

Regenerating California's Soils: Compost Applications for Productivity, Profitability, and Climate Resilience

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Executive Summary

California's farms produce more than a third of the nation's vegetables and two-thirds of its fruits and nuts, but decades of intensive cultivation have depleted soil organic matter, reduced resilience, and increased vulnerability to drought, nutrient loss, and climate change. Compost offers a proven, scalable solution to rebuild soil health, store carbon, and support long-term agricultural productivity.

When applied to croplands and rangelands, compost increases soil organic matter, stimulates microbial activity, enhances nutrient cycling, and improves soil structure and water-holding capacity. California field studies — from perennial orchards to annual grasslands — show that compost can measurably increase soil organic carbon (SOC) stocks, with a portion stabilized for decades through mineral associations and aggregate protection. These benefits are amplified when compost is paired with complementary practices such as cover cropping, reduced tillage, or biochar.

Adoption is supported by state policies (e.g., CDFA Healthy Soils Program, SB 1383) and emerging carbon markets that reward both carbon sequestration and avoided greenhouse gas emissions from landfill diversion. Decision-support tools like COMET-Planner, DAYCENT, and COMMONS can help growers quantify benefits and align practices with incentive programs.

Barriers remain — including cost, access to high-quality compost, infrastructure gaps, and the need for site-specific guidance. Overcoming these challenges will require coordinated investment in compost production and distribution, expanded extension capacity, and integration of compost into whole-farm planning.

With the right support, compost can become a cornerstone of regenerative, climate-smart agriculture in California, improving productivity, profitability, and environmental stewardship while positioning the state's producers as leaders in climate resilience.

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Compost in California Agriculture

Compost for Soil Health and Carbon Sequestration

I. Introduction: California's Agricultural Context

California is one of the most agriculturally productive regions in the world, renowned for its crop diversity, year-round growing seasons, and Mediterranean climate. From almonds, grapes, and citrus in the Central Valley to strawberries and lettuce along the Central Coast, California's farms supply a substantial portion of the nation's food, and its largest economy—in 2023, agricultural exports totaled \$22.4 billion in value (CDFA, 2024; Bohn and Duan, 2025). Yet, the success of California's agricultural sector is sustained by practices that have exerted significant pressures on the soil, leading to degradation that threatens the long-term sustainability of these systems (Fenster et al., 2021)

The intensive nature of farming in this region, characterized by high input use and monoculture cropping systems, has contributed to a decline in soil health, undermining the resilience of these agroecosystems in the face of mounting climate challenges (Flint et al., 2018). Soil organic matter (SOM) plays a foundational role in maintaining ecological function and buffering against nutrient losses. When SOM levels decline—due to intensive tillage, limited organic inputs, or bare soil management, so too does the soil's ability to retain and cycle nitrogen effectively (Balesdent et al., 2000). This degradation is often accompanied by a loss of soil structure, which reduces infiltration and increases the likelihood of surface runoff (Pagliai et al., 2004). In these compromised systems, nitrogen fertilizers are more prone to leaching as nitrate (NO_3^-) into groundwater or volatilizing as nitrous oxide (N_2O), a potent greenhouse gas (Cloy et al., 2015). The breakdown of the soil's buffering capacity results in what is referred to as a "leaky nitrogen cycle," characterized by inefficient nutrient use, increased input dependency, and heightened risk of off-site pollution (Anas et al., 2020). These disruptions not only compromise crop productivity but also exacerbate ecological degradation such as groundwater contamination and atmospheric emissions of reactive nitrogen compounds (Bijay-Singh and Craswell, 2021).

Restoring and maintaining soil health will require practices that rebuild SOM and reverse the decline in biological, chemical, and physical soil functions. Compost amendments present a particularly effective solution, adding organic material that directly increases SOM, supports microbial activity, improves soil structure, and enhances nutrient retention (Cavagnaro, 2014; Adugna, 2016; Amuah et al., 2022). In California, this opportunity is amplified by statewide policies such as SB 1383, which mandates the diversion of organic waste from landfills, creating a growing supply of compost for agricultural use. By strategically applying compost to croplands and rangelands, producers can transform a waste management challenge into a soil health solution. Building long-term fertility,

boosting resilience to drought and climate extremes, and contributing to the state's carbon sequestration goals.



Figure 1. Conceptual illustration of soils as a “savings account.” Inputs such as compost and cover crops act as deposits into the soil system, building soil organic matter and overall soil health. These savings provide returns in the form of agricultural outputs, including crop production and enhanced climate resilience. The piggy bank metaphor emphasizes the long-term value of soil investments, where continual inputs strengthen the capacity of soils to generate both immediate and lasting benefits.

Healthy soil can be thought of as a savings account—one that pays dividends in productivity, resilience, and long-term sustainability. Compost acts as a regular deposit into this account, growing the “capital” of soil organic matter that underpins soil function. Withdrawals happen every season through harvest, erosion, and organic matter decomposition, and without consistent deposits, the account balance declines, leaving soils more vulnerable to nutrient losses, compaction, and drought stress. In California’s high-value agricultural systems, this perspective reframes compost from an expense into an investment—one that yields both immediate returns in crop performance and lasting gains in soil health and climate resilience.

This paper synthesizes practical guidance, field-tested research, and policy context to help producers and agronomists make informed, economically sound decisions about compost use in California agriculture.

II. Soil Organic Matter and the Foundation of Soil Health

Building on the challenges outlined above, understanding soil health is essential for identifying solutions that restore productivity and resilience. Soil health refers to the capacity of soil to function as a vital, living ecosystem that sustains plants, animals, and humans (Kibblewhite et al., 2008). It is often described through three interdependent components: biological, chemical, and physical. While this framework helps structure soil assessment, it is important to recognize that SOM underpins all three domains.

Biologically, SOM acts as the principal energy source for soil microbial communities, fueling the decomposition of organic residues and driving key nutrient cycling processes (Wang and Kuzyakov, 2024). Chemically, SOM enhances a soil's capacity to retain and exchange essential cations, thereby improving nutrient availability, while also buffering fluctuations in soil pH to maintain a more stable chemical environment for plant growth and microbial activity (Senesi and Loffredo, 1999). Physically, SOM promotes the formation and stabilization of soil aggregates, which improve pore structure, enhance infiltration, and increase the soil's capacity to retain plant-available water (Six et al., 2002).

Interwoven across these biological, chemical, and physical functions is organic matter's role as a major reservoir of soil carbon. When stabilized within aggregates and bound to mineral surfaces, this carbon forms long-lived pools that support soil fertility, enhance climate resilience, and contribute to long-term carbon sequestration (Basile-Doelsch et al., 2020).

III. Compost's Contribution to Soil Health

Compost is one of the most effective tools for building soil organic matter and restoring the biological, chemical, and physical functions that underpin soil health. When applied appropriately, it can produce immediate improvements while contributing to long-term resilience.

- **Biological:** Compost additions significantly increase microbial biomass, taxonomic and functional diversity, and enzyme activity—enhancing nutrient mineralization and strengthening root–microbe interactions (Vinhai-Freitas et al., 2010). This stimulation fosters beneficial relationships such as mycorrhizal associations and supports more efficient nutrient cycling (Anthony et al., 2024).
- **Chemical:** Compost improves nutrient retention by increasing cation exchange capacity (CEC), buffers soil pH and reduces nutrient losses through leaching or volatilization. Its humic substances help stabilize acidity and enhance the retention of macro- and micronutrients (Ho et al., 2022)
- **Physical:** Compost improves soil structure by promoting aggregate formation and stability, leading to greater porosity, better water infiltration, and higher water-

holding capacity. It also reduces compaction, particularly valuable in fine-textured or degraded soils. In sandy soils, benefits are often most visible as improved water retention and nutrient-holding capacity, while clay soils see greater gains in aeration and reduced bulk density (Weber et al., 2007)

Through these mechanisms, compost not only replenishes the organic matter “capital” in soils but also creates conditions for sustained productivity, climate resilience, and reduced input dependency.

IV. Compost in Annual vs. Perennial Cropping Systems in California

Annual cropping systems, such as lettuce, strawberries, and tomatoes, are characterized by rapid growth cycles, shallow rooting depths, and frequent soil disturbance. These systems often rely on intensive fertilizer inputs and repeated tillage to prepare beds, manage weeds, and incorporate crop residues. The short-term nature of annual production means soil is often left bare between rotations, increasing the risk of erosion, nutrient loss, and declining organic matter.

In many Californian regions, these crops are produced under monocropping systems, where the same crop is planted repeatedly on the same land. This lack of crop diversity can deplete specific nutrient pools, reduce microbial diversity, and increase pest and disease pressures—ultimately undermining long-term soil health (Liebig et al., 2014; Bogužas et al., 2022). While compost can help buffer these effects by restoring organic matter and improving nutrient retention, its benefits are more pronounced when paired with diversified rotations or cover crops, especially when the cover crop is a mixture of species.

Key management traits of annual systems:

- Shallow rooting (typically <30 cm), limiting access to deep soil moisture and nutrients.
- High fertilizer demand, especially nitrogen and phosphorus.
- Frequent tillage and bed reshaping, disrupting microbial networks and oxidizing soil carbon.
- Seasonal bare soil, increasing erosion and runoff risk.
- Monocropping contributes to nutrient imbalance, microbial suppression, and pest buildup.

Perennial systems, including almonds, citrus, avocados, pistachios, and grapes, perennial orchard and vineyard systems operate under longer timelines and develop deeper root systems that interact with soil at greater depths. Unlike annual crops, these systems are not

replanted each year, which allows for more stable soil structure and longer-term development of microbial communities. However, they also face unique soil management challenges. Organic matter inputs are often limited due to low root turnover and minimal residue return, leading to chronically low soil organic matter. In addition, orchard traffic and machinery use contribute to compaction, while sustained productivity without replenishment can accelerate depletion of key nutrients and soil carbon stocks (Visconti et al., 2024).

Key management traits of perennial systems:

- Deep root architecture (often >1 meter) accessing subsoil resources and enhancing drought resilience.
- Minimal tillage after establishment, preserving aggregates and microbial habitats.
- Minimal or negligible organic matter contributions.
- Increased soil compaction occurs in alleyways due to machinery traffic.
- Greater potential for carbon sequestration due to continuous root inputs of exudation and reduced disturbance for longer periods of time.

The role of compost differs in these systems but remains foundational to soil health:

- In annual systems, compost can offset the negative impacts of disturbance by rebuilding organic matter, supporting microbial activity, and improving nutrient retention in the upper soil horizon (Wang et al., 2022). When paired with cover crops or reduced tillage, it helps restore biological function in degraded soils (Rath et al., 2022).
- In perennial systems, compost applications provide long-term benefits by enhancing soil structure, buffering nutrient release during drought periods, and improving water holding capacity (Hodson et al., 2021; Lawrence and Melgar, 2023). Compost is especially valuable in maintaining productivity in aging orchards or under climate stress. Increased potential for stable carbon pools due to the perennial nature of the systems with orchard/vineyard ages greater than 20 years (Hicks Pries et al., 2023).

By tailoring compost applications to the unique demands of annual and perennial systems, growers can enhance biological activity, support nutrient cycling, and build resilient soils suited to each crop's lifecycle and rooting depth.

IV. Soil Carbon Storage Dynamics

Soil carbon storage is not a single pool, but a continuum of organic matter forms that differ in stability, turnover rate, and accessibility to microbes (Field and Raupach, 2012). When compost is applied, it introduces a mixture of partially decomposed plant and microbial residues that enter this continuum through distinct pathways (Anthony et al., 2024). The overall balance of soil carbon is governed by a simple relationship:

$$\text{Soil C storage} = \text{C inputs} - \text{C losses.}$$

To build carbon, inputs from plant residues, roots, and amendments like compost must exceed microbial and abiotic losses (respiration, leaching, and erosion) (Chen et al., 2025; Enebe et al., 2025). This balance links directly to soil organic matter, which is roughly 50% carbon by mass. Thus, changes in organic matter directly reflect changes in soil carbon stocks (Navarro et al., 1993).

Soil organic matter is not a single, uniform pool but a continuum of fractions that differ in turnover, stability, and accessibility to microbes. Compost inputs interact with this continuum through several key pathways:

- **Particulate Organic Matter (POM):**
POM consists of larger, less decomposed fragments of plant and microbial residues that are readily available to microbes. Although labile, POM plays a critical role in driving short-term nutrient cycling and fueling microbial activity. This activity is essential for the eventual formation of more stable carbon fractions, making POM an important entry point for new carbon in soils (Leuthold et al., 2023). While it is less stable than mineral associated organic matter, durability of carbon in this fraction is not only its chemical composition but also the biological activity within the soil (Yoshimura et al., 2008).
- **Mineral-Associated Organic Matter (MAOM):**
MAOM forms when carbon binds to clay and silt particles or becomes occluded within aggregates. This pool develops more slowly than POM but is far more resistant to microbial breakdown, persisting for decades to centuries (Cotrufo et al., 2019). Compost promotes MAOM formation by increasing microbial biomass, carbon use efficiency, and aggregation—conditions that physically and chemically protect organic matter (Santos et al., 2021).
- **Aggregation and Physical Protection:**
Soil aggregates create protective environments that limit microbial and oxygen access to organic matter. Compost enhances aggregate stability, particularly in clay-rich soils, thereby slowing decomposition and promoting long-term carbon storage (Vormstein et al., 2020; Khadim et al., 2024). This physical protection is a key mechanism by which inputs are retained instead of lost as CO₂.

- **Surface vs. Subsoil Dynamics:**
Compost-derived carbon interacts differently across soil horizons. In surface soils, fresh inputs primarily feed into POM pools and rapid microbial turnover, driving nutrient cycling and short-term carbon storage (Wong et al., 2023). Subsoils (below ~15 cm), by contrast, are defined by slower turnover, stronger mineral associations, and lower microbial activity (Button et al., 2022; Hicks Pries et al., 2023). When carbon reaches these depths—through deep roots, dissolved organic matter, or bioturbation is more likely to stabilize as MAOM, extending mean residence times. Deep-rooted perennial crops are especially important for facilitating this transfer into subsoils.
- **Microbial Processing and Carbon Use Efficiency (CUE):**
The fate of compost-derived carbon depends on microbial efficiency in converting inputs into biomass rather than respiring them as CO₂. High-quality compost with balanced C:N ratios and diverse substrates can increase CUE, leading to greater incorporation of carbon into stable pools (Dannehl et al., 2017). In this way, microbial processing determines whether added carbon contributes to storage or is quickly lost.

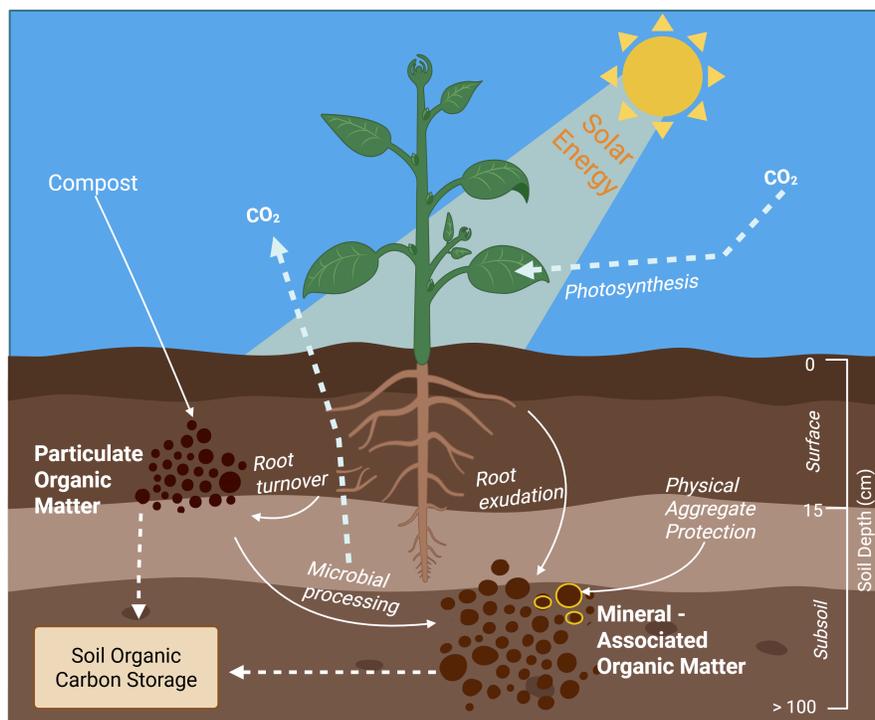


Figure 2. Compost inputs contribute to particulate organic matter (POM) and stimulate microbial processing, root turnover, and root exudation. These processes promote the formation of mineral-associated organic matter (MAOM) and aggregation, which physically and chemically protect carbon and enhance long-term soil organic carbon storage.

Compost-driven carbon gains are dynamic—subject to both accrual and loss—making sustained inputs and complementary practices essential for maintaining soil carbon stocks.

Factors such as soil texture, climate, and management history influence the rate of carbon stabilization, highlighting the need for site-specific strategies. Understanding these mechanisms is critical before linking compost use to carbon market claims, where permanence and verification are central requirements.

V. Carbon Sequestration and Market Opportunities

Soils play a significant role in the global carbon cycle, acting as both a source and a sink for atmospheric CO₂ (Smith, 2012). Agricultural soils, in particular, have been widely degraded through repeated tillage, bare fallow periods, and limited organic inputs (Peng et al., 2023). Compost application represents a promising avenue to reverse these trends by increasing the amount of stable SOC stored in the soil (Chen et al., 2024).

Carbon sequestration through compost is not uniform across landscapes. The rate and stability of SOC accumulation depend on several factors:

- Soil texture: Finer-textured soils with higher clay content can stabilize more carbon through mineral interactions (Li et al., 2022, 2024).
- Soil Microbiology: Microbial communities in soil significantly influence carbon cycling, including its processing, release, and retention (Tao et al., 2023).
- Climate: Warmer and wetter conditions can alter vegetation dynamics, stimulating microbial activity and accelerating decomposition. Without proper management, these shifts may offset potential gains in SOC (Bright et al., 2025).
- Depth of incorporation: Deeper incorporation or systems with perennial root inputs are more likely to support long-term carbon persistence (Fulton-Smith et al., 2024).
- Compost characteristics: High-quality composts with balanced C:N ratios, good maturity, and stable organic matter composition are more effective for SOC formation (Azis et al., 2023; Zhang et al., 2025).

Greenhouse Gas Emissions Tradeoffs

While compost can build soil carbon, it may also influence nitrous oxide (N₂O) emissions depending on nitrogen content, application timing, and soil type and aeration. This effect is most prominent within sandy soils (Zhu-Barker et al., 2015) Well-cured compost applied at agronomic rates is less likely to contribute to excess N₂O, especially when integrated with practices that promote nitrogen uptake and reduce denitrification risk (e.g., cover cropping, improved drainage). In annual rangeland systems, there was no significant increase in N₂O emissions after compost applications (Ryals et al., 2014).

Emerging Opportunities in Carbon Markets

As carbon markets expand, compost-amended systems are gaining attention for their role in carbon sequestration and avoided emissions. While scientific consensus and verification protocols are still developing, several frameworks now include compost as a practice that can generate credits:

- Soil carbon credits: Issued for documented increases in SOC levels via direct measurement or model-based estimation.
- Avoided emissions credits: Awarded for reductions in synthetic fertilizer use, methane avoidance from landfill diversion, or decreased N₂O emissions.

Tools like COMET-Farm and protocols under Verra, Climate Action Reserve (CAR), and emerging efforts by California's Natural and Working Lands Climate Smart Strategy aim to establish clear methods for measuring, verifying, and monetizing soil carbon gains. Yet, several challenges remain:

- High costs of verification and third-party auditing
- Long timelines required for SOC accumulation
- Permanence and reversibility concerns in dynamic agricultural systems

Producers considering participation in carbon markets should approach them as a complementary revenue stream rather than a primary incentive, and align compost use with whole-farm planning, soil health goals, and state or federal cost-share programs.

VI. Compost Use Guidelines: Rates, Quality, and Cost

Guidance Sources:

Compost application recommendations are best informed by established resources such as the California Department of Food and Agriculture (CDFA) and the Natural Resources Conservation Service (NRCS). Both agencies provide science-based guidance tailored to soil type, crop system, and regional climate. CDFA's Healthy Soils Program includes application templates and demonstration project data, while NRCS offers practice standards (e.g., Code 336: Soil Carbon Amendment) that align compost use with conservation planning frameworks. These resources can help growers optimize compost benefits while avoiding overapplication or nutrient imbalances.

- Rate: Application rates should be determined based on the cropping system (annual vs. perennial), soil texture, existing organic matter content, and specific production goals for the crops of interest. Heavier applications may be suitable for degraded or sandy soils, while lower rates may suffice for soils with moderate SOM and adequate structure.

- Rates should also consider compost nutrient content (particularly total N and available P) to avoid over-application. Regular soil testing and compost analysis are essential to adjust rates based on current conditions and crop needs.

Table 1: Proposed Agronomic Rates for Compost Application to Croplands. These application rates were put forth by an Environmental Farming Act Science Advisory Panel, CDFA convened a subcommittee of scientific experts to propose best-available scientific-based agronomic rates of compost application.

Crop Type	Compost Type	Moist Compost Application Rate (tons/acre)	Equivalent Dry Compost Application Rate (tons/acre)	% of Total Plant Required N Represented by Rate
<i>Annual</i>	Higher N (C:N ≤ 11)	3 – 5	2.2 – 3.6	7.3 – 12.1%
<i>Annual</i>	Lower N (C:N > 11)*	8	5.3	8.1%
<i>Perennial</i>	Higher N (C:N ≤ 11)	2 – 4	1.5 – 2.9	6.8 – 13.6%
<i>Perennial</i>	Lower N (C:N > 11)*	6 – 8	4.0 – 5.3	8.6 – 11.4%

*For N composts with a C:N ratio > 11, composts with C:N > 20–25 are likely to have negligible nitrogen release and may result in nitrogen immobilization. Monitoring plant and soil nitrogen status is recommended to ensure adequate crop N availability.

† Equivalent dry rates should be calculated using compost-specific moisture data

- **Compost Quality:** Compost quality can significantly influence both short- and long-term soil responses. Key indicators of quality include:
 - C:N between 10:1 and 20:1, depending on intended outcomes (higher ratios may immobilize N; lower ratios may release it quickly).
 - Stability and maturity, as measured by respiration rates or Solvita tests, ensuring material is fully composted and will not harm seedlings.
 - Contaminant screening for plastics, heavy metals, and pathogens—especially in composts sourced from green waste or municipal organics.
 - Moisture content and bulk density, which affect ease of handling, spreading, and nutrient concentration. Well-cured, pathogen-free compost is essential for food safety and soil stability.
- **Cost Factors:** Compost adoption is often limited by logistical and economic constraints. Important cost drivers include:

- Source proximity: Transportation costs can exceed the price of the compost itself, especially in remote areas.
- On-farm equipment: The need for spreaders, loaders, and incorporation tools may be a barrier for small or diversified operations.
- Compost type and nutrient density: High-nutrient composts (e.g., manure-based) may reduce the volume needed but can be more expensive per ton.
- Labor and timing: Labor availability during critical field windows (pre-planting or post-harvest) can influence whether compost is applied consistently.

Incentive programs (e.g., CDFA Healthy Soils, EQIP) can reduce these costs and improve the economic feasibility of compost use. Proximity to compost facilities and availability of on-farm infrastructure influence feasibility.

VII. Best Management Practices for Compost Use

Successful compost use requires more than just application—it must be integrated into the timing, method, and overall nutrient management of the system. Site-specific conditions, including crop type, soil texture, water availability, and labor logistics, should guide implementation.

- Timing: The timing of compost application is essential to maximize nutrient availability, support microbial activity, and synchronize with crop development stages. Compost should be applied in a way that aligns with both the seasonal nutrient demands of the crop and the climate-driven decomposition window.
 - Fall applications are advantageous in many systems, particularly where winter cover crops or early spring plantings are planned. Applying compost in the fall allows for partial decomposition and mineralization of nutrients—especially nitrogen and phosphorus—during cooler months, leading to improved soil tilth and fertility by spring. Fall applications also support microbial activity over winter, particularly in regions with mild winters and adequate moisture.
 - Spring applications can help stimulate early crop growth and are commonly used in annual vegetable systems. However, spring-applied compost must be well-cured and stable to avoid phytotoxic effects (e.g., ammonia toxicity or oxygen depletion) in germinating seedlings or shallow-rooted crops. Spring applications may be less effective in very dry regions unless followed by irrigation or light rainfall.

- Timing should also be guided by rainfall patterns and soil moisture conditions. Avoid applying compost immediately prior to heavy rainfall to prevent runoff and nutrient loss. Conversely, in arid or Mediterranean climates, compost applied during the early rainy season can leverage natural moisture to enhance microbial activation and nutrient integration.
- In perennial systems, compost is often applied post-harvest (fall) or in early spring before bud break, when trees begin active nutrient uptake. Aligning compost timing with crop phenological stages ensures that nutrients are available when plants need them most.
- Ultimately, compost use should be strategically timed to crop cycles, rainfall patterns, and soil biological rhythms, maximizing both immediate benefits and long-term soil health outcomes.
- Method: Compost can be applied as a surface mulch or incorporated into the soil. In perennial systems, surface mulching is common and minimizes disturbance, whereas in annual systems, incorporation may promote nutrient integration. Reduced-till or no-till systems may utilize banded or localized compost delivery to avoid soil disruption.
 - For crops that are harvested off of the orchard floor (e.g., almonds, walnuts), surface-applied compost must have particle size small enough not to interfere with mechanical harvesting techniques and machinery. Incorporation in these cases may be preferable.
- Frequency: Compost application frequency should be determined by a combination of soil health goals, baseline soil conditions, and cropping system intensity. Depending on these factors, compost may be applied annually, biannually, or on a rotational basis as part of a broader soil health strategy.
 - In intensively managed annual systems with frequent tillage and low organic matter, annual applications are often necessary to replenish lost carbon, support microbial activity, and maintain nutrient cycling. These systems tend to show the most immediate response to compost use, especially when paired with cover crops or reduced tillage.
 - In perennial or less disturbed systems, compost may be applied every two to three years once soil organic matter and structure have improved. In these systems, compost serves more as a maintenance input, sustaining microbial function, nutrient buffering, and soil moisture capacity over time.
 - In degraded or newly transitioned soils, a multi-year sequence of higher-frequency applications may be appropriate during the initial rebuilding phase. Once key soil health indicators improve—such as microbial biomass,

aggregate stability, or cation exchange capacity—application frequency can be reduced and tailored to ongoing needs.

- Compost frequency is most effective when coordinated with cover crop cycles or seasonal rainfall patterns, allowing for better integration of organic matter and improved nutrient capture.

Long-term soil health gains are best observed when compost is part of a consistent, integrated approach, rather than a one-time input. Building soil function through repeated organic amendments supports cumulative improvements in carbon storage, nutrient efficiency, and agroecosystem resilience.

VIII. Stacking Compost with Complementary Practices

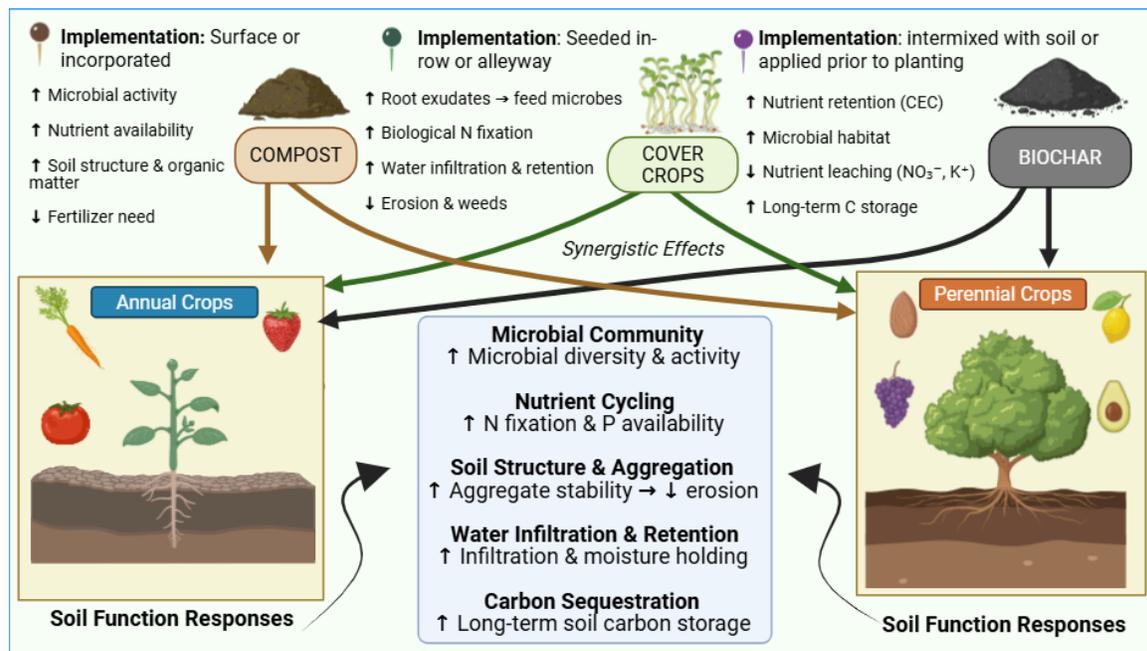


Figure 3. Figure representing the synergistic effects of complementary soil health practices of compost, cover crops and biochar into annual and perennial cropping systems. While they're different plant systems – the soil often responds similarly with improvements to soil's physical, chemical and biological components.

Compost is most effective when used in concert with other soil health practices. These synergistic approaches enhance soil biological activity, improve nutrient cycling, and build long-term resilience:

- **Cover Crops:** The inclusion of cover crops provides continuous root exudates that feed microbial communities, enhancing nitrogen fixation and mycorrhizal colonization. Leguminous species can contribute biologically available nitrogen,

reducing reliance on synthetic fertilizers. Additionally, cover crops protect the soil surface from erosion, suppress weeds, and improve water infiltration and retention (Adetunji et al., 2020; Rath et al., 2022).

- Biochar: When combined with compost, biochar enhances nutrient retention by increasing CE) and provides a stable habitat for soil microbes. It helps reduce leaching losses, especially of nitrate and potassium, and contributes to long-term carbon storage. The synergistic interaction between compost's labile carbon and biochar's porous structure supports robust microbial consortia (Cooper et al., 2020; Yin et al., 2022).

Additional soil health management practices:

- Reduced Tillage: Preserving aggregate stability and fungal networks is critical for maintaining the microbial benefits of compost. No-till and strip-till systems reduce disturbance, slow carbon turnover, and allow compost to remain in the biologically active zone longer (Islam and Reeder, 2014; Acir et al., 2022).
- Diversified Rotations and Perennials: Crops with varying rooting depths and residue quality promote functional diversity in microbial communities and improve the cycling of compost-derived nutrients. Including perennials increases belowground carbon inputs and reduces the frequency of compost reapplication due to more stable biomass contributions (Liebig et al., 2014).

These practices, when layered together, help close nutrient loops, minimize external inputs, and promote a more regenerative approach to soil and crop management. A systems-based strategy that incorporates compost, cover crops, biochar, and adaptive management tools can yield compounding benefits across biological, chemical, and physical dimensions of soil health.

IX. Policy Landscape and Incentives for Compost Adoption

California's leadership in climate-smart agriculture has led to the development of supportive policies and funding streams that incentivize compost use and broader soil health strategies. These programs aim to divert organic waste from landfills, reduce greenhouse gas emissions, and promote resilient food systems:

- CDFA Healthy Soils Program (HSP): Offers financial assistance to farmers for implementing conservation practices, including compost application (Practice Code 336). Through HSP, growers can access cost-share funding, technical guidance, and support in documenting greenhouse gas mitigation outcomes. The program is tailored by soil type, crop system, and climate region, making it a powerful tool for site-specific planning.

- USDA NRCS EQIP: The Environmental Quality Incentives Program (EQIP) provides technical and financial assistance for composting infrastructure and application. Practice standards, such as Nutrient Management (Code 590) and Soil Carbon Amendment (Code 808), align with compost adoption goals and can be stacked with other soil health practices.
- SB 1383: California Senate Bill 1383 mandates a 75% reduction in organic waste disposal from 2014 levels by 2025. This policy has expanded municipal compost production, creating new supply chains for agricultural use. It also mandates procurement targets for jurisdictions to support compost use on public lands, further stimulating demand.
- State and Regional Climate Strategies: Compost use is embedded in broader state initiatives, including the Natural and Working Lands Climate Smart Strategy, Scoping Plan, and Climate Resilience Framework. These policies identify compost as a key pathway for carbon sequestration and GHG mitigation.

Despite robust policy support, barriers remain in translating incentives into widespread adoption. Enhancing grower participation will require coordination between regulatory agencies, compost producers, and trusted agricultural networks.

X. Barriers to Adoption and Grower Considerations

Although compost delivers well-documented benefits, adoption across California agriculture remains uneven. Growers face practical, economic, and informational challenges that can limit implementation:

- **Cost and Access:** Compost purchase, transport, and application can be cost-prohibitive, particularly for small-scale or geographically isolated operations. In some cases, compost delivery costs exceed \$30/ton, even when material is subsidized.
- **Quality Variability:** Inconsistent feedstocks and processing methods lead to variability in compost nutrient content, moisture levels, maturity, and contaminant loads. Growers are often hesitant to invest in materials that may contain weed seeds, plastics, or insufficiently stabilized organic matter.
- **Infrastructure Gaps:** Many regions lack adequate composting facilities, transport networks, or spreading equipment. In cropping systems that rely on mechanized harvest or bed preparation, compost integration may require costly retrofitting.
- **Technical Guidance:** Decision-making around compost use—rate, timing, compatibility with crops—remains highly context-specific. Many producers report a

lack of trusted, site-specific information to guide use, particularly for perennial systems or newer crops.

- **Perceived Risk:** Compost is sometimes viewed as biologically unpredictable or incompatible with existing nutrient management plans. Concerns about food safety, pest attraction, or nitrate leaching may discourage adoption.

Addressing these challenges will require expanded extension capacity, improved compost labeling and quality assurance, investment in regional infrastructure, and co-design of strategies with growers. Where barriers persist, interim strategies—such as compost spot applications, use of finished compost in transplant mixes, or on-farm composting—can bridge the gap toward full system integration. Despite its benefits, compost adoption is not without challenges:

XI. Decision Support Tools and Modeling Frameworks:

To maximize the agronomic and environmental benefits of compost while ensuring informed decision-making, several tools and models are available to growers, agronomists, and land managers:

- **COMET-Planner and COMET-Farm:** Developed by USDA and Colorado State University, these tools allow users to estimate the greenhouse gas mitigation potential of adopting conservation practices such as compost application, cover cropping, and reduced tillage. COMET-Planner provides quick scenario-based estimates for practice-level changes, while COMET-Farm supports detailed, field-specific assessments of GHG emissions and carbon sequestration.
- **DAYCENT Model:** A process-based model that simulates daily fluxes of carbon and nitrogen in terrestrial ecosystems. DAYCENT is useful for understanding long-term soil carbon dynamics, N losses, and greenhouse gas emissions under different management scenarios. Researchers and policy analysts frequently use it to evaluate the effectiveness of compost and organic matter management strategies.
- **COMMONS Planner (Composted Organic Matter Management on National Soils):** This emerging tool integrates compost source characteristics, application rates, and soil properties to help guide compost use for optimal soil health outcomes and carbon benefits. COMMONS aims to support regional compost planning by incorporating climate and site-specific factors into application guidance.

These tools can be integrated into conservation planning, cost-benefit analyses, or grant applications. They are essential for quantifying environmental benefits, optimizing compost strategies, and aligning on-farm practices with state and federal climate-smart agriculture initiatives.

XII. Conclusion

Compost is more than a soil amendment—it is a strategic investment in the biological, chemical, and physical foundations of California's agricultural soils. By rebuilding soil organic matter, compost strengthens microbial networks, enhances nutrient cycling, improves water retention, and contributes to long-term carbon storage. These benefits translate into tangible outcomes: greater drought resilience, reduced dependence on synthetic inputs, and improved economic stability for producers.

While challenges remain—ranging from cost and quality variability to infrastructure and technical capacity—California's strong policy framework, emerging carbon market opportunities, and expanding decision-support tools provide a clear pathway for broader adoption. Integrating compost with complementary practices such as cover cropping, biochar, and reduced tillage amplifies these benefits and creates resilient, climate-smart production systems capable of withstanding both environmental and economic pressures.

The science is clear: compost use is a cornerstone of regenerative agriculture. Scaling its adoption across annual and perennial systems will not only restore degraded soils but also position California's agricultural sector as a global leader in climate mitigation, resource efficiency, and long-term food security. The opportunity now lies in translating knowledge into practice—empowering growers, advisors, and policymakers to make compost a central pillar of California's agricultural future.

XIII. Regional Examples and Case Studies

Case Study 1: Compost Effects on Strawberry Yield and Soil Health

A one-season field trial evaluated four commercial composts—cow manure, spent mushroom substrate, yard trimmings, and vermicompost—across five strawberry farms growing 'Albion' and 'Chandler' cultivars.

Study Design

Location: 5 farms in Northern California

Soil Types by Site:

- CV 1: San Joaquin silt loam
- CV 2: San Joaquin–Xerarents complex
- CC 1: Salinas clay loam
- CC 2: Watsonville loam
- CC-F: Baywood loamy sand

Compost Types: Cow manure, spent mushroom, yard trimmings, vermicompost

Application Rates:

- Manure, Mushroom, Yard Trimmings: 27.19 tons/acre
- Vermicompost: 4.53 tons/acre

Duration: 1 growing season

Key Findings

Soil EC: Manure (9.9 dS/m), Mushroom (7.3 dS/m)

Soil pH: Adjusted to optimal range for up to 7 months

Nitrate: Mushroom compost increased NO_3^- by 32 mg/kg

Microbial Activity: Highest in mushroom and vermicompost plots

Yield: Vermicompost consistently improved yield for both mid and late season.

Takeaway

Vermicompost, even at lower rates, enhanced microbial activity and yield. Compost effects were more evident under suboptimal growing conditions.

Citation: Bolda et al. (2016). *Int. J. Fruit Sci.*, <https://doi.org/10.1080/15538862.2016.1239562>

Case Study 2: Compost Enhances Soil Carbon in Vineyards Without Emissions Tradeoffs

A two-year field trial in a commercial vineyard in Paso Robles, California tested increasing rates of compost made from livestock manure and green waste on soil carbon, structure, GHG emissions, and yield.

Study Design

Location: Paso Robles AVA, California

Soil Type: Sandy loam

Compost Type: Livestock manure + green waste blend

Application Rates:

- Low: 1.82 tons/acre
- Mid: 3.64 tons/acre
- High: 5.46 tons/acre

Duration: 2 years

Key Findings

POXC: Increased from 93 to 156 mg C/kg soil

Aggregate Stability: Improved at mid-rate

N₂O and CO₂ Emissions: No significant differences among treatments

Grape Yield: Unaffected by compost rate

Takeaway

Compost improved soil carbon and structure without raising emissions, supporting its use in sustainable vineyard systems.

Citation: Peltz et al. (2023). *Front. Environ. Sci.*, <https://doi.org/10.3389/fenvs.2023.1123510>

Case Study 3: Compost Mulch Improves Soil Fertility in Almond Orchards

A two-year trial comparing composted green waste (GWC) and manure wood chip compost (MWC) in almond orchards with different soil textures. Compost was applied as a surface mulch to evaluate changes in nutrient dynamics, moisture retention, and soil chemical properties.

Study Design

Location: Two orchards in California's Central Valley

Soil Types: Loam and Sandy Loam

Compost Types: Green Waste Compost (GWC), Manure Wood Chip Compost (MWC)

Application Rates:

- Loam Site: 4.68 tons/acre
- Sandy Loam Site: 7.35 tons/acre

Duration: 2 years

Key Findings

Soil Moisture: Increased by 27–37% in the top 10 cm

Inorganic N: Short-term spikes of 194–277% post-application, returning to baseline

CEC: GWC increased CEC by 112% in loam soils; limited change in sandy loam

SOC: Soil organic carbon increased in both sites, with greater gains from GWC

Potassium: GWC led to higher extractable K in loam soils despite lower initial K content compared to MWC

Takeaway

Compost mulch enhanced water retention, nutrient availability, and soil function—especially in finer-textured soils like loam.

Citation: Villa, Y.B., Khalsa, S.D.S., Ryals, R. et al. (2021). Organic matter amendments improve soil fertility in almond orchards of contrasting soil texture. *Nutrient Cycling in Agroecosystems*, 120, 343-361. <https://doi.org/10.1007/s10705-021-10154-5>

Case Study 4 – Impacts of Organic Matter Amendments on Carbon and Nitrogen Dynamics in Grassland Soils

Study Design

Location: Two annual rangeland sites in California Marin County & Yuba County

Soil Types: Clay loam and sandy loam

Compost Type: Green waste compost

Application Rate: One time application of 1.3 cm surface layer (equivalent to 31.2 tons/acre), containing ~1.42 kg C/m² and 129 g total N/m²

Duration: On going.

Key Findings

SOC Significant increases in total SOC, particulate organic matter C (POM-C), and mineral-associated organic matter C (MAOM-C) at both sites, with relatively greater gains in sandy loam soils.

Nitrogen: Elevated total N and mineral-associated organic N, with plant-available N remaining higher over time.

Microbial Biomass: Compost increased microbial biomass C and N, indicating greater microbial activity and nutrient cycling capacity.

Forage Production: Aboveground biomass increased significantly, especially in drier years, suggesting improved drought resilience.

GHG Fluxes: No significant increases in cumulative N₂O or CH₄ emissions; CO₂ fluxes followed normal seasonal patterns.

Takeaway

A single 70 Mg/ha (31.2 ton/acre) application of green waste compost improved carbon storage, nutrient availability, microbial activity, and forage production in California annual rangelands, with benefits persisting for at least three years and without increasing net greenhouse gas emissions.

Citation: Choy, S., Ryals, R., Eviner, V.T. et al. (2022). Long-term effects of compost amendments on soil carbon and nitrogen dynamics in annual grasslands. *Ecosphere*, 13(1), e03888. <https://escholarship.org/uc/item/9b77j694>

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References

- Acir N, Günal H, Çelik İ, Barut ZB, Budak M, Kılıç Ş. 2022. Effects of long-term conventional and conservational tillage systems on biochemical soil health indicators in the Mediterranean region. *Arch Agron Soil Sci.* 68: 795-808. Taylor & Francis.
- Adetunji AT, Ncube B, Mulidzi R, Lewu FB. 2020. Management impact and benefit of cover crops on soil quality: A review. *Soil Tillage Res.* 204: 104717.
- A dugna G. 2016. A review on impact of compost on soil properties, water use and crop productivity.
- Amuah EEY, Fei-Baffoe B, Sackey LNA, Douth NB, Kazapoe RW. 2022. A review of the principles of composting: understanding the processes, methods, merits, and demerits. *Org Agric.* 12: 547-562.
- Anas M, Liao F, Verma KK, Sarwar MA, Mahmood A, Chen Z-L, Li Q, Zeng X-P, Liu Y, Li Y-R. 2020. Fate of nitrogen in agriculture and environment: agronomic, eco-physiological and molecular approaches to improve nitrogen use efficiency. *Biol Res.* 53: 47.
- Anthony TL, Stover HJ, James JJ, Silver WL. 2024. Impacts of Compost Amendment Type and Application Frequency on a Fire-Impacted Grassland Ecosystem. *Ecosystems.* 27: 848-863.
- Azis FA, Choo M, Suhaimi H, Abas PE. 2023. The Effect of Initial Carbon to Nitrogen Ratio on Kitchen Waste Composting Maturity. *Sustainability.* 15: 6191. Multidisciplinary Digital Publishing Institute.
- Balesdent J, Chenu C, Balabane M. 2000. Relationship of soil organic matter dynamics to physical protection and tillage. *Soil Tillage Res.* 53: 215-230.
- Basile-Doelsch I, Balesdent J, Pellerin S. 2020. Reviews and syntheses: The mechanisms underlying carbon storage in soil. *Biogeosciences.* 17: 5223-5242. Copernicus GmbH.
- Bijay-Singh, Craswell E. 2021. Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem. *SN Appl Sci.* 3: 518.
- Bogužas V, Skinulienė L, Butkevičienė LM, Steponavičienė V, Petrauskas E, Maršalkienė N. 2022. The Effect of Monoculture, Crop Rotation Combinations, and Continuous Bare Fallow on Soil CO₂ Emissions, Earthworms, and Productivity of Winter Rye after a 50-Year Period. *Plants.* 11: 431.
- Bohn S, Duan J. 2025. California's Economy. Public Policy Institute of California. Available online at <https://www.ppic.org/publication/californias-economy/> (accessed August 9, 2025).
- Bright K, Dienes B, Keiluweit M, Rixen C, Aeppli M. 2025. Climate change impacts on organic carbon cycling in European alpine soils. *Soil Biol Biochem.* 210: 109891.

- Button ES, Pett-Ridge J, Murphy DV, Kuzyakov Y, Chadwick DR, Jones DL. 2022. Deep-C storage: Biological, chemical and physical strategies to enhance carbon stocks in agricultural subsoils. *Soil Biol Biochem.* 170: 108697.
- Cavagnaro TR. 2014. Impacts of compost application on the formation and functioning of arbuscular mycorrhizas. *Soil Biol Biochem.* 78: 38-44.
- CDFA. 2024. California Agricultural Exports (2023 - 2024). In. California Department of Food and Agriculture.
- Chen S, Huang J, Guo R, Ma H, Guo J, Ling N, Xu Q, Wang M, Shen Q, Guo S. 2025. Soil net carbon balance depends on soil C: N: P stoichiometry. *Soil Tillage Res.* 245: 106298.
- Chen Z, Du Z, Zhang Z, Wang G, Li J. 2024. Dynamic changes in soil organic carbon induced by long-term compost application under a wheat-maize double cropping system in North China. *Sci Total Environ.* 913: 169407.
- Cloy JM, Ball BC, Shepherd TG. 2015. Evaluating land quality for carbon storage, greenhouse gas emissions and nutrient leaching. *Visual soil evaluation: realising potential crop production with minimum environmental impact.* pp. 103-121.
- Cooper J, Greenberg I, Ludwig B, Hippich L, Fischer D, Glaser B, Kaiser M. 2020. Effect of biochar and compost on soil properties and organic matter in aggregate size fractions under field conditions. *Agric Ecosyst Environ.* 295: 106882.
- Cotrufo MF, Ranalli MG, Haddix ML, Six J, Lugato E. 2019. Soil carbon storage informed by particulate and mineral-associated organic matter. *Nat Geosci.* 12: 989-994. Nature Publishing Group.
- Dannehl T, Leithold G, Brock C. 2017. The effect of C:N ratios on the fate of carbon from straw and green manure in soil. *Eur J Soil Sci.* 68: 988-998.
- Enebe MC, Ray RL, Griffin RW. 2025. Carbon sequestration and soil responses to soil amendments - A review. *J Hazard Mater Adv.* 18: 100714.
- Fenster TLD, Oikawa PY, Lundgren JG. 2021. Regenerative Almond Production Systems Improve Soil Health, Biodiversity, and Profit. *Front Sustain Food Syst.* 5.
- Field CB, Raupach MR. 2012. *The Global Carbon Cycle: Integrating Humans, Climate, and the Natural World.* Island Press.
- Flint LE, Flint AL, Mendoza J, Kalansky J, Ralph FM. 2018. Characterizing drought in California: new drought indices and scenario-testing in support of resource management. *Ecol Process.* 7: 1.
- Fulton-Smith S, Even R, Cotrufo MF. 2024. Depth impacts on the aggregate-mediated mechanisms of root carbon stabilization in soil: Trade-off between MAOM and POM pathways. *Geoderma.* 452: 117078.
- Hicks Pries CE, Ryals R, Zhu B, Min K, Cooper A, Goldsmith S, Pett-Ridge J, Torn M, Berhe AA. 2023. The Deep Soil Organic Carbon Response to Global Change. *Annu Rev Ecol Evol Syst.* 54: 375-401.

- Ho TTK, Tra VT, Le TH, Nguyen N-K-Q, Tran C-S, Nguyen P-T, Vo T-D-H, Thai V-N, Bui X-T. 2022. Compost to improve sustainable soil cultivation and crop productivity. *Case Stud Chem Environ Eng.* 6: 100211.
- Hodson AK, Sayre JM, Lyra MCCP, Rodrigues JLM. 2021. Influence of Recycled Waste Compost on Soil Food Webs, Nutrient Cycling and Tree Growth in a Young Almond Orchard. *Agronomy.* 11: 1745. Multidisciplinary Digital Publishing Institute.
- Islam R, Reeder R. 2014. No-till and conservation agriculture in the United States: An example from the David Brandt farm, Carroll, Ohio. *Int Soil Water Conserv Res.* 2: 97-107.
- Khadim MD, Wesal AB, Peezhand AW. 2024. Overview of the Impact of Compost on Bulk Density, Aggregate Consistency and Cation Exchange Capacity of Soils and its Consequential Effect on Crop Productivity. *Cogniz J Multidiscip Stud.* 4: 344-359.
- Kibblewhite MG, Ritz K, Swift MJ. 2008. Soil health in agricultural systems. *Philos Trans R Soc B Biol Sci.* 363: 685-701.
- Lawrence BT, Melgar JC. 2023. Annual compost amendments can replace synthetic fertilizer, improve soil moisture, and ensure tree performance during peach orchard establishment in a humid subtropical climate. *Front Plant Sci.* 14: 1172038.
- Leuthold SJ, Haddix ML, Lavallee J, Cotrufo MF. 2023. Physical fractionation techniques. In Goss M J, Oliver M (eds.), *Encyclopedia of Soils in the Environment (Second Edition)*. Oxford, Academic Press. pp. 68-80.
- Li Y, Xiong K, Liu Z, Li K, Luo D. 2022. Distribution and influencing factors of soil organic carbon in a typical karst catchment undergoing natural restoration. *CATENA.* 212: 106078.
- Li Y-Z, Bao X-L, Tang S-X, Xiao K-Q, Ge C-J, Xie H-T, He H-B, Mueller CW, Liang C. 2024. Toward soil carbon storage: The influence of parent material and vegetation on profile-scale microbial community structure and necromass accumulation. *Soil Biol Biochem.* 193: 109399.
- Liebig MA, Archer DW, Tanaka DL. 2014. Crop Diversity Effects on Near-Surface Soil Condition under Dryland Agriculture. *Appl Environ Soil Sci.* 2014: 703460.
- Navarro AF, Cegarra J, Roig A, Garcia D. 1993. Relationships between organic matter and carbon contents of organic wastes. *Bioresour Technol.* 44: 203-207.
- Pagliai M, Vignozzi N, Pellegrini S. 2004. Soil structure and the effect of management practices. *Soil Tillage Res.* 79: 131-143.
- Peng Q, Liu B, Hu Y, Wang A, Guo Q, Yin B, Cao Q, He L. 2023. The role of conventional tillage in agricultural soil erosion. *Agric Ecosyst Environ.* 348: 108407.
- Rath D, Bogie N, Deiss L, Parikh SJ, Wang D, Ying S, Tautges N, Berhe AA, Ghezzehei TA, Scow KM. 2022. Synergy between compost and cover crops in a Mediterranean row crop system leads to increased subsoil carbon storage. *SOIL.* 8: 59-83. Copernicus GmbH.

- Ryals R, Kaiser M, Torn MS, Berhe AA, Silver WL. 2014. Impacts of organic matter amendments on carbon and nitrogen dynamics in grassland soils. *Soil Biol Biochem.* 68: 52-61.
- Santos C, Fonseca J, Coutinho J, Trindade H, Jensen LS. 2021. Chemical properties of agro-waste compost affect greenhouse gas emission from soils through changed C and N mineralisation. *Biol Fertil Soils.* 57: 781-792.
- Senesi N, Loffredo E. 1999. *The Chemistry of Soil Organic Matter.* Soil Physical Chemistry, 2nd edn. CRC Press.
- Six J, Conant RT, Paul E, Paustian K. 2002. Stabilization Mechanisms of Soil Organic Matter: Implications for C-Saturation of Soils. *Plant Soil.* 241: 155-176.
- Smith P. 2012. Soils and climate change. *Curr Opin Environ Sustain.* 4: 539-544.
- Tao F, Huang Y, Hungate BA, Manzoni S, Frey SD, Schmidt MWI, Reichstein M, Carvalhais N, Ciais P, Jiang L, Lehmann J, Wang Y-P, Houlton BZ, Ahrens B, Mishra U, Hugelius G, Hocking TD, Lu X, Shi Z, Viatkin K, Vargas R, Yigini Y, Omuto C, Malik AA, Peralta G, Cuevas-Corona R, Di Paolo LE, Luotto I, Liao C, Liang Y-S, Saynes VS, Huang X, Luo Y. 2023. Microbial carbon use efficiency promotes global soil carbon storage. *Nature.* 618: 981-985. Nature Publishing Group.
- Vinhal-Freitas IC, Wangen DRB, Ferreira A de S, Corrêa GF, Wendling B. 2010. Microbial and enzymatic activity in soil after organic composting. *Rev Bras Ciênc Solo.* 34: 757-764. Sociedade Brasileira de Ciência do Solo.
- Visconti F, López R, Olego MÁ. 2024. The Health of Vineyard Soils: Towards a Sustainable Viticulture. *Horticulturæ.* 10: 154. Multidisciplinary Digital Publishing Institute.
- Vormstein S, Kaiser M, Piepho H-P, Ludwig B. 2020. Aggregate formation and organo-mineral association affect characteristics of soil organic matter across soil horizons and parent materials in temperate broadleaf forest. *Biogeochemistry.* 148: 169-189.
- Wang C, Kuzyakov Y. 2024. Mechanisms and implications of bacterial-fungal competition for soil resources. *ISME J.* 18: wræ073.
- Wang D, Lin JY, Sayre JM, Schmidt R, Fonte SJ, Rodrigues JLM, Scow KM. 2022. Compost amendment maintains soil structure and carbon storage by increasing available carbon and microbial biomass in agricultural soil - A six-year field study. *Geoderma.* 427: 116117.
- Weber J, Karczewska A, Drozd J, Licznar M, Licznar S, Jamroz E, Kocowicz A. 2007. Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts. *Soil Biol Biochem.* 39: 1294-1302.
- Wong CTF, Falcone M, Rich G, Stubler C, Malama B, Lazcano C, Decock C. 2023. Short-term effects of increasing compost application rates on soil C and greenhouse gas (N₂O and CO₂) emissions in a California central coast vineyard. *Front Environ Sci.* 11. Frontiers.

- Yin J, Zhao L, Xu X, Li D, Qiu H, Cao X. 2022. Evaluation of long-term carbon sequestration of biochar in soil with biogeochemical field model. *Sci Total Environ.* 822: 153576.
- Yoshimura C, Gessner MO, Tockner K, Furumai H. 2008. Chemical properties, microbial respiration, and decomposition of coarse and fine particulate organic matter. *J North Am Benthol Soc.* 27: 664-673. The University of Chicago Press.
- Zhang S, Chen X, Shi A, Xu M, Zhang F, Zhang L, Zang J, Xu X, Gao J. 2025. Effect of Compost Addition on Carbon Mineralization and Kinetic Characteristics in Three Typical Agricultural Soils. *Agronomy.* 15: 1559. Multidisciplinary Digital Publishing Institute.
- Zhu-Barker X, Doane TA, Horwath WR. 2015. Role of green waste compost in the production of N₂O from agricultural soils. *Soil Biol Biochem.* 83: 57-65.