are many organizations working in this space and many efforts are in progress. Together, our individual efforts can be harnessed in a strategic and coordinated way, resulting in a powerful resource for advancing soil health practices that generate multi-benefit outcomes for California's agriculture, environment, and people.


Photos courtesy of Donny Hicks

# REFERENCES


*2017 Census of Agriculture: United States Summary and State Data* (AC-17-A-51; Volume 1. Geographic Area Series, Part 51, Issue AC-17-A-51). (2019). US Department of Agriculture, National Agricultural Statistics Service.

Acevedo, S. E., Waterhouse, H., Barrios-Masias, F., Dierks, J., Renwick, L. L. R., & Bowles, T. M. (2022). How does building healthy soils impact sustainable use of water resources in irrigated agriculture? *Elementa: Science of the Anthropocene*, *10*(1), Article 1. https://doi.org/10.1525/elementa.2022.00043

Ayres, A., Kwon, J., & Collins, J. (2022). *Land Transitions and Dust in the San Joaquin Valley: How Proactive Management Can Support Air Quality Improvements* [PPIC Report].

Bossange, A. V., Knudson, K. M., Shrestha, A., Harben, R., & Mitchell, J. P. (2016). The Potential for Conservation Tillage Adoption in the San Joaquin Valley, California: A Qualitative Study of Farmer Perspectives and Opportunities for Extension. *PLOS ONE*, *11*(12), Article 12. https://doi.org/10.1371/journal.pone.0167612

Brennan, E. B., & Boyd, N. S. (2012). Winter Cover Crop Seeding Rate and Variety Affects during Eight Years of Organic Vegetables: II. Cover Crop Nitrogen Accumulation. *Agronomy Journal*, *104*(3), Article 3. https://doi.org/10.2134/agronj2011.0331

Brennan, E. B., & Smith, R. F. (2018). Mustard Cover Crop Growth and Weed Suppression in Organic, Strawberry Furrows in California. *Hortscience*, *53*(4), Article 4. https://doi.org/10.21273/HORTSCI12576-17

Carlisle, L. (2016). Factors influencing farmer adoption of soil health practices in the United States: A narrative review. *Agroecology and Sustainable Food Systems*, *40*(6), Article 6. https://doi.org/10.1080/21683565.2016.1156596

Carlisle, L., Esquivel, K., Baur, P., Ichikawa, N. F., Olimpi, E. M., Ory, J., Waterhouse, H., Iles, A., Karp, D. S., Kremen, C., & Bowles, T. M. (2022). Organic farmers face persistent barriers to adopting diversification practices in California's Central Coast. *Agroecology and Sustainable Food Systems*, *46*(8), Article 8. https://doi.org/10.1080/21683565.2022.2104420

Daugovish, O., Faber, B., Takele, E., Whiteford, J., & Wu, L. (2020). Cover crop and mulch practices reduce agricultural pollutant loads in stormwater runoff from plastic tunnels. *California Agriculture*, *74*(1), Article 1. https://doi.org/10.3733/ca.2020a0004

DeVincentis, A. J., Solis, S. S., Bruno, E. M., Leavitt, A., Gomes, A., Rice, S., & Zaccaria, D. (2020a). Using cost-benefit analysis to understand adoption of winter cover cropping in California's specialty crop systems. *Journal of Environmental Management*, *261*, 110205. https://doi.org/10.1016/j.jenvman.2020.110205

DeVincentis, A. J., Solis, S. S., Bruno, E. M., Leavitt, A., Gomes, A., Rice, S., & Zaccaria, D. (2020b). Using cost-benefit analysis to understand adoption of winter cover cropping in California's specialty crop systems. *Journal of Environmental Management*, *261*, 110205. https://doi.org/10.1016/j.jenvman.2020.110205

DeVincentis, A., Solis, S. S., Rice, S., Zaccaria, D., Snyder, R., Maskey, M., Gomes, A., Gaudin, A., & Mitchell, J. (2022). Impacts of winter cover cropping on soil moisture and evapotranspiration in California's specialty crop fields may be minimal during winter months. *California Agriculture*, *76*(1), Article 1. https://doi.org/10.3733/ca.2022a0001

Devine, S. M., Steenwerth, K. L., & O'Geen, A. T. (2021). A regional soil classification framework to improve soil health diagnosis and management. *Soil Science Society of America Journal*, *85*(2), Article 2. https://doi.org/10.1002/saj2.20200

Devine, S., Steenwerth, K., & O'geen, A. (2022). Soil health practices have different outcomes depending on local soil conditions. *California Agriculture*, *76*(1), Article 1.

Esquivel, K. E., Carlisle, L., Ke, A., Olimpi, E. M., Baur, P., Ory, J., Waterhouse, H., Iles, A., Karp, D. S., Kremen, C., & Bowles, T. M. (2021). The "Sweet Spot" in the Middle: Why Do Mid-Scale Farms Adopt Diversification Practices at Higher Rates? *Frontiers in Sustainable Food Systems*, *5*. https://www.frontiersin.org/articles/10.3389/fsufs.2021.734088

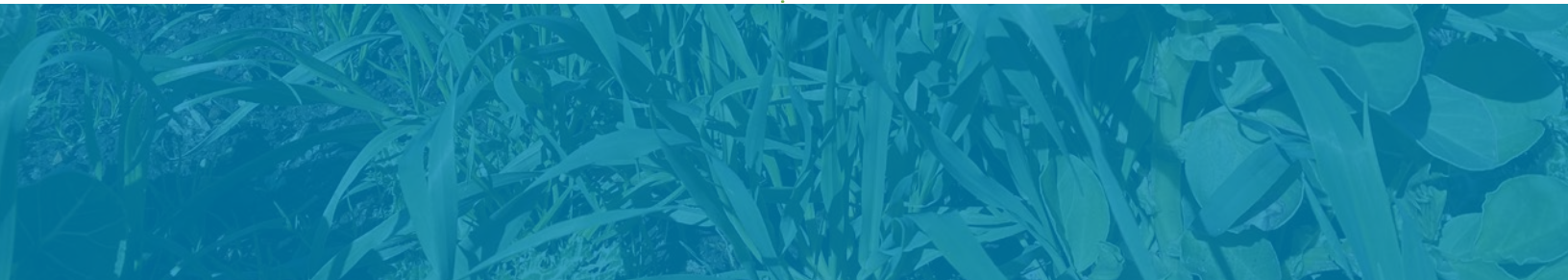
Flint, L., Flint, A., Stern, M., Mayer, A., Vergara, S., Silver, W., Casey, F., Franco, F., Byrd, K., Sleeter, B., Alvarez, P., Creque, J., Estrada, T., & Cameron, D. (2018). *Increasing Soil Organic Carbon to Mitigate Greenhouse Gases and Increase Climate Resiliency for California* (California's Fourth Climate Change Assessment, California Natural Resources Agency Publication number: CCCA4-CNRA-2018-006. U.S. Geological Survey.

*Groundwater Management and Safe Drinking Water in the San Joaquin Valley Analysis of Critically Over-drafted Basins' Groundwater Sustainability Plans*. (2020). The Water Foundation.

Heinrich, A., Smith, R., & Cahn, M. (2014). Winter-killed Cereal Rye Cover Crop Influence on Nitrate Leaching in Intensive Vegetable Production Systems. *HortTechnology*, *24*(5), Article 5. https://doi.org/10.21273/HORTTECH.24.5.502

Horwath, W. R. (2008). Tillage and crop management effects on air, water, and soil quality in California. *UCANR Publications*.

Jackson, L., Wyland, L., Klein, J., Smith, R., Chaney, Ph. D., & Koike, S. (1993). In lettuce production, winter cover crops can decrease soil nitrate, leaching potential. *California Agriculture*, *47*, 12–15. https://doi.org/10.3733/ca.v047n05p12

Joyce, B. A., Wallender, W. W., Mitchell, J. P., Huyck, L. M., Temple, S. R., Brostrom, P. N., & Hsiao, T. C. (2002). Infiltration and Soil Water Storage Under Winter Cover Cropping in California's Sacramento Valley. *Transactions of The Asae*, *45*, 12.

Khalsa, S. D. S., & Brown, P. H. (2017). Grower Analysis of Organic Matter Amendments in California Orchards. *Journal of Environmental Quality*, *46*(3), Article 3. https://doi.org/10.2134/jeq2016.11.0456

Khalsa, S. D. S., Rudnick, J., Lubell, M., Sears, M., & Brown, P. H. (2022). Linking Agronomic and Knowledge Barriers to Adoption of Conservation Practices for Nitrogen Management. *Frontiers in Agronomy*, *4*. https://www.frontiersin.org/articles/10.3389/fagro.2022.915378

Koelsch, R., Andersen, D., Cortus, E., Johnson, L., Schmidt, A. M., & Wilson, M. (2020). What Are the Barriers and Benefits of Manure Use in Cropping Systems? *Crops & Soils*, *53*(6), Article 6. https://doi.org/10.1002/crso.20075

LaRose, J, & Myers, R. (2019). Adoption of Soil Health Systems Based on Data from the 2017 U.S. Census of Agriculture Metrics include Cover Crop and No-till Production Practices. *Soil Health Institute*.

Lepsch, H. C., Brown, P. H., Peterson, C. A., Gaudin, A. C. M., & Khalsa, S. D. S. (2019). Impact of organic matter amendments on soil and tree water status in a California orchard. *Agricultural Water Management*, *222*, 204–212. https://doi.org/10.1016/j.agwat.2019.06.002

Mailapalli, D. R., Horwath, W. R., Wallender, W. W., & Burger, M. (2012). Infiltration, Runoff, and Export of Dissolved Organic Carbon from Furrow-Irrigated Forage Fields under Cover Crop and No-Till Management in the Arid Climate of California. *Journal of Irrigation and Drainage Engineering*, *138*(1), Article 1. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000385

Mitchell, J. P., Klonsky, K., Shrestha, A., Fry, R., DuSault, A., Beyer, J., & Harben, R. (2007a). Adoption of conservation tillage in California: Current status and future perspectives. *Australian Journal of Experimental Agriculture*, *47*(12), Article 12. https://doi.org/10.1071/EA07044

Mitchell, J. P., Klonsky, K., Shrestha, A., Fry, R., DuSault, A., Beyer, J., & Harben, R. (2007b). Adoption of conservation tillage in California: Current status and future perspectives. *Australian Journal of Experimental Agriculture*, *47*(12), Article 12. https://doi.org/10.1071/EA07044

Mitchell, J. P., Shrestha, A., & Irmak, S. (2015a). Trade-offs between winter cover crop production and soil water depletion in the San Joaquin Valley, California. *Journal of Soil and Water Conservation*, *70*(6), Article 6. https://doi.org/10.2489/jswc.70.6.430

Mitchell, J. P., Shrestha, A., & Irmak, S. (2015b). Trade-offs between winter cover crop production and soil water depletion in the San Joaquin Valley, California. *Journal of Soil and Water Conservation*, *70*(6), Article 6. https://doi.org/10.2489/jswc.70.6.430

Mitchell, J. P., Shrestha, A., Mathesius, K., Scow, K. M., Southard, R. J., Haney, R. L., Schmidt, R., Munk, D. S., & Horwath, W. R. (2017). Cover cropping and no-tillage improve soil health in an arid irrigated cropping system in California's San Joaquin Valley, USA. *Soil & Tillage Research*, *165*, 325–335. https://doi.org/10.1016/j.still.2016.09.001

Mitchell, J. P., Singh, P. N., Wallender, W. W., Munk, D. S., Wroble, J. F., Horwath, W. R., Hogan, P., Roy, R., & Hanson, B. R. (2012). No-tillage and high-residue practices reduce soil water evaporation. *California Agriculture*, *66*(2), Article 2. https://escholarship.org/uc/item/4cg3g2cf

Miyao, G., & Robins, P. (2001). Influence of Fall-Planted Cover Crop on Rainfall Run-Off in a Processing Tomato Production System. *Acta Horticulturae*, *542*, Article 542. https://doi.org/10.17660/ActaHortic.2001.542.44

Rudnick, J., Lubell, M., Khalsa, S. D. S., Tatge, S., Wood, L., Sears, M., & Brown, P. H. (2021). A farm systems approach to the adoption of sustainable nitrogen management practices in California. *Agriculture and Human Values*, *38*(3), Article 3. https://doi.org/10.1007/s10460-021-10190-5

Smith, R., Bettiga, L., Cahn, M., Baumgartner, K., Jackson, L. E., & Bensen, T. (2008). Vineyard floor management affects soil, plant nutrition, and grape yield and quality. *California Agriculture*, *62*(4), Article 4. https://escholarship.org/uc/item/79k913pk

*Soil Health Case Study Ralf Sauter, Okuye Farms, CA*. (2019). American Farmland Trust.

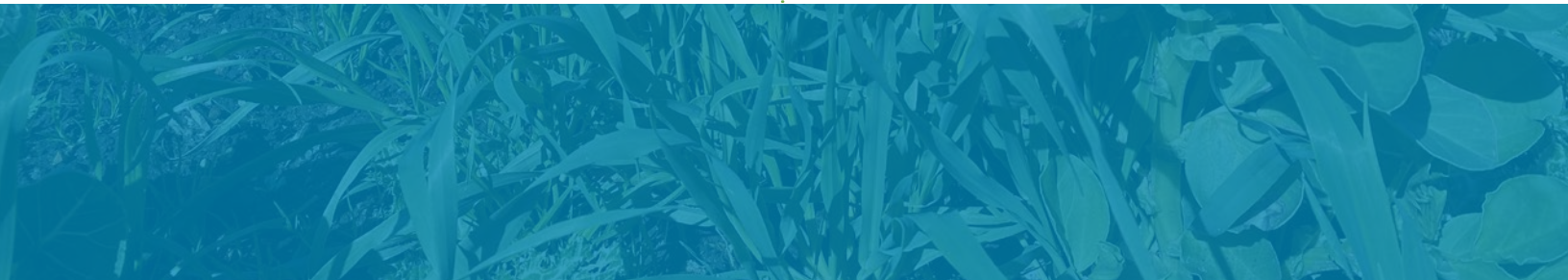
*Soil Health Case Study Tom and Dan Rogers, Rogers Farm, CA*. (2020). American Farmland Trust.

*State Water Resources Control Board. It Lacks the Urgency Necessary to Ensure That Failing Water Systems Receive Needed Assistance in a Timely Manner* (Report 2021-118; Issue Report 2021-118). (2021). California State Auditor.

Villa, Y. B., Khalsa, S. D. S., Ryals, R., Duncan, R. A., Brown, P. H., & Hart, S. C. (2021). Organic matter amendments improve soil fertility in almond orchards of contrasting soil texture. *Nutrient Cycling in Agroecosystems*, *120*(3), Article 3. https://doi.org/10.1007/s10705-021-10154-5

White, K. E., Brennan, E. B., Cavigelli, M. A., & Smith, R. F. (2020). Winter cover crops increase readily decomposable soil carbon, but compost drives total soil carbon during eight years of intensive, organic vegetable production in California. *Plos One*, *15*(2), Article 2. https://doi.org/10.1371/journal.pone.0228677

White, K. E., Brennan, E. B., Cavigelli, M. A., & Smith, R. F. (2022). Winter cover crops increased nitrogen availability and efficient use during eight years of intensive organic vegetable production. *PLOS ONE*, *17*(4), Article 4. https://doi.org/10.1371/journal.pone.0267757



# APPENDIX

## COVER CROPPING

**Water Benefits:**
Increased infiltration
Reduced runoff and erosion
Increased surface shading
Diverse and active soil biology
Nutrient scavenging

### Leading Barriers to Adoption

| | |
|---|---|
| Water is one of the most limiting resources to California growers, thus the reliability and cost of water is one of the most significant constraints to agriculture. Likewise, **knowledge and information** around cover crop water use and impacts on water budgets is a leading barrier to adoption. | Cover crops, like all plants, require water to grow.<br>Winter, rain-fed cover crops are planted in the fall ahead of wintertime rainfall, but uncertainty in timing and lack of consistency of winter precipitation pose a significant challenge to growers.<br>Despite the known water benefits to cover cropping, the net impact of cover crops to on-farm water budgets have been under-researched and is relatively unknown for many California cropping systems.<br>Factors including cover crop species, termination timing, seeding rate, and on-farm conditions impact the amount of water cover crops use relative to their water benefits. |
| There are often **opportunity costs**. For annual cropping systems, winter cover cropping can come at the expense of planting an early spring cash crop and may pose additional operational costs to growers. | The timing of winter cover crop termination is critical to minimizing interference with spring cash crop planting schedules.<br>Weather delays, equipment and labor issues, and poorly decomposed cover crop residue can all adversely affect a grower's planting schedule.<br>Land, labor, and seeds are expensive, so growing a non-cash crop like a cover crop adds to a grower's operational costs.<br>The return on investment for cover cropping may take several years. Thus, cover crops may not provide a clear financial return on timescales relevant to some growers, particularly tenant farmers or non-owner operators. |

## COMPOST APPLICATION

**Water benefits:**
Increased organic matter
Increased water holding capacity
Reduced synthetic fertilizers

| Leading Barriers to Adoption | |
|---|---|
| Concern over **food safety** issues significantly deters the use of compost or other recycled organic amendments on California's orchard and fresh produce farmland. | Regulations and best management practices ensure that compost is produced in a way that eliminates pathogens for safe on-farm use.<br>However, if not treated properly, composted products (decomposed green or animal wastes) can harbor pathogens dangerous for human consumption.<br>For crops like almonds, walnuts, leafy greens, and berries, which are harvested off or near the soil surface, supply chain participants often take a zero-risk tolerance policy to agricultural practices involving animal or organic waste, even ones that can be implemented safely.<br>Even if growers recognize that applying compost can be a safe practice, it can pose a significant risk to their contracts and relationships with buyers. |
| The **quality and consistency of compost** can be highly variable regarding their nutrient, organic matter, carbon to nitrogen ratio (C:N), and contamination content. | The quality and nutrient content of compost depends, in part, on the feedstock material, age, and processing procedure.<br>Growers prefer consistent products, and some struggle with its variable quality.<br>Compost releases nutrients as it continues to decompose but may not completely offset nutrient demand. Few growers rely solely on compost for meeting crop nutrient demand. Thus, growers must still apply fertilizer in some cases.<br>Some composts contain non-organic contamination including plastics, glass, and other undesirable materials. |

## CONSERVATION TILLAGE

**Water benefits:**
Increased infiltration
Reduced runoff and erosion
Increased water holding capacity

| Leading Barriers to Adoption | |
|---|---|
| The upfront **equipment costs** associated with conservation tillage are a significant barrier to adoption. | Conservation tillage requires specialized equipment (tillage implements, seeders) that most growers do not own.<br>Cost savings are realized because fewer tractor passes are required – meaning lower fuel and labor costs.<br>The rate at which a grower sees return on their investment depends on acreage, with large farms benefiting the most.<br>Custom farmers, who get paid based on the number of tractor passes, may be reluctant to shift their business models. |
| Conservation Tillage has not been researched and optimized to fit every specialty crop. Some systems have **significant yield reduction or incompatibility** with the practice. | Organic systems that rely on tillage for weed control can experience significant reduction in yields due to weed competition.<br>Certain shallowly rooted vegetable crops, which require loose soil structure and minimal compaction, are not compatible with the practice. |