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By

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Professor Timothy Bowles, Chair
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Abstract

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Those directly involved in land stewardship—farmers, ranchers, peasants, *campesinos*, Indigenous people—are increasingly called to the frontlines of multiple crises. They are tasked with feeding humanity, maintaining global biodiversity, and sustaining cultures amidst rising global temperatures, corporate hegemony, pandemics, and constant war. In California, farmers and land stewards are called upon to weather the interlocking crises facing the state's agricultural system: increased threat of wildfires, drought, floods, and public health crises. Agroecology is a mobilizing framework utilized by social movements around the world to increase community food sovereignty and create thriving food and agricultural systems. Movements for agroecology and food sovereignty in the United States, however, face severe constraints due to entrenched notions of individualism, private property, market-based solutions, neoliberalism, and the commodification of food and land.

This dissertation aims to illuminate how ecological, social, and cultural forces converge within the body of the soil by focusing on communities enacting forms of food sovereignty in California. By attending to the subterranean and the underground, I seek embodied relationships that realize agroecological transitions in the cracks of California's plantation-based agricultural landscape. How might soil act as a medium for collective memory and action in ways that realize agroecology in the United States? How are (dis)embodied or material relations with food and land entangled with culture, especially for land and capital-limited farmers striving for self-determination? And what personal, ecological, and collective thresholds must be crossed to realize just transitions in agroecology and food sovereignty across the US?

In particular, this dissertation traces connections between soil ecology and social practice among a diverse network of farms, mutual aid organizations, non-profits, and grassroots movements enacting forms of agroecology in California. This work emerges from years-long dialogue with land and capital-limited communities cultivating small (<10 acres) and marginal lands using a hand-scale no-till farming system. This system was developed by farmers and utilized by individuals from diverse racial, cultural, class, and geographic contexts. This dissertation integrates a wide range of methods including soil health measurements, field experiments, on-farm studies, interviews, and participant observation to document the impacts of farmer-developed practices on soil health and agroecological transitions. Overall, these efforts found that hand-scale no-till significantly improved soil moisture, reduced bulk density, raised carbon and nitrogen stocks, and increased nutrient cycling, with important social-ecological forces shaping how the system impacted farms across geographies and soil types. Additionally, this dissertation explores the integration of small-scale agriculture with anti-hunger efforts, demonstrating how principles of food sovereignty can be enacted through attending to personal relationships, self-determination, holistic nourishment, reciprocity, solidarity economies, and power dynamics. By weaving in my positionality and personal connections to California's agricultural history, this dissertation engages with the personal, ecological, and collective thresholds necessary to realize just transitions in agroecology and food sovereignty across the US.

For Mary Sheila Hayden Rainey. May the angels carry you now, and always.

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Acknowledgments

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Introduction

Soil as territory, soil as medium

Soil is a contested territory. Formed over hundreds or thousands of years through the biological and climatic weathering of rock, soil is a finite resource. Soil's capacity to provision food, fuel, and fiber makes it subject to exploitation and degradation. Socially, soil's competing uses, cultural and symbolic significance, and role in shaping social and economic relationships make it a medium for negotiating power. Because of its finite nature, soil is territorialized *viz-a-viz* land. Territorialization, in this context, describes the degree to which assemblages of social, cultural, political, and ecological forces delineate space and negotiate power, (re)shaping relationships to land and resources (1–3).

Soil is a medium where power is negotiated both materially and symbolically. Depending on context, soil can be viewed as an emergent living entity, a source of productivity, a natural resource, or private property to be bought and sold. A single individual can move between these modes of analysis over a day. These diverse claims to the soil are carried out through the everyday actions of people and complicate efforts to steward land, maintain culture, and support lifeways.

Thus, understanding changes in the soil entails understanding social relations. Primary among these is the relationship between those who labor on land (farmers, farmworkers, land stewards, peasants) and landscapes; between the living body called *soil* and the bodies of those who tend to it. Modes of agricultural labor are directly related to the health of the soil. Over the last four centuries, agricultural labor has been changed dramatically by the advent of agrochemicals, synthetic fertilizers, mechanization, and industrial food production. These have altered biogeochemical cycles and degraded soils globally. Such material changes have been produced by the expansion of colonialism, chattel slavery, industrialization, globalization, and urbanization in a global campaign of genocide and ecocide. The extraction from human bodies and soils come hand in hand.

There is a profound connection between the soil and those who labor to cultivate it. In the United States, this connection is marked by systems of oppression and violence. During colonization settlers arrived at the biodiverse plains, forests, and grasslands that sustained Indigenous food systems and began a systematic campaign of death to eliminate Indigenous sovereignty (4–8). This included an assault on Indigenous forms of land stewardship, which were rooted in cyclical, intergenerational, and reciprocal relationships. Settler agriculture instead patterned the landscape with monoculture. The forced labor of enslaved Africans was used to develop plantation agricultural systems (9). Across the globe, colonial and capitalist plantation systems are still carved into the Earth, having destroyed ecosystems, cultures, and languages while fomenting social crises (9). Industrial, mechanized, and chemical-based farming practices that maintain uniform fields have been used as tools of empire, weaponizing cheap food and exporting technologies that lock farmers into dependency on transnational agribusiness corporations (10,11).

Yet underneath this narrative of exploitation and loss is a rich legacy of resistance, emergence, struggle, and defense of life. Despite ongoing agrochemical use, vast monoculture, and heavy tillage, soils underpin and sustain life everywhere. Similarly, peasants, Indigenous agriculturalists, small-scale farmers, food sovereignty activists, and community organizers hold out on front lines against corporate agribusiness and exploitative economic systems. Human hands and more-than-human beings are in constant collaboration to keep us nourished daily. Through their brilliance, determination, and life-honoring practice, land-based peoples take up the mantle of regeneration around the world. Small farmers grow between 53-80% of the world's calories (12). Indigenous and peasant communities steward 80% of the globe's biodiversity (13,14). Restored ecosystems, forests, and soils are increasingly looked to for climate mitigation and adaptation. Land stewardship plays a fundamental role in the liberation and sovereignty of peoples, cultures, traditions, and nations, particularly in communities facing state violence, extraction, and genocide. Amidst a global culture obsessed with apocalypse, crisis, and the "Anthropocene", it is critical to remember that global systems of exploitation and ecocide are everywhere challenged by deep, reciprocal, and nourishing relationships between human beings and the Earth. To better understand how such relationships govern ecological, social, and cultural conditions must become a central focus of agroecology.

This dissertation aims to illuminate how ecological, social, and cultural forces converge within the body of the soil by focusing on communities enacting food sovereignty in California. By attending to the subterranean and the underground, I seek embodied relationships that realize agroecological transitions in the cracks of California's plantation-based agricultural landscape. How might soil act as a medium for collective memory and action in ways that realize agroecology in the United States? And how are (dis)embodied or material relations with food and land entangled with culture, especially for land and capital-limited farmers? Despite its transdisciplinary aspirations, scholarship on agroecology in the US is often siloed into biophysical or natural sciences on the one hand, and socially-engaged research on the other (15–21). Important contributions have been made to bridge disciplines (22,23), but more work is needed. In particular, scholarship that centers marginalized farmers and land stewards (BIPOC, women, LGBTQ2S+, poor, landless people) or uplifts food sovereignty efforts in the US can be enriched by deeper connection to ecology and the more-than-human world (24–29). Class, race, and gender-based inequalities that structure academia and environmental sciences have limited the ability of marginalized communities to enact their place-based or ecological knowledge in ways that are legible to the academy. This lack of visibility or legibility can constitute an important form of *refusal*—efforts for self-determination must at times remain illegible, fugitive, and underground (30,31). To enact food sovereignty in the US, however, some moments call for unearthing the ecology, practice, and movement of those struggling for justice.

This dissertation will trace connections between soil ecology and social practice among a diverse network of farms, mutual aid organizations, non-profits, and grassroots movements enacting forms of agroecology in California. This work emerges from years-long dialogue with land and capital-limited communities cultivating small (<10 acres) and marginal lands, practicing forms of nourishment in the cracks of the industrial food system. This will take us from root-fungal associations to food hubs, from collard greens to encampments. It will also weave in my positionality, tracing my family's connection to California's agricultural history as well as the institutional politics of the academy I am writing within. Tracing these stories will allow us to engage another core question of this dissertation: what personal, ecological, and collective thresholds must be crossed to realize just transitions in agroecology and food sovereignty across the US? What is already growing in the cracks of the dominant system?

My use of the word *cracks* is inspired by the work of Yoruba writer and post-activist Bayo Akomolafe. He invites a direct engagement with the fractures in dominant systems, paradigms, and ways of living. He argues that we "don't design cracks, don't anticipate cracks. Cracks are not part of the furniture; they are the excessiveness of the frame… They are neither external to the frame nor internal. They are not 'solutions', not guarantees, not final answers. But something about 'them' marks deterritorializing tensions, and obliquely trace out new realities" (32). I invoke cracks as the sites of fracture where more liberatory, just, and ecological futures can take root. The individuals and initiatives that inspired this project emerge from the cracks—urban lots, marginal lands, warehouses, housing encampments, sites of food waste, and so on. Cracks are places where new territories can be formed through transformed relationships between soil, bodies, food, and landscapes.

Agroecology and food sovereignty in California

Agroecology is a powerful framework for understanding the ecological, social, and cultural forces that territorialize and transform soils. As a scientific discipline, agroecology emerged as a means of understanding ecologically-based and traditional agricultural systems, positioning ecological relationships as the key to developing vibrant and functional agroecosystems (33). Through its development, agroecology has become a transdisciplinary, participatory, and action-oriented framework for actualizing transitions in the whole food system that address current ecological and social crises (34). Encompassing a science, a practice, and a social movement, agroecology works to transition agricultural systems to become more ecologically sound, environmentally just, and socially responsible (35). Agroecological methods employ principles that are implemented in unique social, political, and ecological contexts (36). A commitment to principles, not prescriptive practices, makes agroecology a holistic and dynamic approach poised to address the complex challenges facing food systems. Broadly, agroecology uplifts and builds upon Indigenous, traditional, and local agricultural systems, integrating diverse knowledge systems (37). Because of an emphasis on reducing external inputs and recycling resources, agroecology is positioned as an effective agricultural methodology for poor and resource-limited farmers working on marginal lands (38).

Agroecology is often understood as a critical framework for achieving food sovereignty. Food sovereignty has emerged as an international movement and mobilizing principle to return agency and self-sufficiency to communities by "putting those who produce, distribute, and consume food at the heart of food systems and policies rather than the demands of corporations" (39). While the precise meaning, scope, and enactment of food sovereignty remains contested (40), it has emerged as a "strategy to resist and dismantle the current corporate trade and food regime" by creating agency over "lands, territories, waters, seeds, livestock, and biodiversity" and forging "new social relations free of oppression and inequality between men and women, peoples, racial groups, social classes, and generations" (Declaration of Nyeleni, 2007). This movement has implications for California's plantation-based food system—a major agricultural producer designed for corporate agri-business, large-scale water projects, and labor exploitation.

Significant constraints, however, are placed on agroecology and food sovereignty movements in California and the US. Since colonization, California has always been a bastion of exploitative and plantation-based agriculture. The California missions marked the beginning of this trend, with the missions carrying out plantation-style agriculture and enslaving Native Californians to perform the labor (41,42). The mission system gave way to the *rancho* system, where the Spanish and Mexican governments offered large land grants to encourage settlement and European-style agriculture (43,44). A significant confluence of events in the 1840s and 1850s led to the rapid transition of land to American settlers: the end of the Mexican-American war, the annexation of California by the US, the Gold Rush, and genocidal policies encouraging the killing of Native Californians (45). The rapid, structural changes in California's agricultural landscape during the second half of the 19th century tell a story of venture capitalism, technological advancement, land theft, and pioneer vigilantism (46) The colonial division of California's landscape made way for the modern industrial agricultural system in California today. Institutional and cultural commitments to individualism, private property, market-based solutions, neoliberalism, and the commodification of food and land antagonize the US food sovereignty movement. Calls for food sovereignty are broadly understood as being dependent on a close relationship between communities and the landscapes they are embedded within, which constitute territories where land-based culture and lifeways can be realized (3,47,48). Across the US, these forms of relationship and territorialization have been decimated by colonization, genocide, corporate hegemony, and a repressive state regime (4,5,9–11,41,49–52).

Yet those directly involved in land stewardship—farmers, ranchers, peasants, *campesinos*, Indigenous people—are increasingly called to the frontlines of multiple crises simultaneously. They are tasked with feeding communities and maintaining global biodiversity amidst rising global temperatures, extreme weather events, pandemics, and constant war. In California, farmers and land stewards are called upon to weather the interlocking crises facing the state's agricultural system. Increased threat of wildfires, drought, floods, and public health crises like COVID-19 are exacerbating challenges for California farmers and farmworkers (53–56). While the state remains a major agricultural producer, its industrial food empire is compromised by decreasing water resources, soil erosion, labor exploitation, and broken supply chains (57–61).

These contemporary challenges, and their historical roots, form the context for my own family history. My family has deep roots in the creation of the settler fantasy of California as a "land of opportunity." I now turn to this history, employing the praxis of reflexivity in research. In examining my family's connections to California's settler colonialism, I seek to better understand the structures and legacies of colonization and how research can be leveraged to undo the harms of contemporary agricultural systems.

A painful legacy: California agriculture from the perspective of my ancestors

I come from a long lineage of settler colonizers here in the so-called United States. The vast majority of my ancestral lines trace back almost 400 years in North America, beginning in Plymouth, Massachusetts, New York, New York, and parts of Virginia. My ancestors belonged to religious groups such as the Brownists and Puritans, who sought freedom, land, and self-determination. In actuality, they brought disease, dispossession, and a genocidal campaign against Indigenous life.

Reflexivity is a concept in feminist scholarship that emphasizes ongoing self-examination and self-awareness of own's background, experiences, and biases in the production of knowledge. This requires authors to locate themselves within the subject they are working on, explicitly recognizing how their identity and social position influence their perspectives and interactions with their research topics. This approach is rooted in the belief that all knowledge is situated, or constructed through the always partial, embodied, and social experience of the knower. "Feminist objectivity," Donna Haraway writes, "is about limited location and situated knowledge, not about transcendence and splitting of subject and object. It allows us to become answerable for what we learn how to see" (62). For Haraway, subject and object compose a dialectic that if engaged can create more meaningful accountability in the production of knowledge. She goes on to argue that "situated knowledges require that the object of knowledge be pictured as an actor and agent, not as a screen or a ground or a resource," and rejects the "master that closes off the dialectic in his unique agency and his authorship of 'objective' knowledge" (62). Sandra Harding further elaborates on this in *The Feminist Standpoint Theory Reader*, where she discusses how the standpoint of the knower affects what is known and the process of knowing itself. Critically, "standpoint theory" suggests that oppressed or marginalized communities have unique contributions to make to the production of knowledge and that all inquiry must speak from a "particular, historically specific, social location" (63). These theoretical interventions invite a deeper entanglement between the author or scholar and their supposed subject. This practice not only enhances the integrity of research, but also aligns with a feminist commitment to justice, ethical knowledge production, and accountability.

In this vein, I am interested in tracing my family's settler roots in California as a way of positioning myself within the study of agriculture in California. Inspired by feminist scholarship, I strive to take a "soil core" of my own lineage. Before attempting to excavate or extract meaning from other landscapes, peoples, and cultures, I must ask myself: what medium have I grown in, and how does it shape the way I make sense of the world? Understanding my family's role in the settler colonial history of California is not just a personal endeavor; it is an essential part of critically examining the structures and systems that uphold exploitation in agriculture and food systems today. By scrutinizing my own lineage, I aim to reveal complicities and privileges that have been historically obscured, thus contributing to a larger discourse of accountability and justice. This process of self-examination is an act of bearing witness to the injustices perpetrated by my ancestors and considering what it means to engage ethically in contemporary movements for agroecology and food sovereignty.

I am a 4th generation Californian on both sides of my family. My great-great grandparents immigrated to California from other parts of the United States in the mid- to late-1800's. They came from North Dakota, Ohio, Idaho, and Kentucky. My great-great-grandfather, Harleigh Johnston, moved to Santa Barbara, California from Massachusetts in 1883 and purchased a property called the San Ysidro Ranch. This property had been part of the original parcel comprising the Santa Barbara Mission (64). Spanish colonization brought lemons and oranges to the region during the mission period, but the first commercial lemon orchard was planted in 1875. Harleigh Johnston's lemon packing company, which began by cultivating lemons at the San Ysidro Ranch, represents one of the first commercial lemon growing operations in the state.

A poem by Tongva writer Megan Dorame evokes the twisted history that the introduction of citrus represents to the Indigenous peoples of Southern California:

> When the sickness came,
> it scudded over the old mission grounds, infecting,
> snake-like and silent.
> The survivors, the ones we descended from,
> were few.
> The survivors, the ones we descended from,
> were made to dig a great hole.
> Into the hole went the ones
> who were not as lucky.
> The hole filled fast,
> and when it did, the padres,
> they wanted to forget.
> To forget,
> a grove of orange trees was planted.
> A grove of orange trees was planted
> over a mass grave.
> The history books say
> these were not your run-of-the-mill oranges,
> they were the sweet ones.
> I want to know if,
> on cold winter mornings, when the trees blossomed,
> was there scent saccarine or stinking?
> And when the trees bore fruit,
> I wonder,
> was it boiled down, and mixed with sugar
> for marmalade? Did the padres spread it over bread?
> And did they lick their lips after they bit into their breakfast?
> What I really want to know is
> if trees grew fruitfully,
> fed by flesh,
> or was their growth stunted
> by the decomposition of a people? (6)

Loss and remembrance are embedded in the soil and across landscapes. As much as the padres tried to forget, as much as my ancestors tried to forget, the grief and violence of colonization is contained in the land, in the soil, and in the bodies of oppressed peoples. The grape and citrus plantations that still mark the lands of the Chumash people are patterned by this same violence. This is soil memory.

Soil memory has emerged in modern soil science to understand how the biological and historical conditions of soil formation are materially retained in "the solid phase of the soil body" (65). Assemblages of microorganisms, the presence of soil-borne viruses and plant diseases, organo-mineral associations, biofilms, and soil pore structure are just some of the conditions that have demonstrated forms of material "memory" (66–68). These forms of biophysical memory support cultural forms of memory that are contained in landscapes through soil; ancestral remains, ancient gathering places, or sites of violence. Soil is the rich, teeming body of the Earth and retains the imprint of these happenings—both literally and symbolically.

A look at some of the visual propaganda created by my family offers a deeper perspective on how genocide, remembrance, and cultural amnesia intersect in the cultural construction of landscapes. The Johnston Fruit Company produced ornate labels that were fixed to crates of lemons and shipped around the country. One label shows an image of the Santa Barbara Mission, glorifying and romanticizing the mission history of the region (Figure 1). White lemon blossoms and a neatly wrapped lemon adorn the white walls and manicured landscape of the mission's church building. The use of this imagery reveals how my ancestors participated directly in the suppression of genocidal histories and the normalization of plantation-based agricultural and social systems. My family's orchards were rooted in the "decomposition" of the Chumash people.

Another label produced by the Johnston Fruit Company further exemplifies the creation of the myth of California as a "cornucopia" and "land of plenty." In this label, three white settlers look out upon a manicured agricultural landscape from a wagon of red flowers. The landscape is pristine and plantationed; offered as a fantasy place for white bodies to come and find plentitude. The outfits worn by these individuals express opulence and wealth. Their smiles are sanguine and easy as they sit in the Southern California sun. This is the "land of plenty"—fetishizing the experience of white bodies as they sought wealth and prosperity in a manufactured landscape of plantation, extraction, and domination. This was the image that my great-great-grandfather placed on crates of lemons and shipped around the country, from San Francisco to New York City. My family's story exemplifies how California's agriculture system came into being.

The other side of my family settled in Riverside, California around the same time period. My great-great grandparents moved to this part of Southern California from Ohio, and established a general store named Backstrand and Grout. Most important to our analysis here, however, is my great-grandfather David S. Bell. David Bell was born in North Dakota and moved to California at the age of seven. Early in his life, David involved himself in citrus growing in the region, quickly growing to prominence in Riverside as a well-connected and distinguished man—so much so that he was the subject of several publications in trade magazines like the *California Citrograph* (69). By 1910, David was running the L.V.W. Brown Estate, a large orange-growing operation and packing house. David was part of many civil society groups, including the Riverside Chamber of Commerce, Tri-County Water Conservation Association, Tri-County Reforestation Committee, Riverside-Arlington Heights Fruit Exchange, Riverside Highlands Water Company, and La Sierra Water Company. David was a trustee of the Calvary Presbyterian Church and a member of the Kiwanis, Elks, and Victoria Clubs (70). He collaborated with the UC Cooperative Extension, local citrus experiment station, and the USDA office in Riverside, even hosting agricultural experiments in his orchards. According to scholar Anthea M. Hartig (who wrote about my great-grandfather and men like him) by "filling offices of local, regional, statewide, and even federal fraternal and governmental bodies, the influential classes were better able to shape southern California into a reflection of their own economic interests" (70). My great-grandfather's institutional affiliations call into question my own affiliations, my embeddedness within institutions of power, and my attempts to enact influence through partnerships with organizations across California.

A.D. Shamel was a photographer and scholar who wrote a story about my great-grandfather, creating a photo series about his home and orchards. One photograph shows my grandfather surveying his private gardens and estate, with the once-abundant waters of the Santa Ana River in the background (Figure 3). Shamel conducted an in-depth interview with David S. Bell. In one passage, my great-grandfather speaks about his ethic regarding tillage and soil:

> While different soils require different cultural practices, we have generally reduced the amount of our cultivation, that is, we do not work the ground at regular intervals and are cultivating only when weed growth is interfering with the soil moisture conditions, and in order to mix fertilizers with the soils, or, for some other definite reason that makes it seem necessary to do so. (69)

Reducing cultivation, or minimizing soil disturbance, is one of the primary focuses of my dissertation. Over 100 years ago, my great-grandfather was talking about the same practices and stewardship ethics that I am today. These parallels are strange and unsettling. How can I valorize my own efforts with this history at my roots? Hartig, the scholar who wrote of my great-grandfather and other men of his time, explained the aesthetic fabulation of citrus industry men in Southern California, quoting Marx:

> Pioneers in the field of advertising, the industry's leaders … carefully crafted a demand for citrus fruits and shaped the citrus belt as a prime tourist attraction. The industry's leaders relied heavily on photographic images, stereocards, stills, and moving pictures, as well as artistic renderings, such as advertisements and packing labels, to promote consumption, tourism, and investment. The entire landscape thus became an advertisement for the industry. Scholarly interpretation of photographs can open up for the historian windows into the Marxian paradigm of ruling-class duplication in their own reality. Karl Marx wrote that man "duplicates himself not only, as in consciousness, intellectually but also actively, in reality, and therefore he contemplates himself in a world he has created. (70)

Do I not also contemplate myself in a world I have created? Have I participated in a form of prefigurative politics that simply recreate material realities to affirm my own belief systems? Am I caught in a dubious tautology of self-aggrandizement, just as my great-grandfather before me? Am I re-creating the plantation, even in subtler or stranger ways?

These questions are complicated by another part of my family's history in Riverside. In Riverside there is a school called the Sherman Indian High School, a boarding school attended by Indigenous youth from across the country. The high school, however, was once called the Sherman Institute. The Sherman Institute was part of a network of Native American boarding schools in the United States designed to assimilate Native youth into white settler society. In a terrible act of cultural genocide, institutions like the Sherman Institute aimed to strip Native youth of their language and culture. They were "aimed at transforming Indian pupils to think, behave, work, and look less like Native people, and more like white Protestant Americans" (71).

In an interview with my grandmother, Elizabeth Westfall Bell, she speaks on my family's connection to the Sherman Institute. "Well, I was raised by Indians … Hopi," she said. "My grandmother was a very good friend of a woman that ran the Sherman Institute … She had to do with the girls at the Sherman Institute. Her name was Mrs. Long … But anyway, she got us Hopi Indians, but they were little girls really. They were just graduates from high school" (72). And indeed—records show that Fred and Etta Long did run the "outing" program at the Sherman Institute in the first part of the 20th century (73). The accolades and notable positions held by my great-grandfather were built on the backs of Indigenous labor. The outing program was effectively run as a labor agency—pairing Indigenous youth with employment working for white families. Women were offered domestic labor, while the men did primarily agricultural labor. They were paid for their labor but at rates far below that of other laborers of the time (73). Under the guise of vocational training, this system subjected hundreds of Indigenous youth to "menial labor and limited expectations" while providing the Sherman Institute with needed funding to continue their operations (73).

Thousands of Indigenous youth from across the country were sent to Sherman Institute and shuttled through this "outing" program. Indigenous bodies were coerced (or worse) into performing forms of whiteness, then marshaled as labor for the creation of settler homes, families, and industries. My family's wealth was not only built *on* stolen Cahuilla, Tongva, Payomkawichum/Luiseño, and Yuhaaviatam lands—it was built *by* stolen bodies. This brings the connection between exploitation of land, or soil, and exploitation of human bodies, into sharp relief. My ancestors participated directly in acts of cultural genocide. What forms of cultural genocide am I complicit in today? How is my life built *on* stolen land and *by* stolen bodies? What forms of atonement, reconciliation, and reparations are demanded when I confront these questions?

Importantly, both Indigenous and non-Indigenous scholars have worked to trouble and complicate a flattening narrative of exploitation in the context of Native American boarding schools—and the Sherman Institute specifically. Clifford E. Trafzer (white), Jean A. Keller (white), and Lorene Sisquoc (Ft. Sill Apache-Cahuilla) have written about how Indigenous students "turned the power" at boarding schools designed to destroy their culture and identity as Native American people:

> Thus the very system that non-Indians had established to "Kill the Indian in him and save the man" provided Indian students with the experience and expertise to "turn the power." Students used the potentially negative experience to produce a positive result—the preservation of Indian identity, cultures, communities, languages, and peoples… (74)

"Turning the power," according to these scholars, is a Native American concept of sending "negative power back to its source," and using that power for one's positive ends. Hopi scholar Matthew Sakiestewa Gilbert builds on this analysis within the context of the Sherman Institute and Hopi students specifically. He writes how boarding school students "demonstrated the ability of Indian pupils to adapt, survive, and excel within a foreign and culturally hostile environment" (71). In his scholarship, Sakiestewa Gilbert traces how Hopi students practiced "their culture to succeed in music, agriculture, trade, sports, and language acquisition," thereby turning "the U.S. government's institution of assimilation into their own" and using "the education at Sherman Institute to contribute to their tribe and village communities" (71).

Black and Indigenous scholarship on fugitivity, Indigenous resurgence, and refusal offer insights into this subversive reading of history. In their work *the undercommons: fugitive planning and black study,* Fred

Moten and Stefano Harney draw on the Black radical tradition to explore how fugitive practice within systems of domination can subvert and unsettle those very systems. They write:

> In that undercommons of the university one can see that it is not a matter of teaching versus research … To enter this space is to inhabit the ruptural and enraptured disclosure of the commons that fugitive enlightenment enacts, the criminal, matricidal, queer, in the cistern, on the stroll of the stolen life, the life stolen by enlightenment and stolen back, where the commons give refuge, where the refuge gives commons. What the beyond of teaching is really about is not finishing oneself, not passing, not completing; it's about allowing subjectivity to be unlawfully overcome by others, a radical passion and passivity such that one becomes unfit for subjection, because one does not possess the kind of agency that can hold the regulatory forces of subjecthood… (75)

The erosion of the subject afforded by the undercommons creates a rupture inside systems and institutions of domination. A person becomes "unfit for subjection" precisely when they do not "possess the kind of agency" that comes with a sense of completion or wholeness. Rather, a queer, fugitive, criminal practice of creating refuge comes into focus. This refuge is held in common but is never complete or whole. To become unsubjectable is to find this subversive and underground commons.

At the Sherman Institute, "Hopis strategically learned to adopt components of the so-called white man's way to suit their agendas" on and off the reservation (71). Indigenous students "creatively adapted their tactics in the seemingly never-ending struggle to draw benefits from a colonial apparatus" (73). They engaged their dances, languages, cultural knowledge, creation stories, and community relationships to create new lifeways at the edges of Indigenous and settler society. Many intertribal movements such as the American Indian Movement were born in the multicultural undercommons of Native American boarding schools (76). The images found in the archives at the Sherman Institute complicate and trouble attempts to reconstruct this history (Figure 4). We see Native youth performing whiteness. We see Indigenous worlds contorted to look like white bodies. And yet, we are offered small glimpses from the archives of how these youth maintained fugitive forms of liberatory practice: a Navajo youth named Wilbert Douglaclesh was able to use money saved through the outing program to purchase sheep for his family, while two Hopi men Don Talayesva and Peter Shelton became sought-after laborers as they utilized Hopi agricultural knowledge on ranches across Southern California (73).

These forms of "turning the power" have much in common with Nishnaabeg scholar Leanne Betasamosake Simpson's concept of radical resurgence. In the face of world-ending, Simpson calls for Indigenous people to be grounded in their languages, cultures, lands, and cosmologies in ways that create the possibility of Indigenous futures (4). "I am absolutely sure," she writes of her own Nishnabeeg community, "that we as Nishnaabeg cannot survive as a people without creating generations of artists, thinkers, makers, and doers that live in Nishnaabeg worlds, that are in respectful relationship with each other, that create a movement that joins us to other Indigenous nations to protect the land and bodies" (4). It is from the land and liberated bodies of people that futures are born. Simpson is speaking to a soil of Indigenous futurity. The possibility of creating alternative lifeways in the cracks of a colonial apparatus is critical to liberatory movements. Simpson writes of the possibility of these movements, arguing:

> We don't need a list of demands because we are the demand. We are the alternative. We are the solution, based on our own nation-based conceptualizations of ourselves. Our bodies and the political orders they house are the demands. Our embodied alternative is the solution.

To embody something other than coloniality in the heart of the plantation is a political order. It is a nation. It is a whole world. My family's story, and the role they played in plantation-based agriculture, Native American boarding schools, and the violent myth of California, is fractured and cracked. It is in the cracks that resurgence and the undercommons emerge. Even in the depths of colonial dispossession and cultural genocide, Indigenous people practiced fugitive arts of survival and culture. They found ways to practice their languages, cultural knowledge, and lifeways.

And yet, so much evades the archive. My family's history is readily found in archival records. It is critical to ask: what evades the archive? Countless dances, languages, songs, prayers, arts, stories, and histories can never, and will never, be captured or recorded. That is part of what makes them *fugitive*. According to Saidiya Hartman in her foundational essay *Venus In Two Acts,* trying to speak truth that exceeds the archive is "predicated upon impossibility—listening for the unsaid, translating misconstrued words, and refashioning disfigured lives." (77) What's more, seeking what evades the archive is "intent on achieving an impossible goal: redressing the violence that produced numbers, ciphers, and fragments of discourse, which is as close as we come to a biography of the captive and the enslaved." (77) She asks the reader:

> How does one recuperate lives entangled with and impossible to differentiate from the terrible utterances that condemned them to death, the account books that identified them as units of value, the invoices that claimed them as property, and the banal chronicles that stripped them of human features? (77)

It is an odd form of privilege that my family's history is so easily read in the archive: the shipping labels, the articles, the photographs. I can reconstruct my family tree with relative ease. This strange and twisted form of privilege renders the archive a vehicle for atonement. These histories invite a deeper commitment to reparations, rematriation, and atonement for the specific harms caused by my ancestors. I can, and must, allow them to motivate concrete and ongoing acts of redistribution and repair. These stories compel me to speak out when forms of colonization and white supremacy manifest in my community today. Understanding where my roots are, or what parent material I come from, is essential to an enriched form of accountability. It allows for recognition that our healing is intergenerational, and our liberation is always entangled and incomplete.

However the promise of accountability cannot be separated, as Hartman notes, from "terrible utterances" of death and dehumanization. By visibilizing the archive, and highlighting the brilliant lifeways and lives that cannot be contained there, we leave open the possibility that something else could emerge from the cracks. In the plantation, the seeds of nourishment and fugitive practice are already lying dormant.

This task—of seeking what grows in the cracks of devastation and exploitation—is the terrain in which this dissertation takes root. Throughout this dissertation, we will seek stories from the margins, the cracks, of California's industrial agriculture and food system. We shall find how communities across California are practicing forms of land stewardship and collective action that actualize food sovereignty on small or marginal plots. Many are farmers with limited access to land or capital. And yet, they find modes of survival and regeneration. To do so, we will seek both social *and* ecological stories.

Unceded territory: Ohlone geographies, shellmounds, soil, and reckoning with desecration

When speaking on how forms of institutional violence and historic dispossession inform knowledge production, I must acknowledge the role of the University of California in the formation of this dissertation. The University of California is not a passive or neutral entity. Rather, the University of California is actively engaged in the ongoing dispossession and exploitation of communities, land, and people. Perhaps nowhere is this more visible than the continued hoarding of Indigenous remains and cultural artifacts in the Phoebe A. Hearst Museum of Anthropology. The Native American Graves Protection and Repatriation Act (NAGPRA) is federal legislation that was passed in the 1990's with the intent of recognizing tribal ownership of materials excavated with blatant disregard for Indigenous customs and permissions (78). The extraction of human remains and cultural artifacts was often used to promote racist pseudoscience, exemplified by the capture of a Yaha man, Ishi, who was put on display at the anthropology museum for years by Alfred Kroeber. And yet, the University of California, Berkeley has only returned 20% of the Indigenous ancestral remains and cultural artifacts held within the Hearst Museum (78,79). Thousands of ancestral remains continue to be stored in the Hearst Museum of Anthropology today. Some are stored within the campanile, the literal ivory tower that stands above UC Berkeley's campus. In this case, reality matches even our most horrific metaphors; the ivory tower is filled with the stolen bodies of Indigenous people.

One of the most potent symbols of theft and dispossession by the University of California can be found in the shellmounds. The shellmounds were, and continue to be, central to Indigenous life in the Bay Area. At one time over 425 shellmounds rung the entire Bay Area, located along the edge of the Bay where salt water met freshwater (80). According to Corrina Gould, spokesperson for the Confederated Villages of Lisjan and founder of Sogorea Te' Land Trust, "the shellmounds are the burial sites of my ancestors, and they're significant in that they are sacred places. There are places where our ancestors resided, and they also had ceremonial places there" (81) The shellmounds were formed over thousands of years, creating organic structures hundreds of meters across where people would live, pray, and perform burials. In recent times, the shellmound has been the site of a movement to return sacred sites to Indigenous peoples. Gould, her family, and their allies have led this struggle for 20 years:

> "[We] came up with this idea to walk the shellmounds. And so we took this old map from 1909 that had four hundred twenty five shellmounds and put together a walking route. And we started in Vallejo and we walked down to San Jose and up to San Francisco and it's three hundred miles and it took us three weeks to walk 18 miles a day and we stopped at all of these sacred places along the way. And what we found were bars and schools and railroad tracks and parking lots and apartment buildings of on top of all of our sacred places. But we stopped and we prayed at those places because we knew that no matter what was on top of it right now, the sacredness of that land was still there. Those were our touchstones. Those were our places. And we prayed there to remind our ancestors that we were still here so that they could remember us and to bring back that relationality again between us."

Years of prayer and action like this have brought the issue of the sacred site protection in the Bay Area to the forefront. In a stunning victory, in the spring of 2024 the West Berkeley Shellmound was returned to the Ohlone-led Sogorea Te' Lant Trust. The West Berkeley Shellmound is the oldest shellmound in the Bay Area. It continues to be of critical importance to the Ohlone community, as it was a vital center of ceremony, burial, and cultural life. In the late 1800's and early 1900's, the West Berkeley Shellmound was desecrated by settlers to pave the streets of the East Bay and fertilize farmer's fields. An archaeological report by UC Berkeley reports this information about the history:

> As is evident from newspaper reports of the time, the shellmound was attractive as a resource for road-building and agricultural soil enhancement. Shellmound material was used extensively for road building because it became nearly impenetrable after soaking. Horse teams were routinely used to cart away large portions of the shellmound, which were then laid down along the major streets in West Berkeley, including San Pablo and University Avenues. The Emeryville Shellmound, to the south in present-day Emeryville, saw a similar pattern of wholesale destruction. In addition, because of the rich calcium, phosphorus, and humus content of the shellmound material, which included large quantities of sea shells, animal bones, human remains, and charred plant matter, it was routinely spread over agricultural fields to fertilize crops and enrich the soil. Indeed, this practice continued until well into the 1940s. (82)

This desecration was also perpetuated by University of California researchers. Many of the thousands of remains held in the Hearst Anthropology Museum were excavated during studies of the Bay Area shellmounds (80).

These acts of extraction and systemic violence are part of how the University of California manufactures consent and reproduces members of the ruling class (83). Especially in regards to land, UC Berkeley has antagonized and attacked community-led efforts to reclaim forms of collective power at the so-called public university. People's Park, a long-time site of mutual aid, street life, community uplift, and alternative lifeways, was also the site of intense police repression and state violence by UCPD and other police agencies (84,85). While the university loves to claim the "Free Speech" brand today, the university has always cracked down on waves of student protest over the years, from the Free Speech Movement (86), to the anti-apartheid movement in solidarity with South Africa (87), to the movement for Palestinian liberation today. UC Berkeley is heavily invested in Israeli apartheid and other forms of the military-industrial complex. In regards to food and agriculture, Berkeley has systematically divested from agroecological programs that once generated important research (88), instead favoring biotechnology, corporate interests, and patentable technologies that bring in revenue (89,90).

It is in this context that other *undercommons* take root. I write this from the student encampment at UC Berkeley for the liberation of Palestine, a powerful embodiment of the revolutionary and fugitive practice of students across the world standing against the genocide of the Palestinian people. The West Berkeley Shellmound was returned to Indigenous stewardship. The Gill Tract (a 10-acre site owned by the UC Regents just north of UC Berkeley) was saved from development through an occupation in 2012; the land remains in control of the community today (91). People's Park, although fenced off behind a wall of shipping containers and all the security that $7.8 million can buy, calls out with a revolutionary vision from the cracks, "May 1,000 Parks Bloom!" (92) All kinds of fugitive and liberatory practices have germinated across UC Berkeley's campus during its history. They continue to take root.

Land, food, and the body

To be in dialogue with movements for agroecology and food sovereignty in California, some key theoretical interventions are needed—namely holistic definitions of *land*, *food*, and the *body*. All three of these terms articulate modes of being essential to engaging with agroecology and food sovereignty in the US context. To explicate these ideas more fully, I look to feminist, Indigenous, Black, and decolonial scholarship.

The word *land* and its layered meanings are critical to understanding how farmers and organizers understand their efforts for food sovereignty. *Kanien'kehá:ka* scholar Sandra Styres offers an Indigenous perspective of "land" in her piece "Literacies of Land," expressing that:

> Land expresses a duality that refers not only to place as a physical geographic space but also to the underlying conceptual principles, philosophies, and ontologies of that space. This duality is not to be construed as dichotomous, oppositional, or binarial but rather expresses the ways Land embodies two simultaneously interconnected and interdependent conceptualizations…Land is more than the diaphanousness of inhabited memories; Land is spiritual, emotional, and relational; Land is experiential, (re)membered, and storied; Land is consciousness—Land is sentient.

Land stewardship invites us into the dialectic between the material or ecological on one side, and the "spiritual, emotional, and relational" on the other. These aspects are not binary or opposites but mutually co-constructed. By engaging deeply with landscapes, and being invited to express and explore one's own agency within that both physical and cognitive space, new knowledges and ways of being can emerge. In her piece "Land Speaking," Okanagan writer Jeannette C. Armstrong emphasizes the epistemological connection between consciousness, land, and language:

> …all my Elders say that it is land that holds all knowledge of life and death and is a constant teacher… the land constantly speaks. It is constantly communicating. We survived and thrived by listening to its teachings—to its language—and then inventing human words to retell its stories to our succeeding generation.

Some of these layers of meaning can also be expressed in the word *landscape*. In his foundational work *Look to the Mountain: An Ecology of Indigenous Education,* Gregory Cajete (Santa Clara Pueblo) writes: "“Ecological education provides the foundation that enables human beings to resonate individual and communal 'inscapes' with the natural landscape" (76). We can also think of landscapes as Dana Powell (white settler) does in her work *Landscapes of Power*. For Powell, "landscapes bear visible and invisible realms and histories that weave geologic time with mythical memories and languages" (198). Further, she argues that landscapes are "the vibrant, material interface of human and nonhuman interaction, across space and time," yet complicated because "spatial unfixity through traveling and translation are central to understanding these landscapes" (15). Landscapes are an important concept in ecology, traditional ecological knowledge, earth sciences, agroecology, geography, and anthropology, motivating different configurational methods and features. Finally, landscapes could be thought of in a spiritual or imaginative sense, as the late Irish poet and philosopher John O'Donohue offers. Landscapes are "just as alive as you," he says. "Landscape recalls you into a mindful mode of stillness, solitude, and silence, where you can truly receive time," he argues (93). O'Donohue understands landscape as a spiritual territory, the horizon we are called to by spirit.

One way that land and food sovereignty intersect is through our bodies. It is the movement and the laboring of human bodies in rhythm with the sprouting, fermentative, prevalence of human and hand-scale cultivation. Mechanization is a hallmark of industrial agriculture, and indeed, mechanization remains a goal of sustainable development for nations around the world (94). Yet for those cultivating marginal lands or living without significant access to capital and machinery, high degrees of mechanization remain elusive. Hand labor and cultivation are central to efforts for food sovereignty, ethical land stewardship, and ecological sustainability. This takes many forms across the world, including the agroforestry chacra of the Kichwa-Lamistas people, terraced rice farming in East and South Asia, cultural fire of California Indigenous nations, and taro cultivation of the Pacific Islands—to name only a few. It is the hands—hands of grandmothers, uncles, comrades, apprentices, caretakers of all kinds—that hold embodied knowledge of how to tend and nourish communities. This dissertation celebrates and wonders at all that is done by human hands on land.

These connections between the body and land can also be extended to food. In their important work on the political ecology of the body, Jessica and Allison Hayes-Conroy write of the body:

> The material body can both confirm and disrupt social trends in eating habits based on gender, race, class, age and other forms of social difference, because the material body is both developmental and unpredictable. Thus, we have suggested that the material processes that produce tastes and other food preferences are best described as a rhizome of forces – some structural and some haphazard – that intersect to produce specific moments of food-body interaction. In short, following in the footsteps of a number of feminist scholars interested in food and bodily materiality… we have insisted that bodies matter – quite literally – to any project of food-based social change (95)

Embodied knowledge is found in the generative and constitutive power of food. Food is a powerful medium for solidarity, mutual respect, and reciprocity. Food is a central aspect of culture, connecting people to their lineages while constituting their daily practices and ways of knowing. Food is also part of the material (re)production of human life, and is connected intimately with nourishment and the body. The importance of using food as our medium and methodology derives from a fundamental tension: our relationship with food is both highly structural (political, economic, always socially determined) and affective (emotional, biological, physical, material). Structural forces may shape what foods we define as healthy, what foods we can access, and what histories or experiences we have with certain foods (96–99). Affective forces, on the other hand, may inform our emotional attachments to particular foods, shape our internal experience of health, or govern our participation in social spheres or cultural practices. Thus, food offers insights into the social and political construction of our world while *at the same time* offering new flavors, experiences, and recipes to the palette of our psyches (100).

This approach inherently challenges scientific objectivity. It rejects what Donna Haraway describes as the "god trick," wherein the "conquering gaze from nowhere… mythically inscribes all the marked bodies," and "makes the unmarked category claim the power to see and not be seen, to represent while escaping representation." (62) A political ecology of the body aligns with feminist scholars who assert that all knowledge is partial, fluid, and socially constructed, situated within the lived experience of the knower (101,102).

This also aligns closely with Indigenous and decolonial scholarship. Indigenous ontology (theories of being) and epistemology (theories of knowledge) are centered on relationality; that is, "relationships do not merely shape reality, they *are* reality." (103) Following the guidance of scholars like Linda Tuhiwai Smith and Shawn Wilson, a focus on relationships allows for the centering of mutual respect, reciprocity, and responsibility as modes of inquiry. My research does not claim to be comprehensive or objective. In fact, it purposefully reflects close relationships of solidarity between the authors, all of whom are participants *and* researchers within a web of mutual stewardship, nourishment, and care. Indigenous and decolonial scholars remind us to be guided by an ethic of reciprocity via the material transfer of power, land, and resources, and the resurgence of languages, cultures, and lifeways (4,104). Working alongside low-income, food-insecure, houseless, and BIPOC communities, it is essential to maintain a vigilant critique of how power hierarchies are being reinforced and replicated through collaborating with academic institutions.

Entangled and expanded notions of land, food, and the body may offer us new aesthetic, experiential, or embodied ways of knowing. A budding relationship with a new landscape, or a bold and different flavor, can offer a vast array of sensorial information that creates new somatic pathways. That is, land, food, and the body collaborate on a material level to achieve strange, rhizomatic, budding possibilities that we could have never *thought*. They break us free from the discursive world—if only for a moment—and deal directly on the level of symbol and sensation. This process is a living, breathing one.

Nishnaabeg scholar Leanne Betasamosake Simpson makes a similar argument when she speaks on the possibility of cultural resurgence for Indigenous communities:

> *How* we live, *how* we organize, *how* we engage in the world—the process—not only frames the outcome, it is the transformation. *How* molds and then gives birth to the present. The *how* changes us. *How* is the theoretical intervention. Engaging in deep and reciprocal Indigeneity is a transformative act because it fundamentally changes modes of production of our lives. It changes the relationships that house our bodies and our thinking. (4)

Simpson is speaking to and for Indigenous communities here, not settlers or those who colonize Indigenous lands. Indigeneity is not a goal or aspiration for settlers to fetishize or covet. However there is wisdom in Simpson's words that can support the just transition of resources, land, and power—key elements of food sovereignty and agroecological transitions in the US. Simpson's intervention highlights the importance of considering *how such* just transitions are realized. Direct and sensorial relationships with land through agroecology can offer a different *how*. Food sovereignty involves entangled and rhizomatic relationships between the land, food, and the body. These relationships change the modes of (re)production, which enable new futurities. The cultivation, preparation, and consumption of food are acts of self-determination and self-actualization mediated by the body. These experiences have the power to break individuals free from more colonized or capitalistic ways of being. They can constitute fugitive practice. Forms of embodied knowledge and agroecological practice on land translate across the boundaries of bodies in an ecosystem; from human hands, to fruiting bodies, to the body of the soil. Land stewardship not only sustains physical bodies but shapes bodies of knowledge, cultural identity, and collective action.

Embodied relations with food and land—expanded and enriched through feminist, Indigenous, and Black scholarship—will form important elements of this dissertation. By situating our discourse in these concepts, we engage with land and food not merely as inert material but as partners with agency, engaged in a dialogue that spans generations. It is in this dialogue that the true essence of agroecology and food sovereignty is realized: land stewardship is understood as nurturing an intergenerational and multispecies community, and profound acts of care and cultural continuity become possible.

Thresholds

A threshold is a critical zone or limit beyond which a system undergoes a state change. This concept spans various fields, including ecology, sociology, economics, and climate science, typically signifying a tipping point in complex, non-linear, or emergent systems. In ecology, thresholds often describe transition points between two stable states within an ecosystem, defined as "critical values of an independent variable around which a change from one stable state to another occurs" (105). This phenomenon has been well-documented across a multitude of environments and ecological systems (106–108). Thresholds can also represent discontinuities in a system's overall response due to small and incremental changes in controlling variables. In this way, thresholds are essential components of emergent systems.

Yet thresholds are also central to Indigenous, liberatory, culturally rooted, and phenomenological ways of knowing. In one of her public lectures, Corrina Gould tells this story:

> A couple hundred years ago, you might stop at this waterway, which would be the edge of that territory. And you would like a fire, a smoke fire, not a big fire. You would announce that you were there at the edge of this territory. And you would wait there, patiently, for someone to come and get you. Folks from the village that was closest there would go and send people out to bring you back to the village. While you were going to the village, you

> might talk and joke around. Then when you got to the village, there would be food waiting for you. And there would be a gathering of people that might have songs to welcome you there. And there would be gifts exchanged back and forth… All of this that happens is called protocol. All of this happens before you even have the chance to say: Why did you need to come? What is your business coming into our lands? Because we understood that you were coming into a place where someone else has the relationship with that land. They know the waterways of that land, they know when it floods, when it is time to pick foods, when it is time to gather medicines… So we come, hoping as a good guest, that they will take care of us when we are on that land.

In this way, thresholds are found at the boundaries of territory—territories of relationship, of embodied knowledge, of intimacy, and of kinship. These are the thresholds that matter in the Indigenous worldview. Territory is marked by the passage of waterways and features of the landscape, but more deeply by relationships to those places. Thus, to cross the threshold one finds a posture of respect and humility as you offer yourself fully to those who have made the crossing many times before. Thresholds, in this view, become territories of relationality. In this dissertation, understanding the boundaries between territories of relationality will become a tool for

The Irish poet, writer, and scholar John O'Donohue also wrote evocatively of thresholds. In his book *To Bless The Space Between Us,* he writes:

> We are [often] surprised by change that seems to arrive out of nowhere. We find ourselves crossing some new threshold we had never anticipated. Like spring secretly at work within the heart of winter, below the surface of our lives huge changes are in fermentation. We never suspect a thing. Then when the grip of some long-enduring winter mentality begins to loosen, we find ourselves vulnerable to a flourish of possibility and we are suddenly negotiating the challenge of a threshold. At any time you can ask yourself: At which threshold am I now standing? At this time in my life, what am I leaving? Where am I about to enter? What is preventing me from crossing my next threshold? What gift would enable me to do it? A threshold is not a simple boundary; it is a frontier that divides two different territories, rhythms, and atmospheres. (109)

Creating more liberated futures will require crossing a threshold. The crossing will happen in our bodies, rooted in landscapes, and amidst human and more-than-human communities. The thresholds will be both internal (personal, emotional, spiritual) and external (ecological, political, cultural). And the crossing will likely not be easy, or intellectual, or clean, or safe. To cross will require decomposition. It will mean losing ourselves. To cross a threshold is to be undone. For new life to emerge, something must first die. Negotiating thresholds will be foundational to the emergence of new ecological and social conditions. Embodied experiences of food and land offer vessels that may allow for these transitions to occur.

One of the central conceits of this dissertation is the idea of soil as threshold *and* of thresholds as a kind of soil. As a medium where power and material relations are negotiated, soil represents a liminal, unseen, underground entity that has outsized importance in our lives. How little we know about this living ecosystem that sustains our entire life! Soil is a threshold to the degree that it invites us to the confluence and boundary-place of self, ecosystem, and culture. Soil is a threshold in its refusal to yield to neat biophysical descriptions or singular cultural narratives. Rather, soil is a limin where powerful forces are mediated; a threshold. Conversely, thresholds are a kind of soil for the soul. When we allow ourselves to live with wonder and possibility, there is a life-giving essence that yields itself to the seeds of our intention. When we are courageous enough to change, and to cross into some new territory that we do not understand, we are afforded a rich and extensive medium for our spiritual sustenance. Thresholds are a fervent and alive place of becoming.

The people and communities who inspired this dissertation were engaged in the negotiation of thresholds as they worked to enact agroecology. These could be thresholds in the landscape they steward—a waterway, a change in soil type, a fenceline. They could be threshold levels of irrigation, compost, or amendments below which crops would fail. Or they could be the personal or emotional thresholds necessary to come into a reciprocal relationship with the land and the more-than-human world. We will now turn to this network of farmers, organizers, land stewards, and community members who embodied agroecological relationships in their attempts to enact food sovereignty.

Communities of practice

A vibrant network of small-scale farmers across California representing diverse geographic, cultural, and socioeconomic backgrounds is stewarding soil in ways that embody these commitments to land and food. This dissertation is in conversation with farmers who have embraced a form of soil stewardship aimed at fostering ecological, economic, and cultural resilience on the margins of Californioa's plantation-based agricultural system. Members of this community display a broad array of agroecological practices, political structures, organizational models, economic strategies, and cultural identities, yet they are united by a common form of land stewardship. Practitioners in this network are farming in urban and rural environments, supporting non-profit and for-profit endeavors, with BIPOC and white communities. Despite these differences, they have all adopted a hand-scale no-till farming system as a means to enhance soil health and maximize local food production with minimal external inputs. The farmers share common management principles: reducing soil disturbance, increasing crop density spatially and temporally, enhancing on-farm biodiversity, and maximizing recycling of on-farm resources. Taken together, these principles are informed by an ethic of stewardship and a desire to boost their adaptive capacity to ecological and economic challenges. Although practitioners of hand-scale no-till report environmental, social, and economic benefits, their efforts have been overlooked by scientific research.

Collaborating with these farmers is a web of mutual aid organizations, non-profits, faith communities, and grassroots movements that strive to address hunger in their community. To achieve nourishment and address hunger in ways that challenge or subvert the industrial, corporate food system are central to their practice. The efforts of this network offers insights into a more holistic approach to food sovereignty in the United States. Embedded within an industrial food system that leads to unequal food access and food apartheid at the same time that it creates obesity

A community of practice is defined as a group of people who share a common interest or passion for a particular domain of work, and who learn together through collective practice and social exchanges (110). Naming a network of actors as a "community of practice" conveys the idea from feminist scholarship that learning is situated—socially embedded, contextual, and always partial. This network of farms, organizations, and grassroots initiatives engages in collective practice; they do not achieve forms of food sovereignty or anti-hunger in isolation. Rather, they collaborate materially and socially through growing and distributing food, linking each entity in the community of practice to others in the network. With this practice, they iterate, transform, change, and grow, learning to better nourish their communities and support one another in their efforts to realize food sovereignty. A community of practice by definition is *intentional*; it defines a group that convenes on a regular basis to to exchange ideas, information and practices, often to achieve systems change or transformation. In the case of these networks of farmers, many know each other and are engaged in explicit networks, convening *encuentros*, field days, farmer-to-farmer exchanges, classes, and workshops. Anti-hunger organizations and initiatives also intentionally convene themselves through dinners, food giveaways, festivals, and other moments of sharing food. It is important to acknowledge, however, that some actors in this network work only in parallel with similar values and practices. Thus, their formation as a "community of practice" is incomplete, or partial. What might it look if they were more intentionally networked? This question was part of the motivation for the research projects described in this dissertation. Through our participatory action research methods, this web of organizations convened to dialogue, learn, and ask questions together. In this way, convening a community of practice becomes both a *means* and an *end* in this work.

Through interviews, meetings, farm visits, field days, and a symposium, participants articulated their perceptions and motivations for engaging with specific agroecological practices. They exchanged insights about soil management, shared seeds, distributed food, and discussed topics ranging from land ownership to mutual aid. This engagement involved farmers, community members, students, university staff, and researchers. Similarly, soil organisms and plant communities communicated their presence through scientific measurements like soil enzymatic activities, pore structures, and mycorrhizal interactions. By juxtaposing these diverse forms of knowledge throughout this project, I aim to enrich our understanding of agroecological transitions in the US context.

In California, small-scale, no-till farmers bridge significant cultural, racial, and socioeconomic differences, yet they are united in their efforts to enhance their autonomy within the food system. These farmers employ agroecological soil conservation techniques driven by ecological and social imperatives to reduce external inputs, utilize limited land and capital efficiently, maximize local productivity, and rejuvenate local ecosystems. The accessibility of these practices, which do not rely heavily on capital investments, mechanization, commercial fertilizers, or extensive land, lowers barriers for producers aiming to gain control over their community food systems. Thus, this study poses critical questions: How might widespread adoption of hand-scale, no-till, agroecological practices help to "scale-out" or democratize food sovereignty? What impact does no-till management have on soil ecology, and how might this influence a community's control over its food system?

This context set the stage for a collaborative endeavor involving farmers, researchers, non-profit groups, and community stakeholders, employing participatory action research (PAR) methodologies to explore the emergence of new agroecological practices and the development of new ecological systems, social connections, food distribution channels, and care networks. By examining the transitions from the soil ecosystem up to the social relationships and distribution networks it supports, this dissertation aims to discern how agroecological thresholds are established—and subsequently crossed.

Participatory action research methods

This participatory action research project was first initiated through conversations between myself, researchers at UC Berkeley, cooperative extension specialists, current and former members of Agroecology Commons, the California Alliance with Family Farmers (CAFF), farmers at Singing Frogs Farm, members of the Gill Tract Community Farm, and other small farmers across the wider San Francisco Bay Area. Over eight years, the project grew to include a wide community of practice including dozens of farms, non-profits, land trusts, and other community organizations engaged in food and land stewardship. Participants entered the project in a variety of ways, from attending workshops, field days, webinars, and talks, to hosting educational programs, to participating in soil sampling and testing. Throughout these forms of engagement, practitioners took on key aspects of the research process: writing research questions, designing our field studies, participating in results sharing, hosting educational events for knowledge sharing, and more. All participants were connected to agroecological projects that sought to build soil health through hand-scale methods, minimizing soil disturbance, and creating thriving agroecosystems systems focused on social and ecological regeneration.

This project is based on the methods and principles of participatory action research, a democratic and participatory orientation to knowledge creation and collective action (111–113). Tensions between theory/practice, subject/object, and experiential/institutional knowledge are directly engaged and seek resolution through iterative, practical, and action-oriented forms of collective experience that transform consciousness. This is called *praxis* (114). Local knowledge and lived experience form the basis for research, as participatory action research places the design, implementation, analysis, and sharing of results in community-driven processes with the goal of uplifting social movements. In particular, this methodology seeks "the acquisition of serious and reliable knowledge upon which to construct power, or countervailing power, for the poor, oppressed,and exploited groups and social classes—the grassroots—and for their authentic organizations and movements." (115) Participatory action research is directly concerned with power relationships, and articulates the participating "community" not as a fixed entity, but a "set of power relations within which people are grouped." (113) With this theoretical grounding, a more authentic and ongoing practice of reciprocity can be nurtured, where individuals can exchange and negotiate power through the process of knowledge creation and political action (116).

This project engaged individuals from diverse and intersectional identities—Black farmers, Indigenous mothers, formerly houseless people, queer land defenders, Latinx students, and children of farmworkers, to name just a few. These individuals spanned racial, cultural, political, and socioeconomic differences, and were spread across both urban and rural geographies. Given this diversity, an explicit focus on power dynamics and emphasis on community participation is particularly important. When working in communities where significant vulnerabilities or power imbalances are present, conventional research can often reinforce existing power relations through logics of extraction by collecting resources and hoarding knowledge for the exclusive benefit of the academy (117–119). For Indigenous communities, whose knowledge systems were systematically destroyed through colonization, ensuring their governance and agency in the creation of new knowledge is especially important (120–122). The local knowledge of farmers and land-based people are also routinely marginalized by research (123,124), further emphasizing the importance of network participation and empowerment in agroecological research. Finally, when it comes to soil, it has been demonstrated that integrating local knowledge dramatically increases outcomes in soil health, fertility, and productivity (125–127).

What is to follow: an outline of this dissertation

The first chapter, *Emergent properties of soil structure, ecology, and functioning under a hand-scale no-till farming system,* examines the agronomic and ecological outcomes of implementing hand-scale no-till. The chapter is grounded in the experiences of a community of farmers in California that has adopted hand-scale no-till methods as a core component of their land stewardship practice. These methods are particularly suited to small, degraded, or marginal lands, and are believed to offer both agronomic and economic gains while fostering a closer relationship between farmers and the landscapes they steward. The study is motivated by farmers' desire to understand how hand-scale no-till influences soil health, or the dynamic physical, chemical, and biological properties of soil. It also sought to understand how these changes in soil health might motivate such a wide community of farmers to implement the farming system in diverse contexts. Farmers placed soil health at the center of their agroecological practice as they perceived it to enhance biodiversity and ecological functioning, increase adaptive capacity to crises, improve economic wellbeing, and reduce reliance on external inputs.

To investigate these claims, this chapter introduces a two-year field experiment that compares four distinct agroecological farming systems. These systems are defined along two primary axes: the use of hand-scale no-till versus tractor-based tillage, and the implementation of winter cover crops versus continuous crop production. This approach allows for a detailed examination of how different management practices influence soil physical, chemical, and biological properties. By focusing on farmer-derived principles such as minimizing soil disturbance and maximizing biodiversity and planting density, the study seeks to bridge the gap between traditional agricultural practices and innovative approaches that could lead to more sustainable farming methodologies. This chapter aims to contribute to the broader dialogue on agroecology in the US by providing empirical evidence on the benefits and challenges associated with hand-scale no-till farming. This study not only addresses the ecological outcomes of these practices but also considers their social and economic dimensions, reflecting the complex interdependencies that define contemporary agricultural systems.

The second chapter, *A community approach to "hunger": the material and social conditions integrating anti-hunger and food sovereignty agroecological transitions in the San Francisco East Bay*, explores the complex interplay between hunger and nourishment within the framework of food security and food sovereignty, using a case study of urban agriculture in the East Bay. It begins with a critical examination of the global food system, highlighting its contradictions—namely, the coexistence of hunger, obesity, and food wastage amidst plenty. The study is grounded in the socio-political context of the United States, where issues of racial and environmental justice are prominent, and where food systems are heavily influenced by corporate consolidation and financialization. The methodology employed is participatory and mixed-methods, capturing data through interviews, participant observation, and food distribution tracking from 2016 to 2021. This approach provides insights into the community of practice around urban agriculture in the East Bay, which is portrayed as a dynamic web of farms, food banks, non-profits, and grassroots organizations collaborating to address hunger and foster nourishment.

Theoretical grounding is provided in the concepts of food security and food sovereignty. Food security is criticized for its emphasis on calorie provision without considering the sources or quality of those calories. In contrast, food sovereignty is advocated for its focus on the right of people to define their own food systems, highlighting the roles of local communities and sustainable practices. The chapter then delves into the specifics of the case study, discussing the mobilization of local resources, community engagement, and the integration of small-scale agriculture with anti-hunger efforts. The community of practice is seen as a potential model for addressing systemic issues in food production and distribution, with urban agriculture emerging as a viable solution during times of crisis, such as the COVID-19 pandemic. Throughout the chapter, the narrative intertwines the affective and structural dimensions of hunger and nourishment, emphasizing the importance of understanding both personal experiences and broader socio-economic conditions. The study seeks to provide a nuanced understanding of how urban agriculture can contribute to both immediate anti-hunger initiatives and longer-term food system transitions. Overall, the chapter argues for a reimagined approach to addressing hunger in the US inspired by a community in the East Bay enacting food sovereignty. I argue that calls for a shift away from the charity model towards strategies that center relationships, reciprocity, agency, solidarity, and power—which support food sovereignty initiatives in the US to more holistically address the root causes of hunger.

Finally, the chapter *"How we treat the land comes down to how we view our spirit": thresholds in soil health and agroecology at the edges of California agriculture"* presents an analysis of how small-scale farmers in California integrate ecological and social dimensions of their work to create agroecological transitions. The focus is on a community practicing hand-scale no-till farming, which prioritizes soil health as a fundamental aspect of agricultural sustainability while addressing the socio-economic barriers posed by limited access to capital and land.

The chapter outlines in more detail our participatory action research methods, which enabled a collaborative exploration of the complex interactions between soil health and the community's socio-cultural dynamics. This approach facilitates a holistic examination of how no-till practices impact soil carbon levels and food web structures, alongside the socio-economic realities of the farmers involved. Our analysis pairs soil health metrics with sociological parameters like degree of urbanization, years of management, This component of my research underscores the significant role of social factors, including labor, land-based education, and stewardship ethics, in shaping agricultural practices and their ecological outcomes. Soil food web analyses via nematode community analysis suggested the presence of more enriched and structured soil food webs in hand-scale no-till systems. This, paired with farmer interviews and site mapping, helps paint a picture of how soil ecology and social forces are deeply intertwined. This interplay is particularly evident in urban settings, with degree of urbanization having a strong effect on both soil carbon and soil food webs. This chapter demonstrates the emergent relationship between landscapes and their stewards, highlighting how agroecological practices are not only ecological acts but also social interventions that foster community resilience, cultural continuity, and environmental justice. Through this dual lens, the study offers valuable insights into the potential for agroecological practices to serve as a conduit for broader societal and environmental transformation in diverse geographic and cultural landscapes.

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Figure 1. A package label from my great-great-grandfather's fruit packing company, the Johnston Fruit Company. The land that Harleigh Johnston owned was called the San Ysidro Ranch, which still exists today. This land was part of the original Santa Barbara Mission. The glorification and romanticization of the mission here stands as an emblem of how genocidal histories were suppressed, and plantation ecologies normalized, by early settlers. My ancestors used these images to ship lemons across the United States—from San Francisco, to Seattle, to New York City.

Figure 2. Another package label from the Johnston Fruit Company. Here, we see the fetishization of California's landscape as benefitting white bodies. Three white people ride in a chariot of flowers. They are dressed in fine outfits and look over a large agricultural landscape. The lemon blossoms and lemmons in the foreground give a kind of edenic quality. The smiles on the faces of these presumed white settlers offers a kind of unsettling languor of the Southern California sun. This is the "land of plenty," sold across the country alongside sweet and sour fruit.

Figure 3. (Top) My great-grandfather David S. Bell surveys his private gardens in Riverside, California. This photo series was prepared for the *California Citrograph*, a trade magazine that was part of the professionalization of citrus growing and dissemination of information about the industry. My great-grandfather was part of an elite class of farmer-capitalists who terraformed Southern California into a citrus plantation, selling both citrus and the *idea* of California in an edenic package. (Below) One of the orchards managed by my grandfather. Pictures like this one were part of the myth-making of California as the "land of plenty."

Figure 4. Images of students from the Sherman Institute, courtesy of the Sherman Indian Museum collection, Sherman Indian Museum, Riverside, California.

Emergent properties of soil structure, ecology, and functioning under a hand-scale no-till farming system in California[1]

Abstract

Land and capital-limited farmers worldwide rely on hand labor. Hand-scale systems may allow agronomic and economic gains while centering relationships and working on small, degraded, or marginal lands. This study took inspiration from a network of farmers in California implementing hand-scale farming systems that minimized tillage, maximized crop diversity, maximized soil cover, maximized planting density, and organic matter inputs via compost. This system, which we call hand-scale no-till, is employed across a wide range of geographic, cultural, organizational, and economic contexts. Despite rapidly growing interest among regional farmers, few studies have investigated this system's ecological or social outcomes, especially related to farmers' questions regarding soil health. To address this, we implemented a two-year experiment that modeled four different agroecological farming systems. The systems were devised by employing farmer-derived principles (e.g. minimize soil disturbance, maximize planting density, etc.) while comparing two common axes of intervention among this community of farmers: 1) implementing hand-scale no-till versus a tractor-based tillage system, and 2) planting winter cover crops versus continuous crop production. Continuous crop production, where vegetable cash crops were grown throughout the entirety of the year, was a common feature in this farmer network. Organic matter inputs, labor, and other aspects varied across the systems following common regional practices. After just two years, soil health was strongly partitioned by tillage system, with soil moisture, micro and mesopores, carbon and nitrogen stocks, and enzyme activity all increasing under hand-scale no-till. Within hand-scale no-till, winter cover crops led to improved water retention and higher particular organic matter, but lower fungal associations and diversity. Soil structure and pore architecture shifted significantly in both no-till systems toward a greater proportion of mesopores with fewer macropores, which also increased soil water storage at all depths. Total organic carbon under no-till increased by two-fold at the soil surface, while higher rates of N-cycling enzyme activity indicated greater microbial activity and nitrogen availability. Contrary to expectations, no-till systems had lower fungal diversity. However, we found that no-till systems with continuous vegetable production had the highest levels of plant associations with arbuscular mycorrhizal fungi. Across tillage treatments, cover crops led to higher particulate organic matter, soil moisture, and porosity, but lower plant-fungi associations and fungal richness. We observed distinct ecological functions in each farming system's soil, but there were no significant differences in crop nutrient density, yields, or biomass across farming systems. Agronomically, hand-scale no-till allowed for more crop rotations per year and extended the growing season, leading to higher overall production when compared to other systems—but required much higher labor inputs.

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Introduction

Land and capital-limited farmers face many challenges maintaining their farms in the face of plantation, industrial, and extractive agricultural systems (1). Limited land access pushes farmers to produce more on marginal land, while limited financial, human, and social capital hinders efforts to subvert exploitative economic conditions. One adaptation farmers in California use is a small-scale, intensively cultivated farming system that foregoes mechanization in favor of more hand-scale labor. To achieve this adaptation, farmers also place soil health at the center of their farming practice to support rapid crop turnover and dense plantings, facilitate hand cultivation, and increase production. This centering of soil is part of a broader ethic of care—for landscapes, biodiversity, people, and cultures. Plantation-based and industrial agriculture has degraded soils worldwide—altering global soil carbon fluxes (2,3), disturbing soil hydrology (4,5), polluting water resources (6,7), driving deforestation and desertification (8), and diminishing both the ecosystem and soil biodiversity (9–11). The financialization and market-based structure of the global food system is a key driver of this ecological harm, allowing a handful of corporations to serve as middlemen and dictate pricing, production, distribution, and consumption (12). This system also exploits the labor of low-income, undocumented, BIPOC, or otherwise oppressed peoples. The exploitation of the soil and human bodies come hand in hand. Thus, efforts to revitalize soil must include care for landscapes *and* people. Creating systems rooted in more reciprocal social, ecological, and economic relationships is essential to actualizing agroecology (13).

This study takes inspiration from a growing movement of small-scale (<10 acres) farmers in California who are stewarding landscapes while growing fruits, vegetables, and herbs using hand-scale, no-till farming methods. In particular, this network shares a common set of principles: minimize soil disturbance, maximize biodiversity, maximize planting densities, maximize soil cover through incorporation of compost and mulches. By implementing hand-scale systems with minimal off-farm inputs on small or marginal lands, this network's members have sought to democratize farming, enhance ecological functioning, reduce economic barriers to production, and increase adaptive capacity to crises. All of these projects practice labor- and knowledge-intensive farming methods, deliberately choosing practices requiring more labor to actualize a range of other ecological and social benefits. Agroecology is knowledge-intensive rather than resource-intensive, built around a plurality of knowledge systems (14–16). Their agroecological stewardship was rooted in expanded notions of kinship and reciprocal relationships between people and landscapes, emphasizing the importance of reconnecting people with the Earth. Projects facilitated these expanded ideas of reciprocity, care, and stewardship through non-traditional employment models, community organizing, solidarity economies, educational programs, mutual aid projects, and more. Practitioners bridge racial, cultural, economic, and geographic differences but share a common land stewardship ethic emphasizing social and ecological wellbeing (17).

A common set of principles informs this shared ecological ethic: recycling on-farm resources, maintaining soil coverage with composts and mulches, minimizing or eliminating tillage, and maximizing on-farm biodiversity. This web of farmers converged specifically around a form of no-till agriculture that sought to minimize disturbance by utilizing hand labor over mechanization. Practitioners employed the soil health principles mentioned above primarily through hand labor. It is important to note that a wide range of systems are referred to as "no-till," some of which are highly mechanized, industrial, and rely heavily on chemical fertilizers and herbicides. No-till, in this network, refers to an organic and human-scale system of minimal soil disturbance, hand cultivation, maintaining root residues, and surface mulch application. Practitioners reported that this system allowed them to maintain highly productive farms on marginal land with minimal capital and off-farm inputs. However, the ecological and social outcomes of this largely hand-cultivated system remain understudied. Most studies on no-till agriculture have investigated large-scale, mechanized and chemical-dependent no-till systems (18). This study, in part, seeks to address this gap in the literature.

This study aims to illuminate how a farmer-inspired and hand-scale no-till system affects the soil's physical, chemical, and biological properties. How does the soil, as an emergent and living entity, respond to no-till systems employed by hand labor? How are soil carbon, water, structure, nutrient cycling, and biological communities transformed through low disturbance, high crop diversity and rotations, growing on marginal lands? How do these changes in the soil illuminate *why* such a diverse group of actors were adopting this common farming method? A team of agroecologists, city planners, cooperative extension specialists, students, and community organizations identified these questions in collaboration with farmers involved in a multi-year, community-based participatory action research project. The full scope of organizing and participatory research methods conducted to produce this study is covered briefly below and more deeply in other publications (17).

In order to evaluate these questions, we implemented four agroecological farming systems over two years. The systems were developed by implementing farmer-derived principles (minimize soil disturbance, etc.) while comparing two axes of intervention used in this farming network: 1) hand-scale no-till versus tractor-based tillage, and 2) winter cover crops versus continuous crop production. Hand-scale no-till was compared to a more conventional tractor-based tillage system that would mechanically rip, harrow, and form the soil between each planting. Layered on top of this tillage treatment was a comparison between winter cover crops and a continuous crop production system. Continuous cash crop production was common in this network, and made possible by coast California's Mediterranean climate and cool, rainy winter season. Forage radish (*Raphanus sativus var. longipinnatus*) was selected as a cover crop species for its large taproot which has been demonstrated to break up soil compaction and improve soil aeration and tilth. For continuous crop production, broccoli was cultivated with compost mulch and harvested throughout the winter season. These systems all had the same cash crop rotations and irrigation, but were managed as whole systems and so differed in important ways regarding organic matter inputs, fertilizer amendments, and timing of crop rotations. For a detailed overview of their implementation, see Figure 3. Broadly, the systems reflect distinct management regimes designed by small-scale farmers in California. We designed our study to evaluate how hand-scale cultivation would alter soil functioning and ecology and how that would, in turn, influence crop health, nutrient density, response to stress, and water availability—metrics that farmers indicated were important to them.

Alongside this network, we hypothesized that hand-scale no-till (carried out on marginal lands or small plots) would exhibit changes in soil health: diverse and abundant soil microbial activity, higher fungal diversity, more complex food webs, improved water storage and infiltration, reduced need for fertilizer inputs, and increased carbon stocks relative to conventional tractor-based tillage. Because farmers designed this system for small or marginal lands with limited access to capital, these observed improvements to soil health became essential to adoption. Perceived improvements in soil health were a key motivation for practitioners to adopt a labor-intensive system. These changes in the soil ecosystem were understood as increasing farm productivity as well as adaptive capacity–or ability to buffer against climatic and ecological stressors. These agronomic benefits were widely reported by practitioners and also allowed for more economically viable operations even on small or marginal lands.

This combination of ecological and agronomic benefits-–mediated through the soil—makes this system particularly successful for land and capital-limited farmers. The adoption of hand-scale no-till across a range of racial, cultural, and geographic differences is another marker of its success. Farmers were employing the same principles and methods in tiny urban lots, on wooded slopes, and in coastal lowlands. And they were using this farming system in a range of organizational and economic contexts, spanning from non-profit educational farms (with no sales) to for-profit market operations. Hand-scale no-till is a widely accessible system requiring minimal machinery, equipment, or external inputs. This also supports widespread adoption in diverse social and ecological contexts. While capitalist, industrial, and supremacist forms of worldmaking seek solutions that scale *up*, these communities emphasized scaling *out* and *deep*; that is, recognizing that locally adapted, culturally specific, politically grounded, and relationship-based solutions are best suited to address the multi-pronged challenges of our time (19).

What emerged from implementing these farmer-inspired principles and practices on our study site were distinct farming systems that fell along a gradient in soil disturbance, labor inputs, off-farm inputs, and cultivation intensities. Each system had unique outcomes in soil ecology and functioning, with hand-scale no-till increasing carbon stocks, improving soil water retention, increasing N-cycling enzyme activity, decreasing bulk density, and altering soil fungal communities. Our study corroborates the experiences of many farmers that hand-scale no-till is a rapid and effective means of transforming soil ecology and functioning. The ability to transform soil health through changes in stewardship could serve as a foundation for land and capital-limited farmers as they actualize agroecology: extending the growing season, increasing production, reducing water loss, increasing soil organic matter, increasing tilth, and reducing barriers to implementation.

Placing this study

We implemented this project in the unceded territory of xučyun (Huichin), the ancestral and unceded land of the Chochenyo speaking Ohlone people. UC Berkeley's central campus is situated on an Ohlone village and ceremonial site, including a shell mound at least 200 ft in length along the bank of Strawberry Creek (20). The emblems of Indigenous life reside in the soil as mollusk shells, human remains, cultural artifacts, and sacred sites hidden beneath the literal ivory tower (21). This study occurred at the northern edge of UC Berkeley on the so-called "Oxford Tract," a research station owned by the Regents of the University of California in Berkeley, CA (37°52'34.35 N, 122°16'01.81 W). The Oxford Tract, like so many places, holds stories of Indigenous lifeways, colonization, urbanization, contamination, and regeneration (Fig. 1). The site once had a creek along its northern edge, which was culverted in the early 19th century. This proximity to a creek bed and its position near the bottom slope of the Berkeley hills produced clay-rich Terra complex soils and vertisols with an average of 64 cm of rainfall annually. The site's soil is specifically classified as an Urban land-Tierra complex with a 2 - 5% slope. According to her paper, *Remember Schoolhouse Creek*, Rebecca Sutton writes of the creek that adjoins the study site:

> "[The creek's] route was crowded with a variety of oaks, as well as bay laurels, California buckeyes, and many other large trees. [...] A dense understory of shrubs, vines, and groundcover plants spread over creek banks and spilled into the surrounding valley. [...] the Huichin group found a variety of uses for streamside plants, as foodstuffs, medicines, and basket-weaving and building materials. Their homes and canoes were built largely of tule grass collected each year from coastal marshes. Animals attracted to and supported by the creeks also furnished the people with a wide variety of food and materials. When the Spanish arrived in the East Bay, beginning in 1770, they were awestruck by the "natural bounty" of the land, little realizing the considerable role the Huichin played in supporting it…" (22)

Corrina Gould, spokesperson for the Confederated Villages of Lisjan, has spoken often about the cultural importance of these creeks to Ohlone people today:

> "My ancestors lived in villages that were close to the water. Our houses, boats, water, skirts, baskets—all sorts of things—were made of tules that grew along the marshes. Two hundred years ago, you can drink water out of every freshwater creek in the Bay Area, and salmon and rainbow trout swam up here, and there was an abundance in our territory...Our ancestors lived in reciprocity with the land [and] were able to take care of the land so that it continued to feed us and our future generations." (23)

Ohlone lifeways, cosmologies, and nations were destroyed when the Spanish arrived and established the mission system in 1776, with most Chochenyo-speaking people, including the Huchiun, brought to Mission Dolores and Mission San Jose. A system of slave labor, forced assimilation, and Christianization was carried out alongside the genocide of Indigenous people, much of it in service to the early establishment of California's agricultural economy (24,25). Here, we see direct evidence of how violence against human beings is instrumental in the extraction and exploitation of the soil.

With time, settlers built homes over portions of the Oxford Tract in Berkeley until a fire destroyed them in 1923. The fire led to elevated levels of heavy metals on the site, some still present today. The land was purchased that year by the Regents of the University of California for the purpose of agricultural research and placed under the management of the College of Natural Resources. Since then, the site has been managed as an agricultural research station for over 100 years, with regular mowing, harrowing, and cultivation of grains, vegetables, and transgenic crop varieties. For decades, researchers primarily used the site to cultivate genetically modified corn, according to the current site manager. Maps of the site from the 1970s and 80s indicate use by the then "Plant Genetics Department," which is now part of the Genetics and Plant Biology Department in the College of Natural Resources.

The Oxford Tract is a contested site. As a site for academic "research," institutional mechanisms (land use applications, funding sources, administrative oversight, etc.) are in place that legitimize natural science research over more socially-engaged or community-based research. Legacies of heavy metal contamination remain a concern in parts of the landscape due to the homes that once stood on the site; lead and zinc levels are particularly high. There have been waves of student engagement, soil testing, and advocacy to ensure safe use and access to the site (26). As a space for urban agriculture, the Oxford Tract was – and continues to be – under near-constant threat of housing development. UC Berkeley's Chancellor and Capital Strategies office have repeatedly announced their decision to develop student housing on the site as part of their push to develop, in Chancellor Carol Christ's words, "all the land we have" (27). Waves of activism, research, mutual aid, community organizing, and farming initiatives that center community wellness, food access, mental health, and social cohesion have challenged these development claims to the site. This places the Oxford Tract within a broader land struggle with the University of California over sites like the Gill Tract and People's Park (28–30), connecting it to land reform movements across the world. These struggles situate our study of soil health within a complex web of social, cultural, and political forces. They complicate the interpretation of "soil health" on contested landscapes.

Methods

We initiated this study in 2016 through conversations between the authors and a coalition of non-profit and for-profit farming projects across the wider San Francisco Bay Area. The study system was designed by visiting collaborating farmers and observing their intensive, hand-scale, no-till methods. Collaborating farmers also visited the Oxford Tract to advise on the implementation and maintenance of the project by integrating a common set of principles derived from the farmer network (Fig. 4). During four community field days at the study site held over two years, we engaged practitioners and the public in conversations about the benefits of promoting soil health and democratizing farming by reducing the need for external inputs, capital, land, and machinery. We also organized a day-long symposium in Davis, CA, with the participation of over 30 farmers practicing hand-scale, no-till cultivation. This gathering helped develop research questions that supported soil health, economic resilience, food sovereignty, and farmer livelihoods. Over seven years, the project grew to include a wide network, including dozens of farms, non-profits, land trusts, and other community organizations engaged in land stewardship.

In the Fall of 2017, we implemented four farming systems at the Oxford Tract in a randomized split-plot block design with four replicates (Fig. 2). These systems were designed around two core practices used within this network (no-till and cover cropping), comparing hand-scale no-till to a tractor-based tillage system, each implemented with and without cover crops. Tillage treatments were the main plots, and cover cropping was the split plot. Plots were 100 ft long and 2.5 ft wide, with 2 ft furrows and 10 ft buffers along the entirety of the experiment. The plots' close physical proximity and small area were suitable for measuring fine spatial changes in soil health, including physical, chemical, and biological functioning. This scale of transformation is highly relevant to the small farms, urban farms, and marginal lands on which these systems are typically implemented. We did not design the plots to assess changes that only manifest over large areas (e.g., groundwater recharge) or changes at deeper soil depths (≥ 1m).

The hand scale no-till system was managed to minimize soil disturbance, which involved extensive use of hand tools and initial broadforking in Year 1, followed by zero disturbance for the remainder of the experiment. During each cropping cycle, we applied a 50:50 mixture of vegetable- and chicken manure-based compost at 56 tons per hectare (or 50 gallons per 100 ft growing bed). We managed weed pressure by hand weeding, dense spatial planting through intercropping, and tightly sequenced seeding and transplanting after each crop cycle. Crop termination and bed turnover were achieved by hand cutting all crops at the soil surface, applying compost and amendments, and planting directly into that admixture on the same day. Crop residues were composted off-site.

The tillage systems were managed by mechanized mowing, discing, roto-tilling, and bed forming via tractor after each crop cycle. Fallow periods were inevitable due to delays from wet soil and necessary decomposition time after tilling. We applied compost to this system at 28 tons per hectare, a rate that is at the higher end of recommended application rates for organic vegetable production in California (31). While compost rates were lower in the tilled systems, organic matter inputs were partially balanced since aboveground crop residues were mechanically incorporated into the soil during tillage. In contrast, they were removed in the hand-scale no-till system.

Split-plot treatments of cover cropping were layered on top of these tillage systems. A cover crop is a non-harvested plant grown to benefit the agroecosystem, often to promote soil health. The cover crop ("cover") treatment in this study included winter growing of forage radish. In hand-scale no-till plots, the cover crop was terminated and hauled off-site for composting, and the next crop was transplanted the same day. In tillage plots, the cover crop was mowed and disced into the soil and left for 4-8 weeks for decomposition, and then crops were transplanted. In contrast, continuous production ("continuous") included the continued growing of vegetable crops for harvest, with broccoli (*Brassica oleraceae* var. italica) grown during the winter months. "Continuous" plots included an additional round of soil preparation, fertilization, transplanting, and ongoing harvesting throughout the season.

All four systems had the same crop rotations and irrigation schedule throughout the experiment. Organic matter and fertilizer amendments were different according to the Feather meal (12-0-0) and oyster shell amendments were added at 0.43 tons per hectare and applied between each cycle of cash crops.

Labor hours, or the total hours spent on each management system, were tracked during the 2017-2019 seasons using an online web application throughout the experiment. Hours were recorded and labeled by the type of task performed, the study system, and the number of individuals involved.

Plant sampling and analyses

Total yield was measured by calculating the mass of all harvested crops from each plot throughout a growing season. Aboveground biomass was measured in two 1 m^2 sections within each plot by measuring the total wet biomass aboveground, then drying the material at 44.4 °C and measuring the total dry biomass.

During the summer of 2019, more intensive sampling was performed on a crop of Black Turtle bush beans (*Phaseolus vulgaris)*. Seeds were planted on June 16 and irrigated at 100% evapotranspiration (ET) from planting to anthesis (June 16 - August 1) to ensure plant establishment, then reducing irrigation to 50% ET from anthesis (August 1 - August 18), and finally eliminating irrigation for the remainder of the season with harvest on September 18. Total aboveground biomass was measured by the total mass of all plants harvested within two 1 m subsections in each plot. Root samples were collected from three individual plants per subsection and composited. For fungal association measurements, roots were washed upon sampling, and a 25 g subsample was placed in ethanol, while a 10 g subsample of root tissue was immediately stored at -80°C for DNA extraction. Total bean yield was collected from the entire treatment area.

Stem water potential was used as a proxy for plant water stress, measured at mid-morning each week from the onset of reduced irrigation until harvest. Three mature leaflets were briefly covered in an opaque bag for at least 15 minutes to prevent leaf transpiration. Following this, each leaf was excised and placed in a Scholander-style pressure chamber (#3005; Soil Moisture Equipment Corp., Goleta, CA, USA), where pressure was slowly ramped until it reached equilibrium with the pressure within the leaf xylem (Choné et al., 2001). The resultant pressure is called stem water potential, which quantifies the level of suction pressure the plant must exert on the soil water profile to achieve its water needs.

Root association by arbuscular mycorrhizal fungi (AMF) was measured using a root staining method. Roots were cleared in 10% KOH, acidified in 1% HCl, and stained with trypan blue (Koske & Gemma, 1989). Percent association was evaluated using a root intersection method at x200 magnification (McGonigle et al., 1990) and calculated as the number of AMF structures (arbuscules, vesicles, or hyphae) over the total root intersections counted (100 per sample).

Bean nutrient content was measured by collecting 5 g of dry beans and grinding them in a ball mill at 30 Hz for 3 minutes or until the resultant material was a fine powder. Samples were then sent to the UC Davis Analytical Laboratory at the University of California, Davis, CA, to analyze essential macro (N, P, K) and micronutrients (Ca, Mg, Zn, etc.) via nitric acid digestion.

Soil sampling, physical and chemical analyses

Each summer of 2017-2019, composite soil samples were taken from each plot at depths from 0-5 cm, 5-15 cm, 15-30 cm, and 30-50 cm using 15 cm dutch augers and homogenized. Unless otherwise noted, soils were air-dried, ground, and sieved to 2 mm before analysis. In 2019, soil sampling occurred at planting (June 16), anthesis (August 1), and harvest (September 18), with different analyses being carried out at each timepoint (see Supplementary Table 2). On August 1, soil samples were separated into four size fractions of 2000-250 µm, 250-53 µm, 53-20 µm, and <20 µm using a particle size fractionation method. Building on the protocol of Cotrufo et al., samples were fractionated via dispersal using 0.5% sodium hexametaphosphate in centrifuge tubes on a reciprocal shaker, then successive wet sieving at 250 µm, 53 µm, and 20 µm (32).

To measure total organic carbon (TOC), soil samples were collected at harvest, air-dried, and sieved to 2 mm. Soils were then processed in a ball mill and measured on an Elementar soliTOC cube (Elementar, Ronkonkoma, NY). The soliTOC improves SOC measurement precision over traditional elemental analyzers (33) by combusting higher sample masses (up to 3g of soil vs ~50 mg) and separating total organic C (TOC), residual organic C (ROC), and total inorganic C (TIC) via a temperature ramping method, DIN19539 (34).

Permanganate oxidizable carbon (POXC) was evaluated on soils collected at anthesis via the protocol outlined by Weil et al. using permanganate oxidation (35). In brief, 2.5 g of soil sample was weighed into 50 ml polypropylene tubes prior to oxidation. Oxidation was initiated by adding 18 mL of deionized water and 2 mL of 0.2 M $KMnO_4$ to each sample, which was then shaken for exactly 2 minutes at approximately 240 oscillations per minute on a reciprocal shaker. After settling for 10 minutes, 0.5 mL of supernatant from each tube was diluted in 49.5 mL of deionized water to quench the oxidation reaction. An aliquot of each dilution was transferred into a 96-well plate and analyzed by UV–Vis spectrophotometry to quantify MnO_4^- remaining in solution by absorbance at 550 nm.

Total soil N was characterized on soils collected at harvest by combustion, and soil micronutrients Zn, Mn, Cu, and Fe were evaluated by digestion using DTPA (diethylenetriaminepentaacetic acid) in the UC Davis Analytical Laboratory at the University of California, Davis, CA. Soil inorganic N was measured at planting, antithesis, and harvest. To evaluate soil inorganic N concentrations, soil extractions with 0.5M K_2SO_4 were performed immediately to minimize disturbance-induced N transformations associated with delays in processing (36). Inorganic N was extracted from moist soils with 2 M KCl and analyzed colorimetrically for ammonium ($NH4^+$) and nitrate ($NO3^-$) (37).

To evaluate potential enzyme activity, soils sampled at anthesis were sieved to 2 mm and processed within 24 hours of sampling. 50 mM acetate buffer was blended with 1g of soil using a Magic Bullet blender for 30 seconds each. Fluorimetrically labeled (4-Methylumbelliferone (MUF) and 7-amino-4-methyl coumarin (AMC)) substrates were used to standardize the activity of enzymes Glucanase/1,4-β-Cellobiosidase (CBH), β-glucosidase (BG), Exochitinase (NAG), and Leucine-amino-Peptidase (LAP). MUF was specific for enzymes CBH, BG, and NAG, while AMC was the standard used for calibrating LAP. A dilution series was prepared for each standard to obtain standard curves of enzyme reactions with the substrates. Working solutions of substrates for each enzyme were prepared at a concentration of 1.0 mM. 96-well black microplates were then prepared with the soil suspensions, standards, and substrate. Soil suspensions were pipetted out of the sample cups using wide bore tips, each sample corresponding to one row on a microplate. Measurements of activity were taken at timepoints of 1.5 hours and 3 hours after the addition of substrate using a fluorescence spectrophotometer at an extinction of 365 nm and emission of 450nm.

Gravimetric soil moisture content was evaluated at harvest by weighing samples before and after oven-drying at 105 °C for 24 hours. Full water retention curves were reconstructed at harvest using a HYPROP tensiometer and WP4C water potential meter (METER, Munich, Germany). Briefly, intact 250 cm^3 soil cores (10 cm in length) were collected from each experimental plot at a 5-15 cm depth. Samples were soaked in degassed, deionized water for 24 hours using capillary rise to full saturation. Two mini-precision tensiometers were inserted into the saturated core, and the sample was allowed to air dry on a balance until cavitation in the tensiometer shaft was reached or from water potentials approximately from 0 to -0.1 MPa. This was followed by characterization with the WP4C, using a chilled mirror dew point sensor method, to reconstruct the rest of the water retention curve from -1 MPa to -300 MPa. Raw water retention curves were modeled using a bimodal Van Genuchten (VG) fit, selected based on a minimized root mean square error compared to other models.

To further probe the pore architecture of the soil based on treatment, pore size distributions were calculated from retention curves using the formula $EPD = \frac{4\sigma cos\alpha}{\rho gh}$, where σ is the surface tension of the water (72.8 mN m^{-1} at 25° C), α is the angle of the meniscus (assumed to be zero), ϱ is the density of water (0.998, g cm^{-3}), g is gravitational acceleration (980 cm s^{-2}), h is the matric pressure (cm water) and EPD is the equivalent pore diameter in micrometers (38,39). This transformation assumes that, to first order, soil pores of a given size adhere water to their surface with a known potential. This allowed for the construction of pore size distributions and division of soil water into specific classes (between saturation, field capacity, wilting point, and below), as well as the mean, median, and mode pore size (dMean, dMedian, dMode), further probing changes in soil structure and hydrology.

Soil fungal community analysis

DNA was extracted from 0.25 g of soil at harvest using the DNeasy PowerSoil Kit (Qiagen), and DNA concentrations were measured with the Quan-iT IX dsDNA HS Assay Kit (Life Technologies, Gaithersburg, MD, USA) to ensure that concentrations were normalized to 5 ng/µl. The ITS2 rRNA region (5.8Fun/ITS4Fun) was amplified to characterize fungal community composition. ITS2 primers have been shown to match well with all lineages of the subphylum Glomeromycotina (40) and have successfully characterized high-resolution patterns of AMF community succession (41). The forward and reverse primers contained a 29 (forward) or 25 (reverse) base linker, a 12 base barcode, a 29 (forward) or 34 (reverse) base pad, and a 0–8 base heterogeneity spacer (42,43). Briefly, PCR amplification was carried out for each sample in 25 µl reactions containing: 2 µl template DNA, 10 µl 5PRIME HotMaster Mix (Eppendorf-5Prime, Gaithersburg, MD, USA), 3 µl BSA, 2.5 µl reverse primer, and 5 µl nuclease-free water. Amplification was performed using a single-step PCR method on the Gene Amplification PCR System (BioRad Laboratories Inc.) under the following conditions: denaturation at 96°C for 2 min, 35 cycles of 94°C for 30s, 58°C for 40s, and 72°C for 2 min, with a final extension at 72°C for 10 min. Amplicon libraries were produced from a pool of three separate PCRs per sample, with PCR product again quantified and pooled at equimolar concentrations of 50 ng of each sample. Sequencing of amplicon libraries was performed on the Illumina MiSeq platform (Illumina, San Diego, CA, USA) with 300 bp paired-end reads at the QB3 Genomics Laboratory at the University of California, Berkeley, CA.

Fungal sequence data was analyzed using the AMPtk pipeline (v.1.4.1). To begin, forward and reverse sequences were demultiplexed and primers removed. Then, the UNOISE 3 algorithm denoised the dataset into exact sequence variants, removing likely artificial sequences, including chimera, contaminants, and predicted sequence errors (Edgar 2016). Sequence variants were then clustered into amplicon sequence variants (ASVs) using the AMPtk pipeline. Briefly, this pipeline merges paired-end reads, filters reads by size, and then utilizes DADA2 to denoise and obtain ASVs. Once the reads are mapped to ASVs, a filter module uses a synthetic mock community to calculate the observed rates of index bleed from other samples to remove spurious ASVs (Palmer et al., 2018). Taxonomy was assigned using the AMPtk 'last ancestor' approach by combining global sequence, *UTAX,* and *SINTAX* (Edgar, 2016) alignments against the *UNITE* v.8.3 database (Koljalg et al., 2013). The final ASV table contained 987 fungal ASVs (1,110,187 reads). Raw sequence read files are available in NCBI SRA accession ###########.

Fungi richness was estimated using the observed taxa (S_{obs}) and using the Chao 1 estimator (S_{chao}) (Chao et al., 2006) with the *vegan* package in R (Oksanen et al. 2013). Fungal diversity was estimated using the Shannon diversity index (transformed as $\log_e + 1$). Fungal ASVs were assigned a putative function using the package *FUNGuild*, a Python-based tool that taxonomically parses fungal ASVs by ecological guild using a community-annotated reference database (Nguyen et al., 2016). This allowed us to compare the relative abundance of certain fungal-mediated ecological roles in the agroecosystem, particularly on AMF, plant pathogens, and saprotrophs.

Statistical analyses

First, the effects of management systems on different soil physical, chemical, and biological metrics were tested using generalized linear mixed models with the *lme4* and *lmertest* packages in R (Bates et al., 2015; Kuznetsova et al., 2017). All models accounted for the interaction between the tillage system and cover cropping treatment, plus the fixed effect of depth or random effect of the block when relevant to a particular measurement. Model validation graphs were prepared of 1) residuals versus fitted values to confirm the homogeneity of variance, 2) a Q-Q plot of the residuals to verify normality, and 3) residuals versus each explanatory variable to assess independence. These graphs were visually inspected to assess and confirm model assumptions. Then, four separate ordinations were conducted to reduce the dimensionality of the following datasets: 1) soil chemical and physical properties, 2) soil fungal community, 3) plant response measurements, and 4) root fungal community. Ordinations were accomplished using the *rda* and *metaMDS* functions from the *vegan* package. For summarizing model effects, modeled means and standard errors were calculated for each treatment group using the emmeans package. This involved post-hoc analysis to adjust for multiple comparisons and control the family-wise error rate, typically using methods like Tukey's HSD when interpreting the pairwise differences among treatment levels.

For soil health and plant growth metrics, Bray-Curtis dissimilarities were constructed for each dataset using the *vegdist* function in *vegan*. To illustrate the effect of treatment on these datasets, dissimilarity matrices were ordinated by a principal coordinates analysis (PCoA) with the *rda* function in *vegan.* For soil and root fungi ASVs, Bray-Curtis dissimilarities were also calculated for fungal community matrices, then transformed by a non-metric multidimensional scaling (NMDS). To determine correlations between fungal community composition, soil health indicators, and plant responses, we used the *envfit* function in *vegan* to project vectors onto the ordination, scaled by the strength and direction of correlations. A linear discriminant analysis (LDA) was performed on ASV matrices to evaluate differential abundance across treatments, using the *diff_analysis* function in *MicrobiotaProcess* package in R.

To test the impact of soil management on soil health indicators and plant growth, as well as the differentiation by management in soil and root fungal communities, permutational multivariate analysis of variance (perMANOVA) was applied to dissimilarity matrices using the *adonis2* function in *vegan*. perMANOVA tests the compositional differences across group levels by examining whether the centroids of sample clusters differ by group level. Multivariate homogeneity of group dispersions was tested using the *betadisper* function in *vegan* and confirmed by performing ANOVA tests on the group dispersion values.

To estimate the correlation between soil properties, plant growth, and fungal community composition across treatments, we evaluated the matrix correlation between dissimilatory matrices using the *mantel* function in *vegan*. Mantel statistics were generated between paired data sets and used to estimate the correlation between this study's suite of soil health indicators, plant responses, soil fungi ASVs, and root fungi ASVs. Pairwise Mantel tests were run on each pair of dissimilarity matrices using the function *mantel*, which permutes over the matrix and estimates Pearson's correlation coefficient to generate a single value for matrix correlation. From the results of Mantel tests, we used partial distance-based redundancy analysis (dBRA) applied to dissimilarity matrices to determine which measured indicators of soil health and plant growth were highly correlated with soil fungal community composition. These models were constructed using the *rda* function in *vegan*, revealing whether the matrix of chosen explanatory variables significantly determines the dissimilarities derived from the Bray-Curtis distances in the ASV matrix. A permutation-based ANOVA, using 999 permutations, was performed on the partial dbRDA model to determine the significance of the resulting coefficients.

Results

A gradient in labor, inputs, and disturbance

The farming systems implemented in this study required increasing levels of labor and cultivation intensity, creating a clear gradient in labor input from till to no-till and cover cropping to continuous production (Fig. 5). Average labor hours greatly increased with no-till management (Table 1), with hand-scale no-till requiring 40-45% more labor hours to manage each farming system on a biweekly basis. Here, labor hours signifies the amount of time required *per person* to manage each farming system. Thus, our data shows that hand-scale required an additional day of labor (8 hours) per farm employee each week when compared to tillage-based systems. Continuous crop production also increased labor demands by an average of 2.5 hours biweekly. Our farmer interviews, symposium, and field days corroborated these findings.

Increasing labor also came with increased cultivation intensity, characterized by increasing crop rotations (i.e. an additional crop rotation within a given year), higher rotational diversity, increased compost and organic fertilizer inputs, and longer season length. Tractor-based tillage combined with cover cropping had the lowest labor demands, fewer crop rotations per year, and the lowest cultivation intensity. Meanwhile, hand-scale no-till management combined with continuous cropping required the highest levels of labor and had the highest number of crop rotations, inputs, and longest season.

The implementation of these practices also created a distinct gradient in soil disturbance (Fig. 3). The thick tap roots of the forage radish cover crop represented higher levels of soil disturbance than the shallow, thin roots of the *Brassica oleracea*, which was the overwintering cash crop in the continuous cropping system. When combined with tillage, this represented both mechanical (tractor) and biological (forage radish root) sources of disturbance. On the other side of the gradient, hand-scale no-till combined with continuous production created relatively low levels of soil disturbance.

This gradient emerged organically from implementing farmer-inspired practices and principles. We did not design this gradient *a priori*, but it is critical to understanding the ecological transition that occurred during the study.

Soil health and ecology

After just two years, the soil's physical, chemical, and biological properties demonstrated significant differentiation by the farming system. Taken together, soil health indicators differentiated with increasing degrees of agroecological intensification (Fig. 6). They were most strongly partitioned by tillage (Fig. 6; perMANOVA, $F=20.0$, $p=0.001$), with soil moisture, micro and mesopores, carbon and nitrogen stocks, and enzyme activity all increasing within the no-till systems. Tillage systems, on the other hand, exhibited increased fungal richness and diversity. Winter cover cropping versus continuous cash crops had a less significant impact on soil health (Fig. 6, perMANOVA, $F=3.53$, $p=0.062$), although specific biological and physical properties were influenced by cover cropping. Within tillage systems, cover cropping had little effect under tillage and a stronger effect under no-till, increasing particulate organic matter, nitrogen availability, soil moisture, and enzyme activity when these practices were used in combination.

Soil structure and hydraulic properties changed by farming system, with tillage negatively affecting gravimetric water content at all depths (Table 1), and cover cropping increasing water content by as much as 30%, particularly at deeper soil depths (50 cm; Table 1, Fig. 7A). Soil structure, here expressed as pore size distribution derived from a soil water retention curve, changed significantly with farming system in the second but not the first year (Fig. 7B). Hand-scale no-till with winter cover crops increased the percentage of mesopores that occupied a range of 0.2 - 60 μm (corresponding to water potentials of -1.5 to -0.01 MPa), increasing plant-available water by 23% (Table 1). Meanwhile, tillage systems increased macroporosity (> 60 μm) by 20%, introducing larger pores that freely drain with gravity and increase evapotranspiration. Pore size mean, median, and mode all increased by 25% in tilled systems, illustrating the tractor's physical creation of soil cavities during tillage. Finally, the hand-scale no-till system with continuous crop production created more micropores (<0.2 μm equivalent to -1.5 MPa), effectively increasing soil water storage below the wilting point and making it unavailable to plants.

Soil organic carbon (SOC) increased by 207% (at 0-5 cm) and 47% (at 5-15 cm) after two years of implementing the hand-scale no-till system, with tillage system driving changes in soil carbon stocks (Table 2, Fig. 8A). Carbon stock increases were more modest at depth, but were still increased by hand-scale no-till systems, including increases from 65 Mg C/ha with tillage to over 80 Mg/ha under no-till at 30-50 cm. Size-based fractionation revealed a significant 25% increase in the concentration of mineral-associated organic carbon and a 250% increase in the concentration of particulate organic carbon under hand-scale no-till (Table 2, Fig. 8B).

POXC, a common soil health indicator that is associated with lignin levels in soil (44), also had the highest concentration in hand-scale no-till systems, with an average 182% increase in POXC when compared to tilled systems (Table 2, Fig. 9). As POXC was measured over the two years throughout implementation, we were able to determine that the tilled systems were depleted in POXC from baseline by an average of 145%.

The potential activity of C-cycling (Glucanase/1,4-β-Cellobiosidase; CBH), β-glucosidase; BG) and N-cycling enzymes (Leucine-amino-Peptidase; LAP, Exochitinase; NAG) were mostly undifferentiated across the particulate and mineral-associated soil fractions. There was one notable exception to this trend. BG was significantly higher under hand-scale no-till in the POM fraction (Table 3), indicating higher C-cycling of small organic molecules in dynamic, particulate matter. In the bulk soil, carbon and nitrogen cycling were both increased under hand-scale no-till. Surface soils from hand-scale no-till plots had BG activity averaging 47% higher than tilled systems, signaling increased decomposition of small organic compounds, potentially driven by high compost application rates (Table 3). C-cycling potential enzyme activity in POM fractions was 25% higher with cover cropping but an average of 7.5% higher in MAOM fractions with continuous crop production. This demonstrates a shift in enzymatic activity and nutrient cycling from particulate to mineral-associated fractions, possibly due to a shift from incorporating unprocessed crop residues (cover crop) to higher compost application (continuous cash crop). The potential activity of N-cycling enzymes was strongly differentiated by farming system across depths, with hand-scale no-till increasing both NAG and LAP potential activity by as much as 150% at the soil surface (Fig. 7A). Principal coordinate analysis of N-cycling enzymes across depths, farming systems, and soil fractions revealed distinct N-cycling regimes between tillage systems, as supported by perMANOVA ($F=6.2, p=0.002$) (Fig. 7B).

These differences in N-cycling under hand-scale no-till were coupled with higher total N, nitrate, and ammonia levels in the bulk soil and soil fractions (Table 4). Total N was over twice as high in bulk soils, particulate organic matter, and mineral-associated organic matter when comparing hand-scale no-till to tillage systems.

Fungal species richness, or the number of unique fungal taxa within a given soil sample, was altered by winter cover more than by tillage system—both the Observed richness index were significantly higher under continuous cash cropping (Table 5, Fig. 8A). Soil fungal diversity was also found to be increased under tillage-based systems systems, as estimated by the Shannon index (Fig. 8B).

The community composition of AMF was partitioned by farming system, with distinct assemblages of the fungal symbiont across each treatment (Fig. 9A). In three systems–the two tilled systems and the no-till, continuous system–*Claroideoglomus, Rhizoglomus,* and *Rhizophagus* were the main taxa in

AMF communities. However, when cover cropping was combined with no-till, the AMF community was dominated by *Funneliformis, Glomus, and Rhizophagus*. This data is paralleled by AMF association measurements, which were most influenced by the cropping system (Table 5). Association rates in the continuous, no-till farming system exhibited a 210% increase in arbuscules, vesicles, and hyphae within plant roots compared to other systems (Table 5, Fig. 9B). Meanwhile, the hand-scale no-till system with cover cropping had the lowest association measurements.

The farming systems also led to distinct fungal plant pathogen and saprotroph communities. Differential abundance analysis revealed that no-till management was particularly enriched in the genus *Cylindrocarpon* ($\log_{10}$(LDA)=9.0), a large family of pathogens that cause root rot (Sup. Fig. 1). Higher rates of fungal root damage were observed during the implementation of the project; these data confirm observations at the study site of plant pathogen pressure with conversion to no-till. No-till systems had a higher differential abundance of thermophilic saprotrophs that aid in cellulose degradation, including genera *Myceliophthora* ($\log_{10}$(LDA)=8.4) and *Thermomyces* ($\log_{10}$(LDA)=8.7). These saptrotrophs, in combination with significantly higher levels of POXC found in no-till systems, suggest tilled systems were enriched in three main genera of saprotrophic fungi–*Schizothecium* ($\log_{10}$(LDA)=8.5), found in fecal matter, *Spizellomyces* ($\log_{10}$(LDA)=8.4), a pollen-degrading family of fungus, and *Mortierella alpina* ($\log_{10}$(LDA)=7.6), a soil-dwelling and chitin-degrading fungal species. Patterns of richness and diversity of pathogens and saprotrophs mirrored the overall patterns in fungal community composition—continuous production sustained higher levels of richness and diversity of these fungal guilds.

Overall, soil physical properties (pore sizes, bulk density) were generally negatively correlated with biological and chemical indices (enzyme activity, plant nutrients, carbon) (Fig. 6A), demonstrating a key connection between agroecological practice, soil structure, and improved soil ecological functioning.

Plant responses and adaptive capacity

Despite the changes in a broad suite of soil health indicators, plant growth metrics were less responsive to management (*perMANOVA, $F=0.97$, $P=0.45$)*. Root fungal community composition was also far less responsive to farm management than soil fungal communities, demonstrating mild partitioning by tillage system (perMANOVA, $F=1.9$, $P=0.047$) but not by winter cropping system.

Farming systems did not significantly affect aboveground biomass, below-ground biomass, and total yield of the focal crop (black beans, *Phaseolus vulgaris)* (Table 5, Fig. 9). The small changes in biomass and yield (e.g. 5% lower in hand-scale no-till), although statistically not significant, are consistent with farmer observations that no-till management can lead to initial yield decreases.

Stem water potential, a metric related to plant plant stress, of the focal bean crop steadily declined as soils dried throughout the end of the season (Fig. 11). There was a moderate effect of the farming system on stem water potential, with the interaction between tillage and cover cropping having a larger impact on plant stress than either factor alone (Table 1). Other plant response metrics, such as pod production, shoot weight, and aboveground biomass, were largely unaffected by the farming system. Redundancy analysis that modeled the effect of plant growth on root fungal communities found that AMF associations was the only plant metric highly correlated with root ASVs composition (RDA ANOVA, $F=3.8025, p=0.016$). These results corroborate our molecular methods. A measurable and significant correlation exists between observed fungal root association and the fungal communities in the soil. We found no differences in crop nutrient content between the farming systems (Supp. Fig. 2). Macronutrients (N, P, K) and micronutrients (S, B, Ca, Mg, Zn, Mn, Fe, Cu) were not differentiated by farming system in the focal bean crop.

Total annual vegetable production was highest in the no-till and cover cropped system, averaging 3260 kg/acre higher cash crop production across the 2019 season when compared with tilled systems (Table 5, Fig. 12). No-till systems had higher total production due to an additional growing cycle that we were able to plant when fields were still too moist to proceed with tillage.

Relationships between soil health, fungal communities, and plant indices

Groups of soil, plant, soil fungi, and root fungi measures revealed a strong correlation between soil health indicators and plant growth, as well as between plant growth and soil fungal community composition (Table 6). While plant responses to farming system were less significant in this study, plant growth metrics were correlated with changing soil properties and soil fungal community composition.

On the other hand, root fungal community composition was not correlated with soil fungi, plant growth, or soil properties. Bray-Curtis dissimilarity matrices of root fungal ASVs were not correlated with any of the other dissimilatory matrices compiled in this study. This demonstrates a relative inflexibility in root endophytes, or root-dwelling fungal species, to changing soil, vegetative, and environmental conditions.

Critically, plant-available water (PAW) was the only soil health parameter found to be a valid explanatory variable of soil fungal community composition. Specifically, the volume percentage of soil water held between the wilting point and field capacity was the soil health parameter retained in a model explaining the Bray-Curtis dissimilarity in the soil fungal ASV matrix (RDA ANOVA, $F=4.8299$, $p=0.02$).

Discussion

Given the marked physical, chemical, and biological changes observed in the soil under hand-scale no-till, it is no wonder that practitioners were interested in understanding the system's impact on their farms, soils, and crops. However, higher labor inputs were required to increase cropping intensity and reduce soil disturbance in our study system. Reduced soil disturbance led to rapid and dramatic changes in the soil ecosystem. Hand-scale no-till systems, compared with mechanized tillage systems, altered soil structure and increased soil moisture even at depth, increased carbon stocks across the soil profile, and increased N-cycling enzyme activity while reducing fungal diversity. Meanwhile, winter cover cropping—as opposed to continuous crop production—increased water retention at all depths and led to the accumulation of particulate organic matter but decreased fungal species richness.

The changes in soil structure, ecology, and functioning in this study were the outcomes of whole farming systems, with all four treatments implementing organic farming practices intended to support biodiversity and ecological functioning. These systems were derived from farmer-identified principles, creating four distinct management systems differentiated not only by tillage system and winter cover, but also by crop rotations, season length, inputs, crop termination, and labor.

Taken together, a picture emerges of four systems with distinct labor, inputs, and cultivation intensities. Continuous crop production paired with hand-scale no-till management had the highest levels of labor, external inputs, and crop rotation, while cover cropping paired with tillage had the lowest levels. Rather than understanding these as alternative farming methods, we might better understand them as various levels of intervention that farmers could employ in diverse contexts. Some farmers might practice all four systems in a single season. On the other hand, due to land and capital constraints, only one method might be available to others. Continuous production and no-till may be the only feasible option for an urban community garden, whereas a rural farmer with limited labor support and marginal soils may require cover cropping and tractor-based tillage. Understanding these systems-level considerations and adaptive moves that employ principles—not prescriptive practices—helps contextualize the results found in the soil and plant responses to these farming methods.

These differences, in turn, produced emergent responses in soil health. Changes in soil health were emergent to the degree that they were non-additive, non-linear, and dynamic—while the assemblage of principles and practices in this study created a gradients in management, soil health responses did not follow those gradients.

Changes in soil health across a gradient of farming systems

Hand-scale no-till with year-round crop production was influenced by a unique combination of relatively high compost and organic fertilizer inputs, high labor inputs, and rapid succession of crops. This farming system shifted soil structure to the lowest bulk density and highest soil moisture at the surface—but these effects disappeared at depth. The minimal disturbance of this system created a layer enriched in carbon, soil moisture, and biological activity in the first 5-10 cm of the soil. This system also decreased the number of macropores (16-37%) and increased the number of micropores (27-36%), which aligns well with a recent meta-analysis on the effects of no-till agriculture on soil pore structure (45). This pore architecture, in combination with the highest levels of mineral-associated organic matter, suggests that changes in organic matter adsorption to the surface of clay particles may have been partially responsible for changes in soil pore structure. This system also had unique biological attributes, with the highest levels of AMF association and N-cycling enzymes at the soil surface and relatively enriched fungal richness compared to no-till paired with cover cropping. The enriched layer of carbon, water, and biological activity that formed at the soil surface did have some influence at depth—average carbon stocks of 85 Mg C per hectare at 50 cm depth approached that of California annual grasslands (46)—but we observed the most dramatic changes in this system at the soil surface.

However, introducing deeply rooted cover crops within no-till led to changes across the soil profile. Forage radish cover crops created a higher degree of disturbance, allowing for important shifts in pore architecture, bulk density, and soil moisture at depth. Soil moisture was highest in this system throughout the profile, with cover cropping emerging as an important driver of soil moisture in a mixed-effects model. This was likely driven by observed decreases in bulk density and increases in microporosity. Micropores (between 5 - 30 μm) contain highly immobile water that is still available for extraction by plants, especially critical in water-limited California climate that these farmers are working in. Particulate organic matter was strongly increased under no-till with the introduction of cover crops, increasing POM by 38% compared to continuous winter production and 163% compared to tilled systems. High inputs of labile, particulate carbon, and high soil moisture could have driven observed changes in biological functioning, including high extracellular N-cycling enzyme activity, low AMF association, low fungal richness, and a dramatic change in functional diversity of AMF taxa. Low association and diversity of mycorrhizal fungal partners occurred in the system with the highest plant biomass and overall highest production, although those outcomes were not significant. Crops may have downregulated collaboration with fungal symbionts in nutrient- and water-rich soil environments, particularly high levels of phosphorus, which have been shown to limit plant-AMF associations (cite). Similarly, no-till with continuous production was highly enriched with pathogenic fungal genera like *Cylindrocarpon*, which may have contributed to higher levels of AMF association. Other studies have demonstrated that pathogen pressure can lead to higher recruitment of AMF in crop roots and that AMF can help suppress plant pathogens (47–49). Deeply rooted cover crops in the winter months, as opposed to continuous crop production, created conditions in clay-rich soils for improved root penetration, increased soil moisture, POM accumulation, and microbially-mediated N acquisition.

Finally, the tilled soils diverged significantly from those under no-till. Routine ripping, discing, and harrowing with a tractor were performed cyclically throughout the growing season and represent standard practice for years for the site. Compared with the newly established no-till systems, the tilled systems had lower soil moisture, higher bulk densities, and higher macroporosity—large pores that could more easily lose water during the dry summer growing season. Tillage systems reduced soil moisture by as much as 55%. On average, the tilled system also had 52% lower carbon stocks (0-15 cm) and reduced MAOM and POM fraction concentrations. These physical and chemical differences coincided with distinct biological functioning—tilled systems had higher fungal richness and diversity, but lower extracellular enzyme activity and observed AMF association rates in roots. We speculate that the higher proportion of organic matter inputs as whole plant biomass and intact crop residues to the tilled systems led to a more diverse fungal community (50–52). Higher disturbance in natural ecosystems can have higher fungal richness (53), especially when an intermediate level of disturbance is introduced (54–56). Our study suggests this as well. Tilled systems did have the highest measured yields in the focal bean crop but ultimately lower total production compared to no-till due to the increased season length that hand cultivation allowed. Biologically mediated C and N-cycling was greatly reduced in the tilled system, as evidenced by extracellular enzyme activity.

While soil health indicators showed significant differentiation between farming systems, plant growth metrics were far less responsive to management and were broadly undifferentiated across farming systems. For those concerned with yield decreases under no-till (18,57), this study supported farmer's recognition that yields under hand-scale no-till can be comparable to those in conventional tillage systems given certain climates (e.g., more arid conditions), soil types, on-farm diversification, or agroecological practices (58–60). Crop macro and micronutrient density was also undifferentiated by management system, emphasizing the need to expand and complicate a narrow view of how agroecological practice might influence nutrition (12,61,62). The farming systems influenced a few plant growth measurements. Stem water potential, a measure of crop water stress, decreased under no-till likely due to changes in soil pore structure and organic matter increases. Fungal-root association numbers and total yield were highly correlated with the community composition of soil fungi, indicating the strong control that soil fungi have on plant growth and endophyte entry into root systems. However, this provides little insight into the mechanism of these soil fungal communities in the context of no-till. Rather, they corroborate our findings via molecular methods, confirming that fungal diversity and community composition observed by sequencing are highly correlated with fungal root associations.

Thresholds of ecological change

The concept of a threshold might further illuminate the ecological, agronomic, and material transformations observed in this study. We propose that the implementation of this study created key thresholds in soil disturbance, inputs, cultivation intensity, and labor. A threshold is a critical zone or limit beyond which a system changes state. The concept of a threshold appears in various fields, including ecology, sociology, economics, and climate science. It typically signifies a tipping point in a highly complex, non-linear, or emergent system. In ecology, thresholds most often describe transition points between two stable states in an ecosystem, where thresholds are "critical values of an independent variable around which a change from one stable state to another occurs." (63) This has been documented in a wealth of environments and ecological systems (64). These "threshold" zones are discontinuities in the overall response of a system resulting from small and incremental changes in a set of controlling variables (65). Thus, thresholds are inherent parts of emergent systems.

In this study, tracing changes in soil structure is an entry point for describing this emergent behavior. Soil structure is a key component of soil health and a governing property of soil functioning, including gas exchange, respiration, water infiltration and storage, root penetration, and soil organisms' dispersal and life cycles (66). In addition, soil structure is one of the soil parameters directly manipulated by distinct tillage treatments and has been shown to improve through soil health-promoting practices that increase biological structure formation (67). After just one year of implementation, none of the systems in this study had observable changes in soil structure or bulk density (Fig. B). One year of reduced disturbance, cover cropping, compost application, and hand-cultivation was not enough to measurably alter the soil's bulk density or physical structure. However, after two years, a critical threshold was reached and the soil structure began to diverge dramatically between farming systems. Implementing no-till and deeply-rooted winter cover crops shifted soil structure towards a greater number of mesopores, reducing bulk density even at depth. This directly impacted soil water retention, with soil moisture increasing across the soil profile by as much as 50%, thus impacting soil biological functioning. Redundancy analysis revealed that plant available water—derived from soil water retention curves—was the only soil health metric that best determined the community composition of soil fungi. These cascading effects of soil structure on water, biological communities, and ecological functioning help illustrate the emergent process by which soil structure can radically alter soil functioning through feedbacks and non-linear transformations (68,69).

Fungal community composition, AMF in particular, offer more examples of ecological thresholds in this study. AMF community composition was similar across all the farming systems except the unique combination of no-till and cover crops[2]. In that system, overall fungal community richness, AMF community diversity, and AMF association decreased dramatically. This change in AMF coincides with the highest measured soil moisture, soil carbon, and surface nitrogen levels. However, AMF diversity and plant-association changes are not linearly related to these soil properties. If they were, we would see a more intermediate level of diversity and association in the other no-till plots, which had similar levels of soil water and nutrient availability. This is not what we observed. At some threshold level, the soil ecosystem was sufficiently saturated that the whole fungal community underwent a phase change and the mycorrhizal fungal communities collapsed. Note that AMF associations in the no-till system with *continuous* cropping was, on average, 120% higher than the system with cover cropping. By changing one small variable in management—the species variety and root morphology of our winter crop—an enormous and outsized influence on the fungal composition of the soil was produced. Forage radish's taproot, when fully grown, can present a significant level of soil disturbance, even in clay soils. The richness, diversity, and life cycle of soil fungi was an emergent property of the soil ecosystem that led to community collapse and high levels of plant-associations, depending on small shifts in crop species diversity. This demonstrates a complex interaction between disturbance, cropping system, and soil fungal species richness and diversity, with continuous plant cover emerging as a key driver of fungal species richness regardless of differences between tillage systems.

[2] It should be noted that neither Forage radish (*Raphanus sativus var. longipinnatus*) nor Broccoli (*Brassica oleracea var. italica)* form relationships with arbuscular mycorrhizal fungi (AMF), but have not been demonstrated to negatively affect subsequent AMF associations in cash crops (70).

This trend continued when looking at carbon and nitrogen cycling. N cycling in the particulate-associated soil fractions increased by 43% in the no-till and cover crop plots. This indicates a shift in N acquisition towards larger, particulate organic compounds with cover cropping, with implications for microbially mediated carbon storage and N use efficiency. The acquisition of N through biologically mediated pathways is a key indicator in shifting nutrient acquisition and cycling strategies across farming systems. Carbon cycling within the no-till systems was also highly altered. Higher mass percentages of carbon in mineral associated fractions, along with *lower* rates of carbon cycling enzymes in those same fractions, is possible evidence for improved soil C storage by mineral association under no-till management. While compost application can account for relative changes in soil carbon levels, it does not necessarily explain a shift in the division of soil carbon across particle sizes. This phenomenon, coupled with decreased C potential enzyme activity within mineral-associated soil fractions and shifts towards smaller soil pores, suggests higher rates of C storage that can result from minimizing soil disturbance.

All these observations, taken together, offer evidence of emergent soil properties that took shape while implementing the systems described in this study. A small change in winter crop species diversity—substituting forage radish for continuous broccoli production—and their root morphologies dramatically reduced AMF diversity, fungal richness and diversity, and AMF plant associations. A single additional year of minimal tillage led to a change in the pore architecture of the soil, with cascading consequences for soil water storage, root penetration, plant growth, and fungal community composition. The soil fungal ecology exhibited rapid collapse with relatively small changes in management, perhaps definining a thresholds at which requisite soil water, carbon, and plant nutrient availability were reached. These emergent behaviors complicate and subvert reductive analyses that deem certain practices as "better" or prescribe particular practices in a given context. Rather, it shows that a range of adaptive possibilities are available to farmers as they attempt to care for soil, landscapes, and people.

Implications for farmers and practitioners

This study's findings offer implications for practitioners of no-till using hand labor, especially those employing the technique to overcome economic challenges or limited land access.

First, our study offers direct evidence that the transition time to an intensive no-till system for vegetable production can occur relatively rapidly—within two years, in our case. Before implementing the hand-scale no-till system described in this study, the site was tilled multiple times per year and the soil's tilth was maintained via mechanical harrowing by a tractor. After two years, the soil ecology under hand-scale no-till cultivation had diverged significantly from the other systems without significantly reducing yields. It is common to hear, even amongst no-till practitioners, that there will often be a "transition time," in which farmers will have to take losses to transition to no-till. While farmers may experience losses due to the learning curve of new agronomic techniques, our study suggests that yield losses and long transition times are not inevitable with hand-scale no-till adoption.

Moreover, hand-scale no-till expanded the growing season and increased overall production by reducing crop turnover time and allowing for fieldwork during wet soil conditions. Crop turnover time was reduced as our team transplanted or direct-seeded into the soil after removing the previous crop. The elimination of tractor work meant that we did not need to wait for drier soil conditions to plant, thus increasing the length of the growing season. A narrow focus on yields, whose results were inconclusive in this study, misses the more systems-level outcome of getting a whole additional crop planted and harvested under no-till.

The limited differences in crop performance between farming systems offer another important insight: Farmers may be able to move along certain gradients in soil disturbance, inputs, and cropping intensity without negatively impacting crop growth. These findings are highly dependent on local conditions, of course, but they do corroborate the testimonies of practitioners. It is important to note that the systems explored in this study were all regenerative to a certain degree, involving crop rotations and compost application without biocides or chemical inputs. Switching individual practices within organic and biologically intensive systems may not dramatically alter crop performance.

Another major implication of this study is drought resilience and water use efficiency of no-till farming. Improving soil water retention and infiltration is critical for those growing in water-scarce areas such as California and using irrigation systems to maintain their farm operations. The direct through-line in our dataset between changing soil structure, higher levels of soil moisture, and reduced crop water stress provides compelling evidence that no-till can improve drought and water stress. It offers compelling initial evidence for the mechanism of improved water retention and infiltration under organic, hand-scale no-till systems, which merits further investigation by practitioners and agroecologists alike.

Labor, specifically hand labor, emerged early on in this study as a critical dimension identified by this network of farmers. Implementing no-till via hand labor required more labor hours than tractor-based tillage. Farmer interviews, field days, and focus groups corroborated these results. However, not just the quantity but also the *type* of labor changed. The nature of labor in agriculture matters (71). Careful attention must be paid to who is performing labor, who is benefitting, and who is being exploited. The long-term nature of the farming systems employed in this study and the ongoing nature of their upkeep meant that new relations between our research team and the field site had to be established to carry out the work. New labor relations between volunteers, students, researchers, and community members emerged to complete the tasks necessary. Harvesting broccoli in January is not a typical field research technique, but it was in this case. In other words, our research team members became long-term stewards, which fundamentally changed the nature of the work. Ethics of care complicate seemingly straightforward notions of agricultural labor. One form of labor most obscured by patriarchal, colonial, and capitalist social systems is care work (72–74). At its root, agriculture is a practice in care—caring for and attending to the needs of plants and agroecosystems. Economic pressures, exploitative working conditions, extractive economies, and ideologies of domination and supremacy often obfuscate this. Within the context of this study, care is an organizing principle *and* emergent property of the hand-scale farming system.

An ethos of care was also reflected in the community that inspired this study. Our community-based participatory action approach revealed that a spirit of care—for the soil, for landscapes, for people—was often a motivating factor for adopting this farming system. This enriches a sense of why such a diverse group of practitioners—spanning many political formations, organizational structures, economic models, cultural backgrounds, and geographic locations—would adopt a similar farming system. There is remarkable flexibility in a hand-scale farming system that does not require specialized machinery or inputs. There is unique organizing power in a farming system that requires more labor power, creating new social relations to achieve the needs of (and care for) its practitioners. The unique social and labor relations employed by this network of farmers are critical to understanding the system's success. Ultimately, the outcomes in the soil were rapid, structural, and directly observable. Measured differences in soil biological community composition, soil structure, and soil water are directly observable by practitioners.

Ultimately, this study not only transformed the soil ecology of the contested land on which it was situated but also the social, cultural, and political conditions. Because of the more permanent nature of hand-scale no-till and the high levels of volunteer labor needed to implement it, a permanent community sprung up around the project. Berkeley Student Farms, a coalition of student-led agroecology projects, was founded partly due to this project. The permanence of the no-till beds also created cracks in the institutional mechanisms of land access at UC Berkeley, allowing a foothold for more community-based projects to gain access. Overall, the entire 1.8-acre site is now cultivated with herbs, vegetables, and fruits distributed for free to the community and has become the site of regular community education, organizing, and celebration. These are likely the most important thresholds crossed—paradigmatic shifts in how a community cares for itself and the Earth.

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Figure 1. Images from the history of the so-called Oxford Tract. Above, a historic photograph after the 1923 fire that swept through North Berkeley, burning homes to the ground and making the parcel available for purchase to the University of California. This fire has led to elevated levels of lead and other heavy metals on the site. Below, students and organizers in dialogue at the Oxford Tract in 2023. The site is now a space for agroecological education, practice, and movement building.

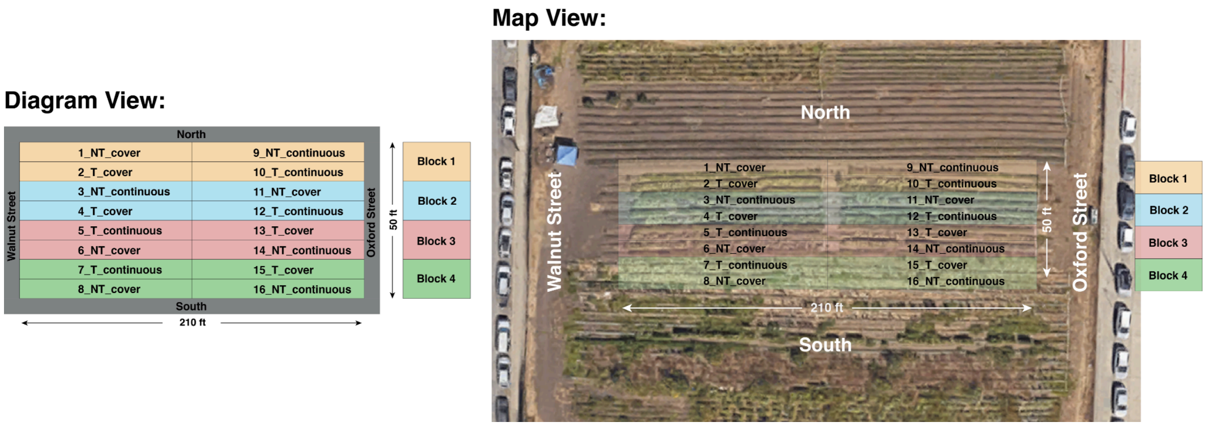


Figure 2. The Oxford Tract field station, and study design, with four replicates of each farming system randomly assigned within a block.

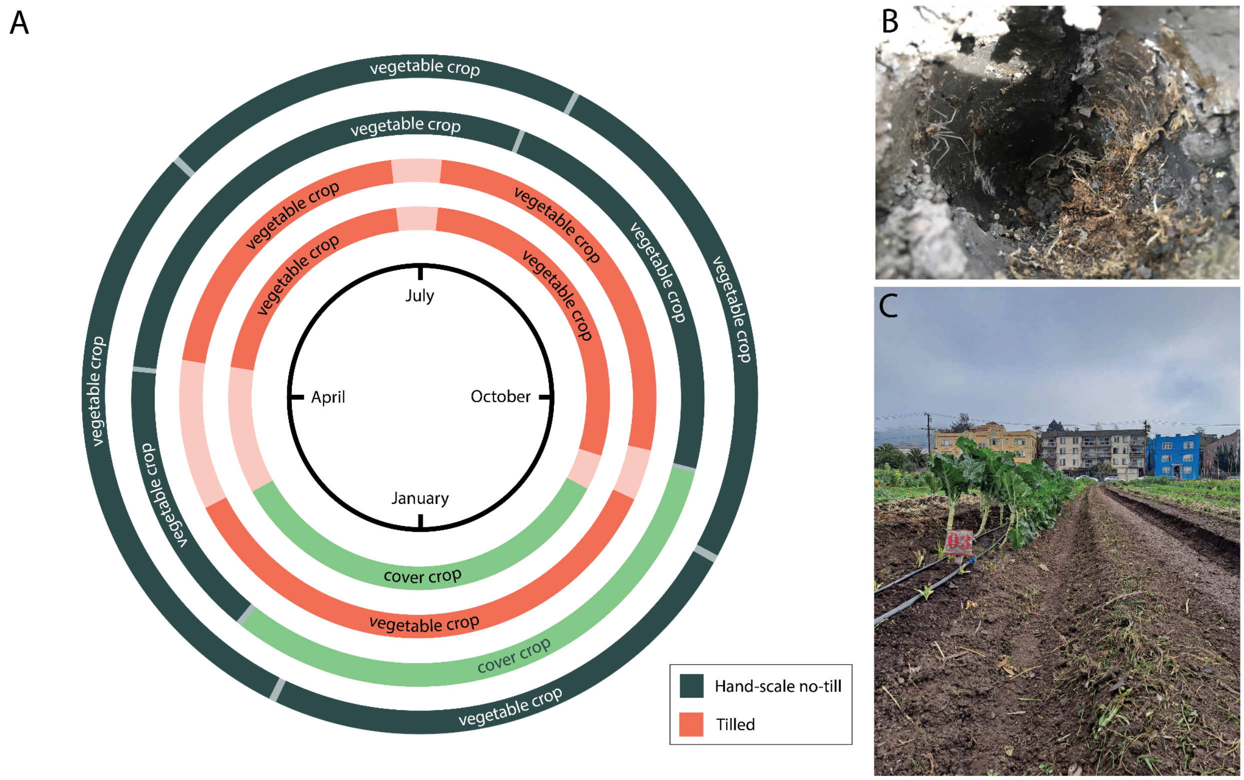


Figure 3. (A) A diagram showing the annual management schedule of the four different farming systems from this study. Breaks between crop cycles indicate the transition time for soil preparation. In the tilled systems (orange) these breaks are significantly longer than in hand-scale no-till. Particularly during the wet winter season, there was a period where the tractor could not enter the field due to wet soil conditions. Mowing, discing, harrowing, waiting for crop residue decomposition, and the preparing planting beds could take up to two months. Meanwhile in the hand-scale no-till (blue), transitions between crops were made immediately—often on the same day! Note that during each crop cycle (*not* including cover crops) amendments of compost were made. In the hand-scale no-till the compost application rate was 56 tons/ha, whereas in the tilled system it was 28 tons/ha. (B) This is an example of a large macropore created by the Daikon forage (or tillage) radish. Note the spider for scale. (C) A crop of collard greens (left) is adjacent to a recently tilled bed. An illustration of the offset timing of our systems, and the ability to maintain crop production under hand-scale no-till while tillage was still underway in the tilled system.

1. Minimize soil disturbance (i.e. no-till) especially through hand-scale techniques that forego mechanization (i.e. hand-scale)

2. Maximize coverage of soil, especially through the use of composts and mulches

3. Maximize planting densities in both space and time; maximize living roots

4. Maximize biodiversity at all scales; enhance functional biodiversity via natural enemies, antagonists, soil biota, etc. by creating appropriate ecological conditions

5. Maximize recycling of on-farm resources; optimising organic matter decomposition and nutrient cycling

Figure 4. The principles of a hand-scale no-till farming system, as articulated by this community of practice. These principles were derived from farm visits, field days, a one-day symposium, and the collaborative implementation of a field experiment alongside an advisory team of local farmers.

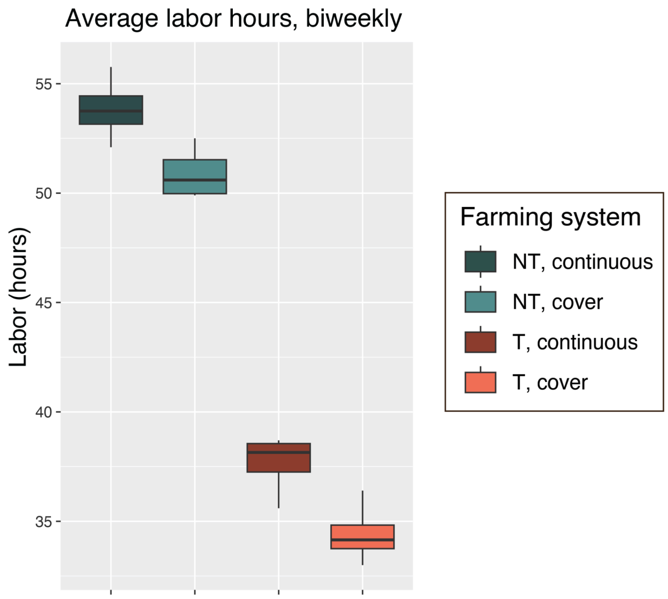


Figure 5. Average hours worked per person every two weeks to manage the farming systems in this study. Labor hours data were collected daily via an online form accessed on a smartphone.

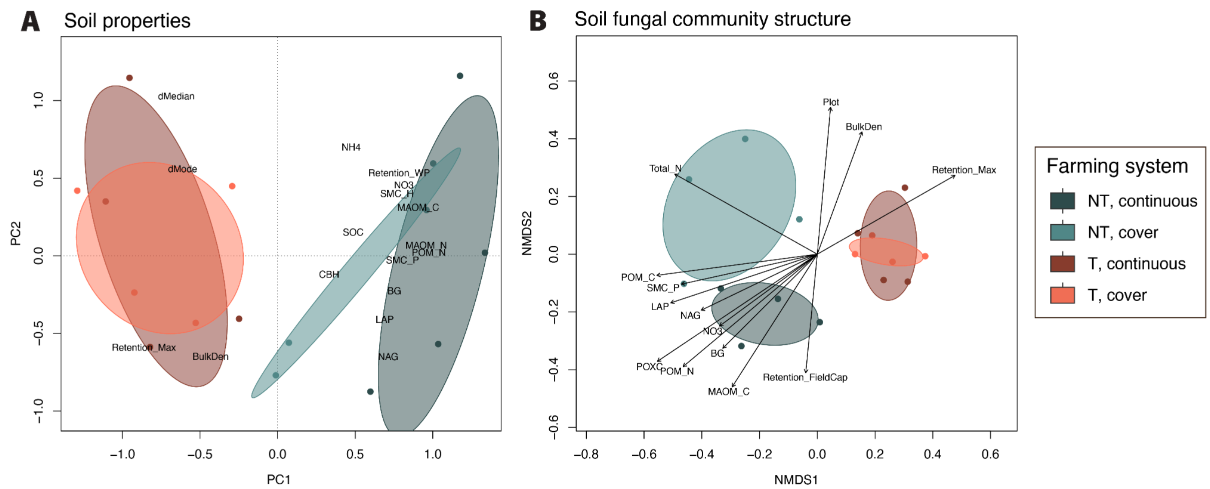


Figure 6. Principal component analyses of soil properties (A) and NMDS of soil fungal communities (B). Soil biological, chemical, and physical metrics demonstrate strong differentiation by management system after just two years (*F=1.995, P=0.003*). No-till systems exhibited elevated levels of inorganic nitrogen, potential enzyme activity, and soil moisture, among other metrics. Soil fungal communities demonstrated strong partitioning based on management, correlated strongly with differences in soil N stocks, water retention and soil moisture, as well as soil enzyme activity.

Variable	Hand-scale no-till				Tilled				Tillage	Cropping	Tillage x Cropping
	Continuous crop		Cover crop		Continuous crop		Cover crop		F	F	F
	Mean	SE	Mean	SE	Mean	SE	Mean	SE			
Gravimetric water content, at harvest (g H2O / g soil)											
0-5 cm depth	0.10	0.011	0.10	0.01	0.04	0.003	0.05	0.006	**48.3 (***)**	0.59	1.00
5-15 cm depth	0.12	0.011	0.14	0.02	0.10	0.011	0.09	0.007	**6.1 (*)**	0.06	1.25
15-30 cm depth	0.11	0.008	0.13	0.01	0.10	0.008	0.11	0.005	3.13	3.74	0.72
30-50 cm depth	0.12	0.006	0.15	0.01	0.10	0.006	0.13	0.007	**5.8 (*)**	**10.3 (**)**	0.12
Volume fraction of soil pore classes											
<0.2 μm (-1.5 MPa)	0.14	0.01	0.17	0.02	0.12	0.01	0.11	0.01	**10.1 (**)**	0.62	2.31
0.2 - 60 μm (-1.5 to -0.01 MPa)	0.12	0.01	0.17	0.02	0.13	0.01	0.13	0.02	0.65	2.19	1.70
>60 μm (-0.01 MPa)	0.19	0.01	0.16	0.04	0.25	0.01	0.24	0.01	**11.2 (**)**	0.99	0.56
Stem water potential (bar)											
8/2/19	-4.7	0.14	-5.0	0.18	-4.9	0.17	-4.6	0.08	0.35	0.01	**5.9 (*)**
8/6/19	-5.5	0.21	-5.9	0.29	-6.1	0.19	-6.8	0.53	**5.2 (*)**	2.6	0.17
8/15/19	-8.1	0.73	-7.0	0.39	-6.8	0.12	-8.3	0.23	0.001	0.12	**9.0 (*)**
8/23/19	-7.5	0.70	-7.2	0.61	-8.6	0.66	-8.1	0.67	2.1	0.36	0.023
8/28/19	-10.2	0.34	-9.8	0.75	-9.5	0.50	-9.5	0.42	0.90	0.11	0.18

Table 1. Soil and plant water metrics measured across the four farming systems, with modeled means, standard error (SE), and F-statistics reported for each treatment and their cross terms. (* = $p < 0.05$., ** = $p < 0.01$, *** = $p < 0.001$)

Variable	**Hand-scale no-till**				**Tilled**				**Tillage**	**Cropping**	**Tillage x Cropping**
	Continuous crop		Cover crop		Continuous crop		Cover crop		F	F	F
	Mean	SE	Mean	SE	Mean	SE	Mean	SE			
Total Carbon											
Concentration (g C / kg soil)											
0-5 cm depth	5.5	1.2	5.4	1.2	2.4	0.2	2.3	5.5	**13.1 (**)**	0.03	0.004
5-15 cm depth	3.3	0.2	3.4	0.2	2.3	0.1	2.5	3.3	**23.5 (***)**	0.3	0.1
15-30 cm depth	3.0	0.6	2.8	0.6	2.2	0.2	2.2	3.0	2.4	0.1	0.0
30-50 cm depth	2.5	0.3	2.7	0.1	1.9	0.2	2.1	2.5	**6.8 (*)**	0.6	0.0
Stocks (Mg C / ha)											
0-5 cm depth	39.9	7.7	36.4	8.4	16.5	1.0	16.5	39.9	**14.4 (**)**	0.10	0.09
5-15 cm depth	48.5	2.8	46.0	3.5	31.6	1.9	35.2	48.5	**24.4 (***)**	0.03	1.23
15-30 cm depth	71.0	14.6	65.5	15.3	49.4	2.2	49.3	71.0	3.13	0.07	0.06
30-50 cm depth	80.8	11.6	86.0	2.5	60.0	3.7	68.0	80.8	**6.3 (*)**	0.74	0.03
Permanganate Oxidizable Carbon (POXC, mol MnO^{4-} reduced / kg soil)											
5 cm	945	115	955	63	521	25	566	945	**34.3 (***)**	0.15	0.06
15 cm	740	52	810	45	552	43	562	740	**24.7 (***)**	0.83	0.46
30 cm	555	92	713	34	528	46	536	555	3.09	2.06	1.67
50 cm	571	74	404	100	479	91	471	571	0.02	1.23	1.00
Soil fractions (g C / kg soil)											
Particulate Organic Carbon	2.9	0.6	2.6	0.6	1.2	0.1	1.2	2.9	**13.7 (**)**	0.13	0.12
Mineral-Associated Organic Carbon	1.6	0.1	1.7	0.1	1.4	0.1	1.4	1.6	**8.7 (*)**	0.88	1.10

Table 2. Soil carbon metrics measured across the four farming systems, with modeled means, standard error (SE), and F-statistics reported for each treatment and their cross terms. ($* = p < 0.05$., $** = p < 0.01$, $*** = p < 0.001$)

Variable	Hand-scale no-till				Tilled				Tillage	Cropping	Tillage x Cropping
	Continuous crop		Cover crop		Continuous crop		Cover crop		F	F	F
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**			
Bulk soil, potential enzyme activity (nmol g^{-1} hr^{-1})											
NAG											
0-5 cm depth	9054	2225	12396	1943	4300	867	4522	260	**16.7 (**)**	1.33	1.02
5-15 cm depth	9538	1206	7615	979	5504	1026	6961	265	**6.2 (*)**	0.06	3.23
15-30 cm depth	6567	869	6907	502	4453	684	4818	426	**7.7 (*)**	0.22	0.00
30-50 cm depth	6220	1113	3704	502	4445	751	4748	486	**0.23**	2.14	3.47
CBH											
0-5 cm depth	3317	738	4817	686	3257	717	3775	166	0.78	2.61	0.62
5-15 cm depth	2575	1861	4115	1144	4002	475	3496	491	0.12	0.20	0.80
15-30 cm depth	3495	1183	3735	591	3672	549	3172	415	0.07	0.03	0.25
30-50 cm depth	2840	267	1510	274	2403	500	2751	601	0.86	1.28	3.72
BG											
0-5 cm depth	20735	1411	29265	2071	15863	1784	18010	987	**24.9 (***)**	**10.9 (**)**	3.90
5-15 cm depth	19762	1582	20660	1267	21900	3370	17776	809	0.03	0.65	1.56
15-30 cm depth	18832	2979	17456	3303	17716	470	16980	2082	0.10	0.18	0.02
30-50 cm depth	14344	2747	8164	1882	14732	2308	14571	2296	2.13	1.85	1.67
LAP											
0-5 cm depth	11595	1709	13128	2352	5310	1194	6136	865	**16.6 (**)**	0.52	0.05
5-15 cm depth	9386	769	11071	1166	8020	1010	6292	725	**10.8 (**)**	0.00	3.33
15-30 cm depth	8022	1657	8639	1668	6064	750	5241	366	4.61	0.01	0.33
30-50 cm depth	6060	1011	5482	840	6026	716	6501	829	0.33	0.00	0.38
Soil fractions, potential enzyme activity (nmol g^{-1} hr^{-1})											
Mineral-Associated Organic Matter											

BG	14718	2302	10643	1432	8378	1073	10433	1062	4.5	0.42	3.9
CBH	4679	708	4234	569	3572	323	3691	589	2.1	0.08	0.25
LAP	1959	316	1793	243	1849	212	1471	127	0.85	1.3	0.20
NAG	5913	727	5252	226	5002	435	4510	635	2.3	1.1	0.02
Particulate organic matter											
BG	6482	770	6102	355	4618	619	4504	405	**9.5 (**)**	0.19	0.056
CBH	1508	216	1787	113	1800	405	1609	361	0.036	0.022	0.62
LAP	1127	146	1057	91	1016	229	1006	135	0.26	0.064	0.037
NAG	3539	649	3204	523	2668	359	2372	329	3.1	0.43	0.002

Table 3. Potential soil enzyme activity measured across the four farming systems, with modeled means, standard error (SE), and F-statistics reported for each treatment and their cross terms. ($* = p < 0.05$., $** = p < 0.01$, $*** = p < 0.001$)

Variable	Hand-scale no-till				Tilled				Tillage	Cropping	Tillage x Cropping
	Continuous crop		Cover crop		Continuous crop		Cover crop		F	F	F
	Mean	SE	Mean	SE	Mean	SE	Mean	SE			
Total Nitrogen											
Concentration (g N / kg soil)											
5 cm	0.74	0.08	0.81	0.05	0.38	0.04	0.29	0.09	**40.7 (***)**	0.02	1.36
15 cm	0.53	0.03	0.57	0.05	0.36	0.03	0.39	0.04	**21.5 (***)**	1.04	0.02
30 cm	0.43	0.13	0.41	0.13	0.33	0.05	0.31	0.03	1.12	0.04	0.001
50 cm	0.31	0.06	0.40	0.04	0.22	0.04	0.25	0.05	**6.2 (*)**	1.43	0.48
Nitrate (NO_3^-, µg N g^{-1} soil)											
5 cm	12.9	4.0	14.3	2.3	8.2	2.0	10.4	3.0	0.11	4.41	0.10
15 cm	4.2	1.1	3.8	0.5	2.1	0.5	2.6	0.8	**5.4 (*)**	0.003	0.42
30 cm	3.6	1.5	4.4	1.0	4.5	1.6	4.0	1.4	0.02	0.01	0.23
Ammonium (NH_4^+, µg N g^{-1} soil)											
5 cm	6.7	1.0	3.7	0.7	3.3	0.8	2.9	0.6	**6.8 (*)**	4.54	2.75
15 cm	2.1	1.1	1.3	0.6	0.9	0.3	1.2	0.5	0.9	0.13	0.64
30 cm	1.2	0.8	1.9	0.9	1.7	0.9	1.6	0.6	0.009	0.10	0.26
Soil fractions (g N / kg soil)											
Particulate Organic Nitrogen	0.19	0.06	0.28	0.02	0.10	0.02	0.06	0.01	**21.5 (***)**	0.71	3.28
Mineral-Associated Organic Nitrogen	0.29	0.04	0.30	0.02	0.20	0.01	0.19	0.02	**12.5 (**)**	0.001	0.42

Table 4. Soil nitrogen metrics measured across the four farming systems, with modeled means, standard error (SE), and F-statistics reported for each treatment and their cross terms. (* = $p < 0.05$., ** = $p < 0.01$, *** = $p < 0.001$)

Variable	Hand-scale no-till				Tilled				Tillage	Cropping	Tillage x Cropping
	Continuous crop		Cover crop		Continuous crop		Cover crop		F	F	F
	Mean	SE	Mean	SE	Mean	SE	Mean	SE			
Labor											
Biweekly hours (per farm employee)	53.8	0.8	50.9	0.6	37.7	0.7	34.4	0.7	**545.0 (***)**	**19.4 (***)**	0.04
Focal crop biomass (average, 1 m sections											
Shoots (dry, kg)	0.09	0.02	0.17	0.04	0.08	0.02	0.09	0.02	2.37	2.37	1.9
Pods (dry, kg)	0.32	0.16	0.22	0.07	0.17	0.03	0.18	0.03	0.97	0.24	0.36
Total biomass (dry, kg)	0.64	0.02	0.67	0.03	0.68	0.02	0.69	0.02	1.4	0.64	0.16
Total yield (kg)	3.19	0.41	3.26	0.21	3.57	0.20	3.70	0.18	2.3	0.13	0.007
Total production (2019, kg)	55.6	12.1	80.3	21.0	46.0	15.1	41.8	19.3	1.9	0.35	0.70
Fungal richness and diversity											
Shannon (Diversity Index)	3.63	0.04	3.48	0.25	3.88	0.04	3.89	0.07	**6.2 (*)**	0.34	0.36
Simpson (Diversity Index)	0.94	0.00	0.91	0.04	0.96	0.00	0.96	0.00	2.6	0.44	0.76
Observed (Richness Index)	155.3	5.27	140.8	9.75	174.5	5.42	161.0	6.96	**7.7 (*)**	3.9	0.005
Chao1 (Richness Index)	242.3	13.8	198.9	22.67	255.9	17.73	233.6	16.03	1.8	3.4	0.35
Arbuscular mycorrhizal associations (%, of root intersections)											
Totals	53.3	17.0	16.5	6.7	30.3	11.7	24.5	10.3	2.2	**5.6 (**)**	2.0
Hyphae	32.5	8.0	10.0	4.1	20.3	5.0	17.0	7.7	2.1	**7.1 (**)**	2.6
Arbuscules	3.0	1.9	4.3	2.5	2.0	1.4	4.0	2.2	0.13	0.20	0.04
Vesicles	8.5	5.9	0.5	0.3	4.5	2.3	2.8	1.5	0.76	3.0	0.93

Table 5. Farm labor data, alongside plant growth metrics, measured across the four farming systems with modeled means, standard error (SE), and F-statistics reported for each treatment and their cross terms. ($* = p < 0.05$., $** = p < 0.01$, $*** = p < 0.001$

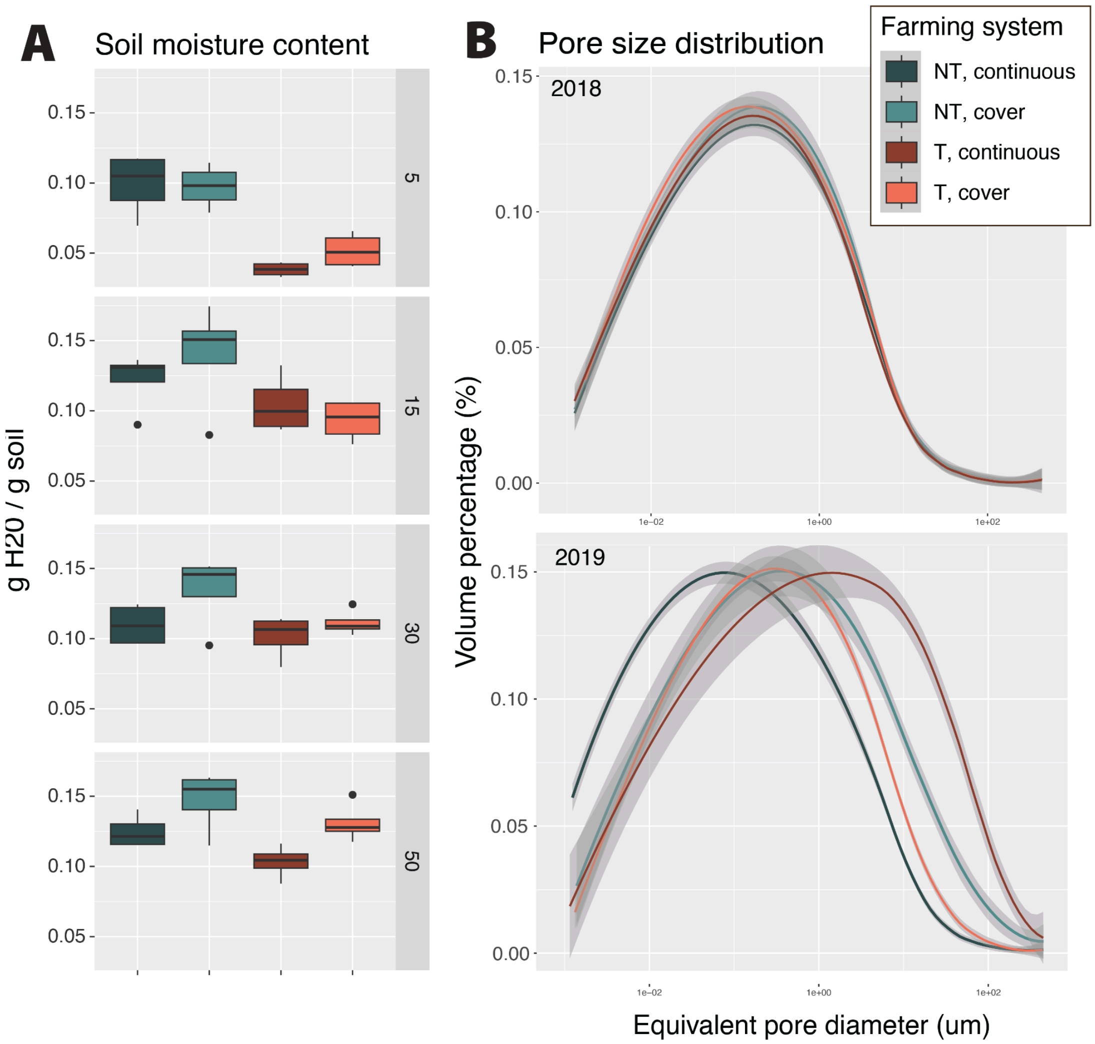


Figure 7. Soil hydrological properties, demonstrating (A) soil moisture content at four depths (5 cm, 15 cm, 30 cm, and 50 cm), showing higher quantities of water stored under no-till management and (B) pore size distributions evaluated in 2018 and 2019, showing a rapid shift in pore architecture between the first and second year of the study. The bottom-right quadrant illustrates a shift towards small pores in low disturbance, cover cropped systems and demonstrates a physical mechanism for observed changes in soil properties.

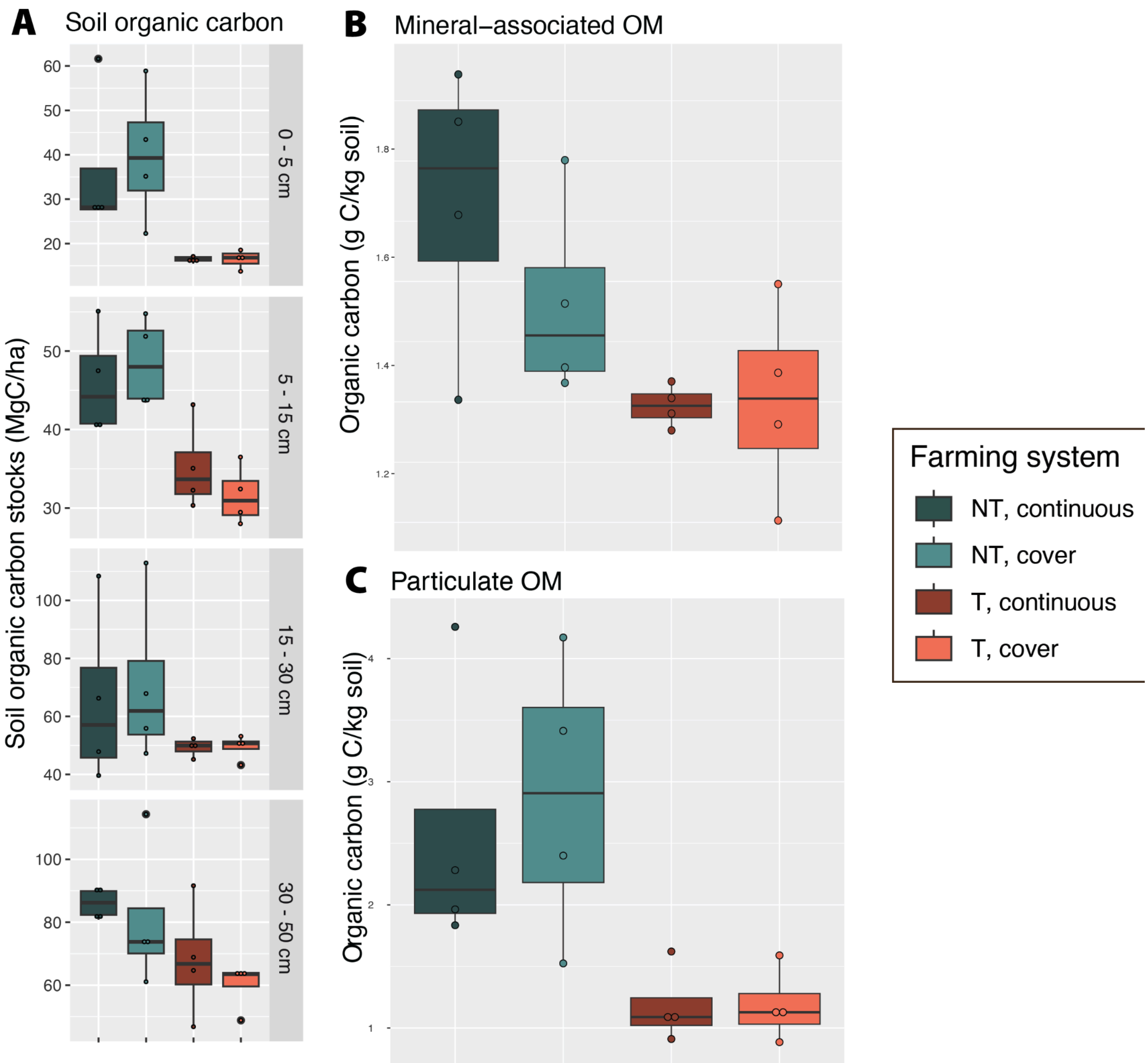


Figure 8. Soil organic carbon (TOC), mineral-associated organic matter (MAOM), and particulate organic matter (POM). Soil organic carbon stocks increased by as high as 207% under the hand-scale no-till farming. Of significant interest are the modest increases at 50 cm depth, from 6.5 Mg/ha to over 8 Mg/ha under no-till. MAOM is a measure of fine particulate organic matter (<53 um) that is likely to be bound to mineral surfaces, decreasing the likelihood of its degradation by microorganisms. POM includes larger pieces of organic matter (>53 um) and include plant residue, partially decomposed material, and more chemically recalcitrant particles.

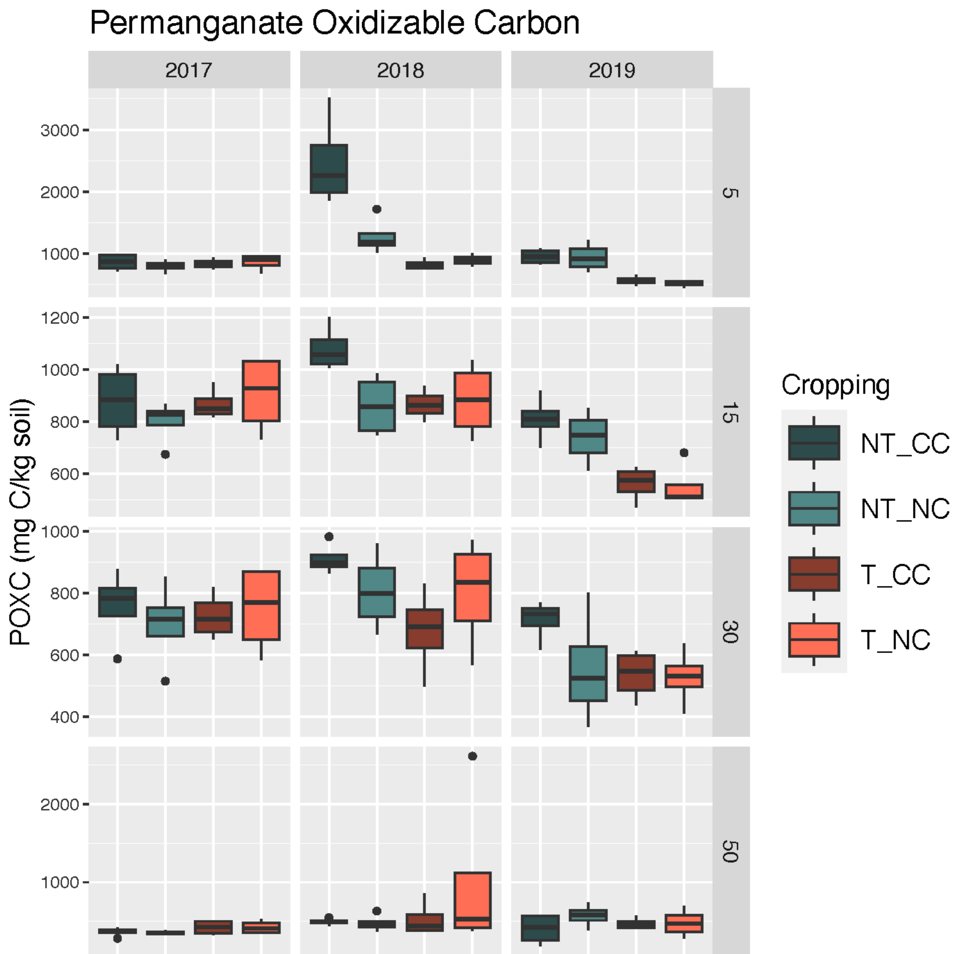


Figure 9. Permanganate oxidizable carbon (POXC) measured across three years (2017-2019) and four depths (0-50 cm).

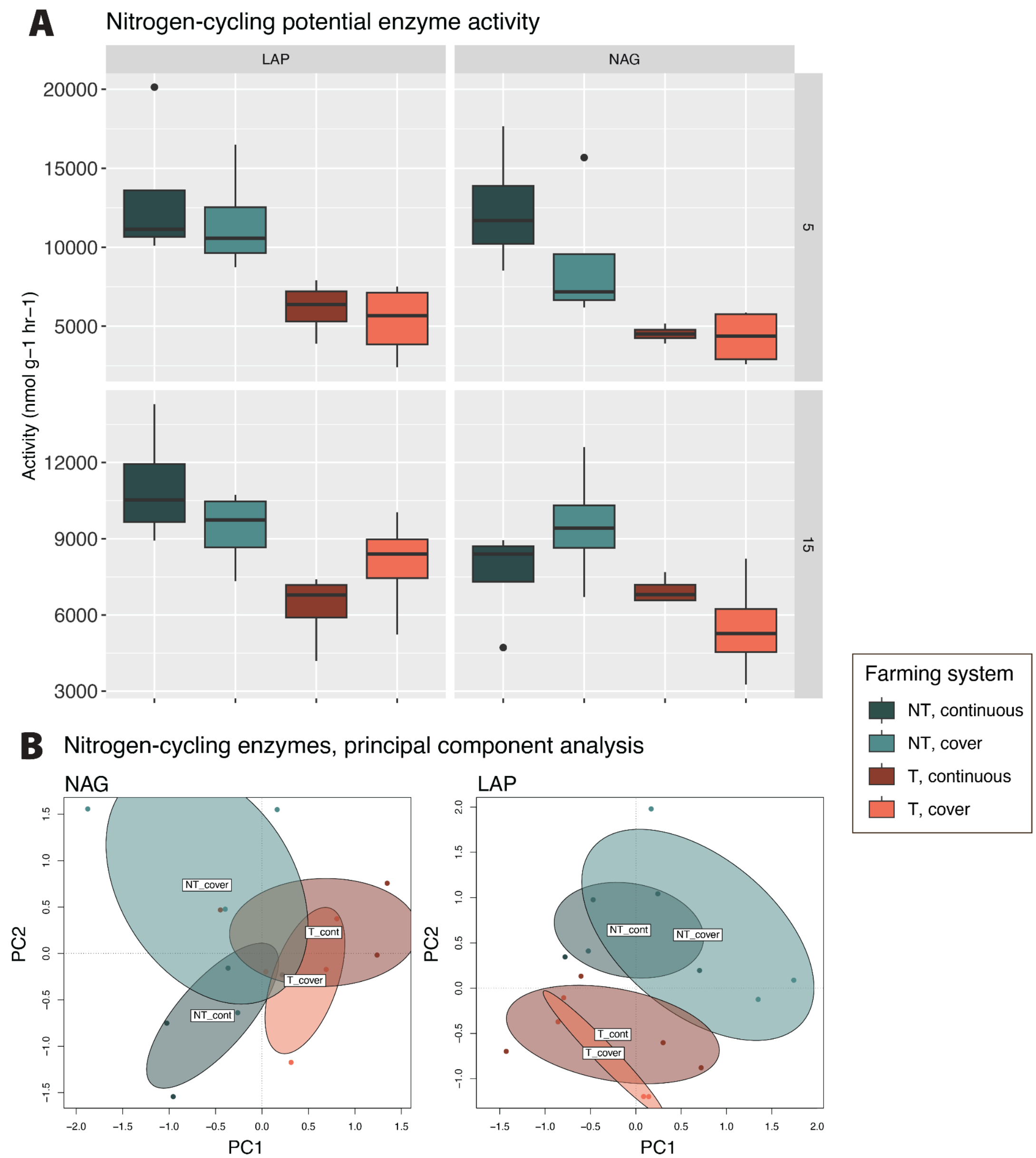


Figure 7. (Top) Potential N-cycling enzyme activity within the top depths of the soil, demonstrating as high as 150% increases in potential N-cycling rates with minimized soil disturbance. (Bottom) Principal component analysis of Exochitinase (NAG) and Leucine-amino-peptidase (LAP) enzymes, analyzing potential activity at all four soil depths and four size-based fractions, and demonstrating the broad differentiation of N-cycling and acquisition across the soil profile by farming system. Minimizing tillage dramatically increased N-cycling enzyme activity across down to 30 cm. This has implications for N use efficiency and nutrient cycling under different farming systems, with no-till and cover crops both increasing biologically mediated N acquisition.

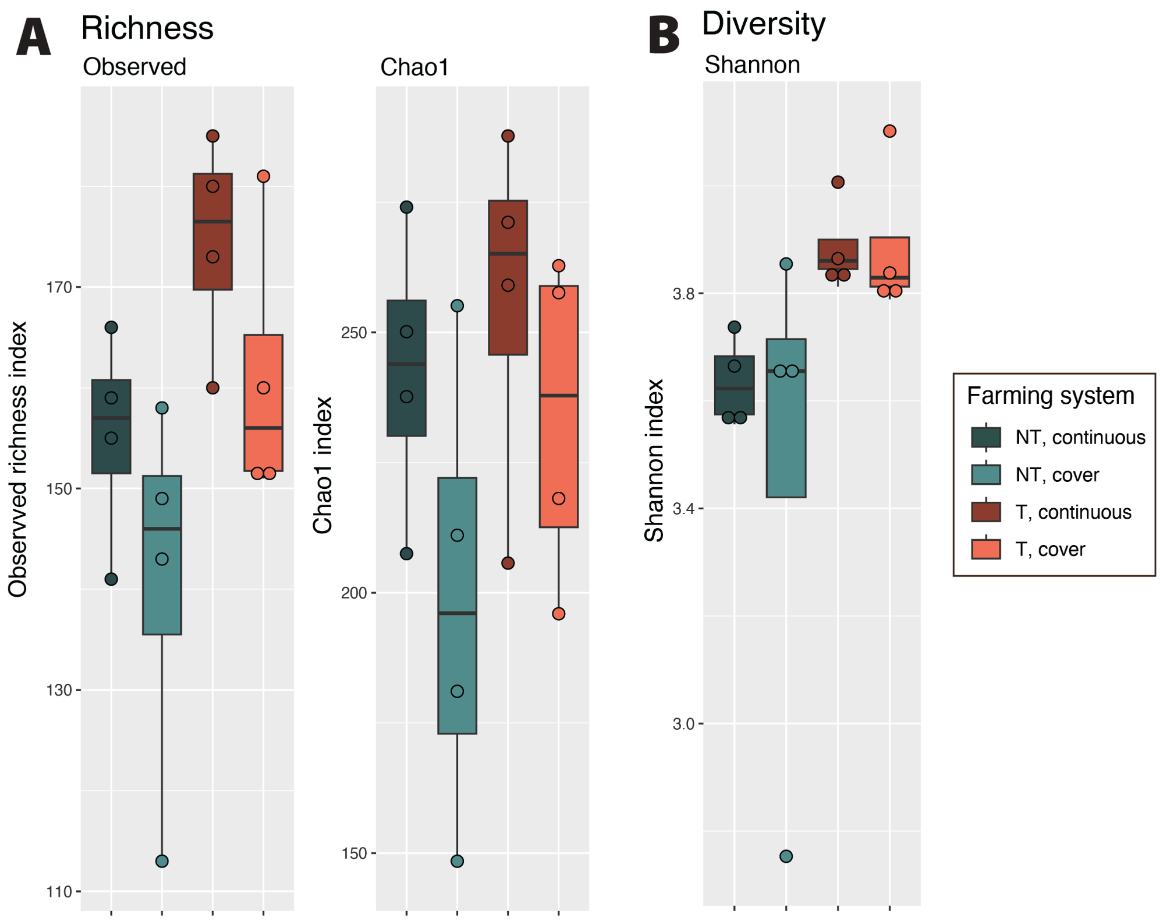


Figure 8. Species richness (Observed, Chao1) and diversity (Shannon) metrics were evaluated for both soil samples, classified by farming system. Continuous crop production had a significant positive effect on species richness. Continuous, intensive vegetable production sustained the highest number of soil fungal species in the study regardless of tillage. Fungal diversity, however, was uniformly higher in the tilled systems.

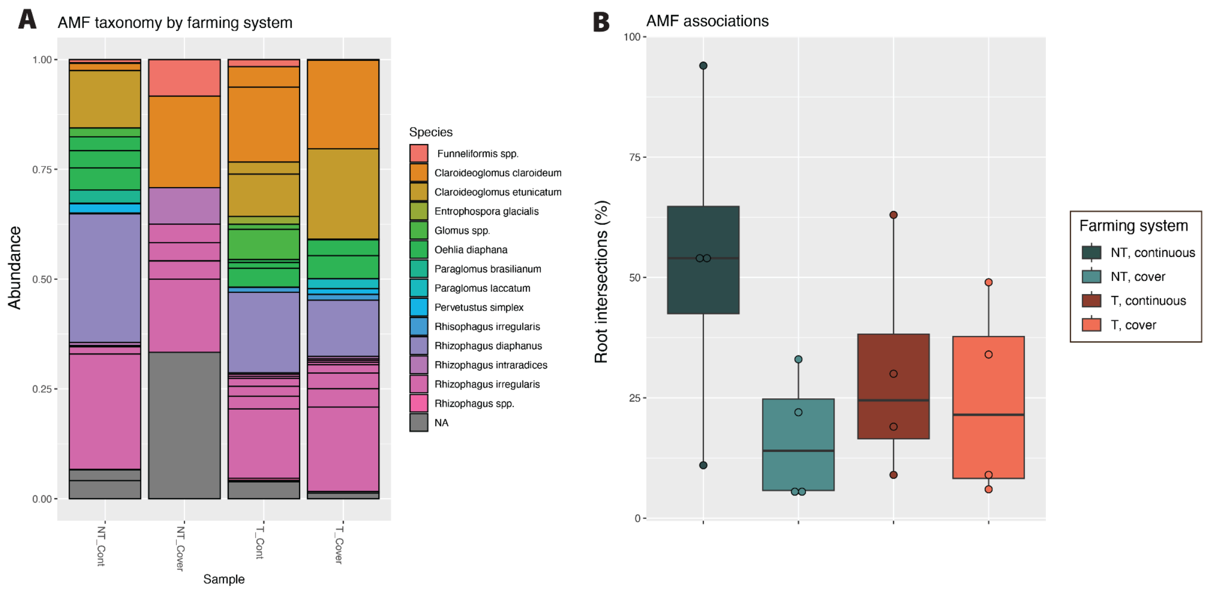


Figure 9. (A) Relative abundances of arbuscular mycorrhizal fungi (AMF) at the species level according to farming system. Changes in the AMF communities between no-till and tilled systems are stark, shifting from *Claroideoglomus* to a higher relative abundance of *Rhizophagus* and *Funneliformus* species. There is also a significant difference across cropping systems even within no-till plots, demonstrating the influence of crop cover and crop residue recycling methods on mycorrhizal partners. These changes in the AMF ASVs found through molecular methods corroborate the low colonization counts under the no-till, cover cropped treatment. Meanwhile, soil management also had a measurable influence on fungal plant pathogens living in the soil, specifically an enrichment in the genus *Cylindrocarpon*, a large family of pathogens that cause root rot. Higher rates of fungal root damage were observed during the implementation of the project; these data confirm observations at the study site of plant pathogen pressure with conversion to no-till. (B) AMF association rates, measured as the percentage of root intersections with AMF structures. Hand-scale no-till with continuous cash crops had the highest levels of AMF-plant associations.

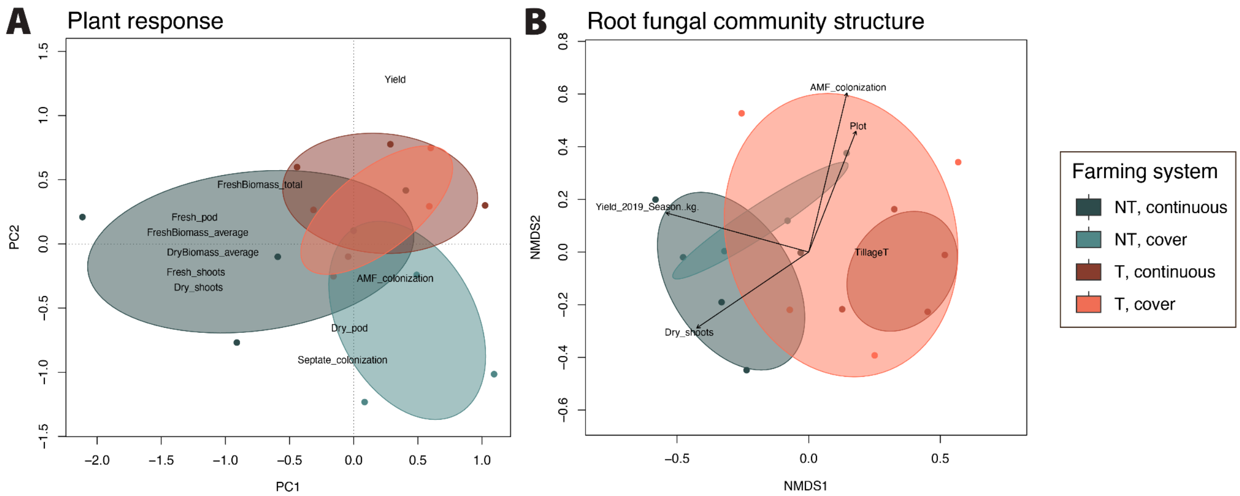


Figure 10. Plant response PCA by management system (left), demonstrating a limited response of plant growth metrics to management system. An NMDS of root fungi communities demonstrates much less differentiation in the fungal community than in the soil, suggesting that plant roots buffer fungal community composition transformation under changing environmental conditions.

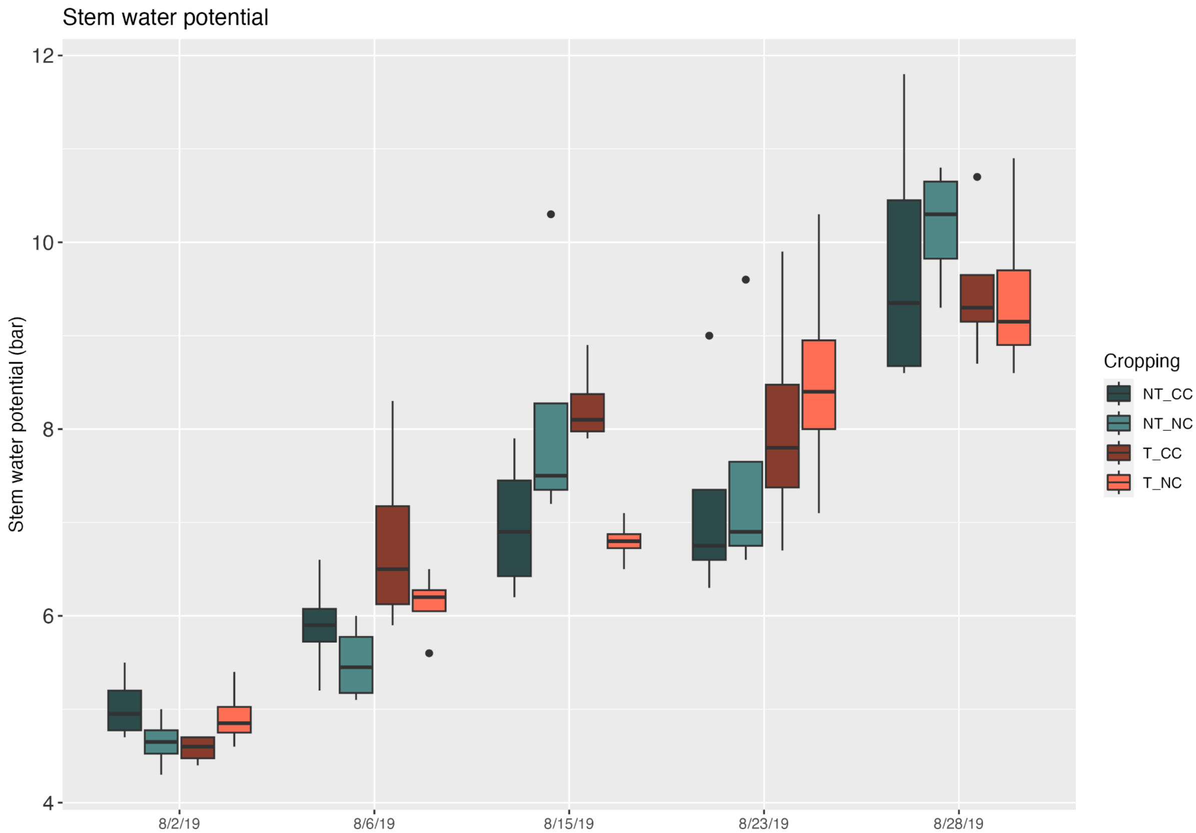


Figure 11. Stem water potential, a measure of the pressure that the crop xylem is exerting to draw water from the soil, was measured throughout the flowering and fruit set of our focal crop. It can be a proxy for water stress in plants. Note that as the soils dried throughout the summer season, stem water potential rose steadily across all systems. There was a significant interaction effect of tillage and winter crop system on stem water potential across the season, demonstrating that the unique aspects of each system combined to create unique water regimes within the soil.

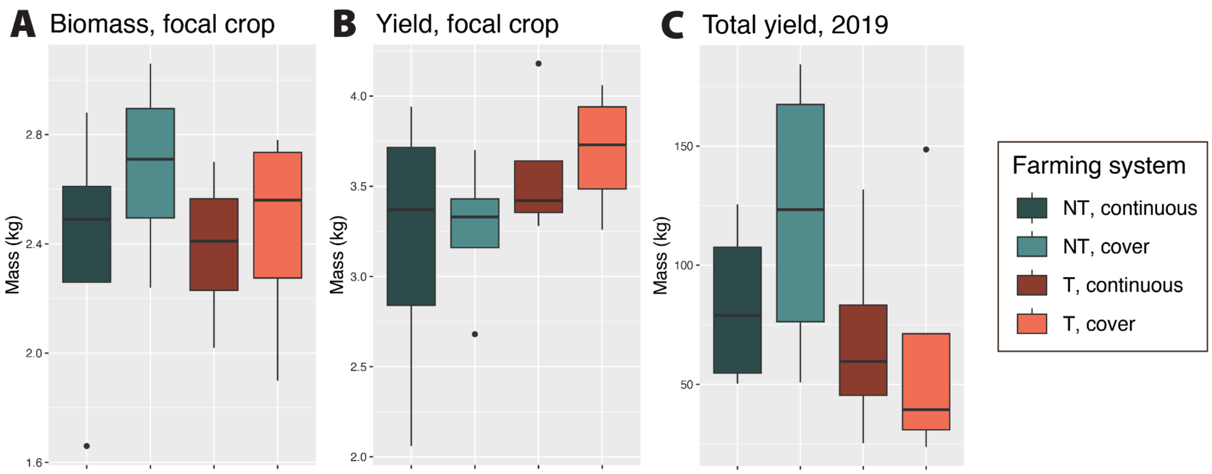
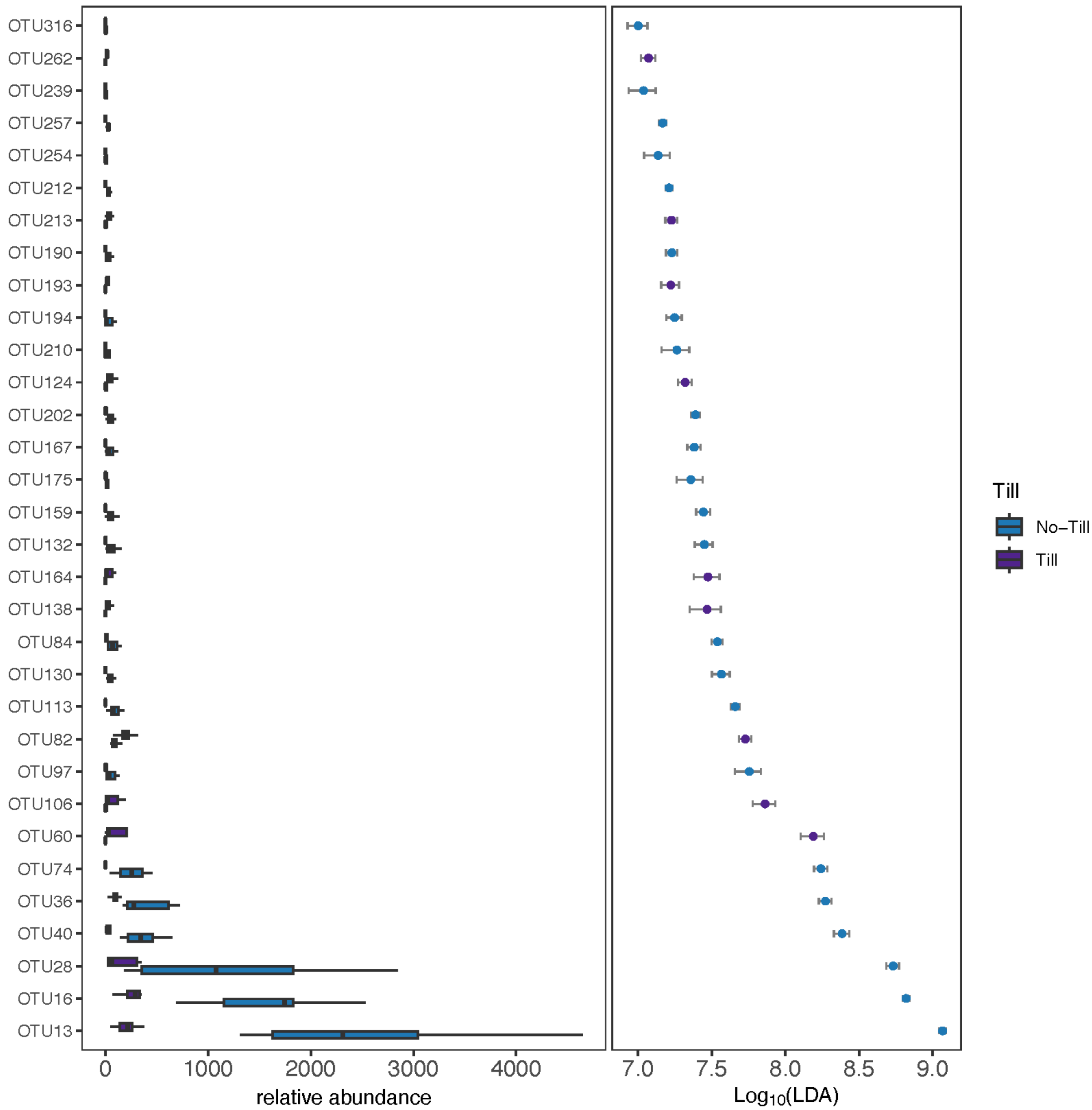


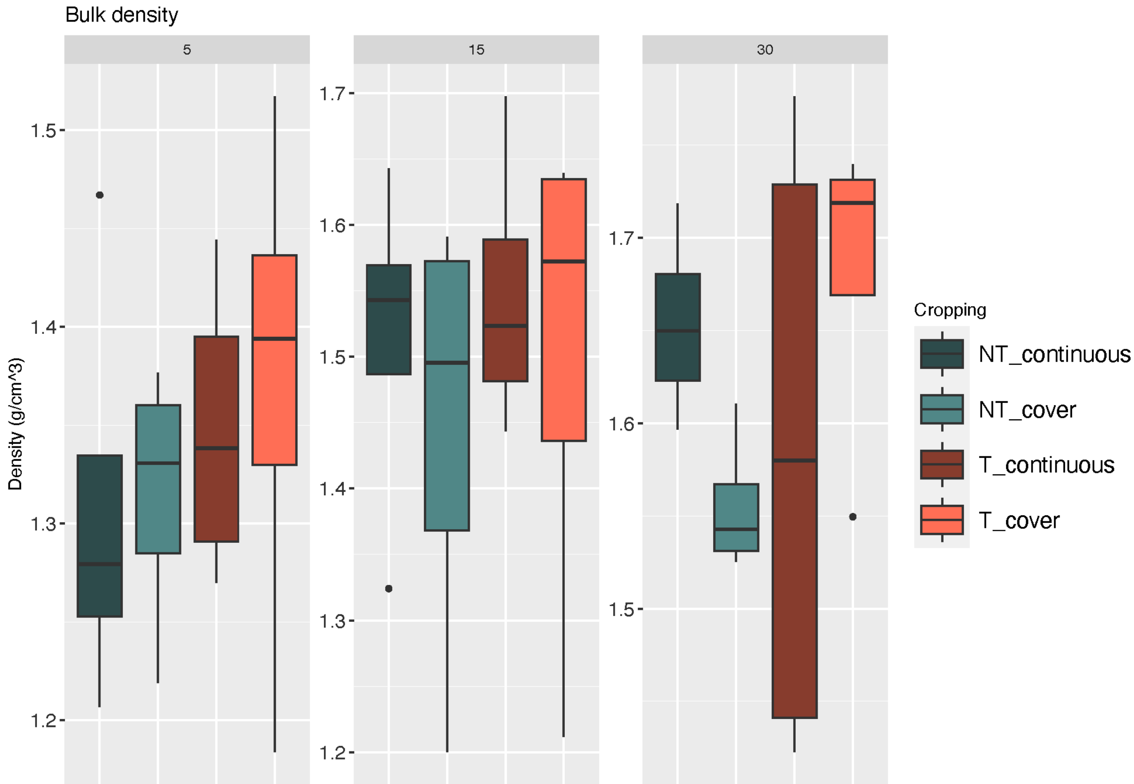
Figure 12. (Left and center) Aboveground biomass and yield of this study's focal crop (black beans, *Phaseolus vulgaris)*. Neither of these data were conclusive or significantly dependent on treatment, but are reported here to highlight small relative changes in yield and plant biomass across farming systems. (Right) Total production for the season and average labor hours per month were influenced by farming system.

Dataset	Soil properties	Plant responses	Soil ASVs	Root ASVs
Soil properties	--	--	--	--
Plant responses	0.4323 (*P=0.002)*	--	--	--
Soil ASVs	0.3726 (*P*=0.002)	0.4387 (*P=0.009*)	--	--
Root ASVs	0.0485 (*P=0.346*)	0.0404 *(P=0.392*)	-0.0952 (*P=0.701*)	--

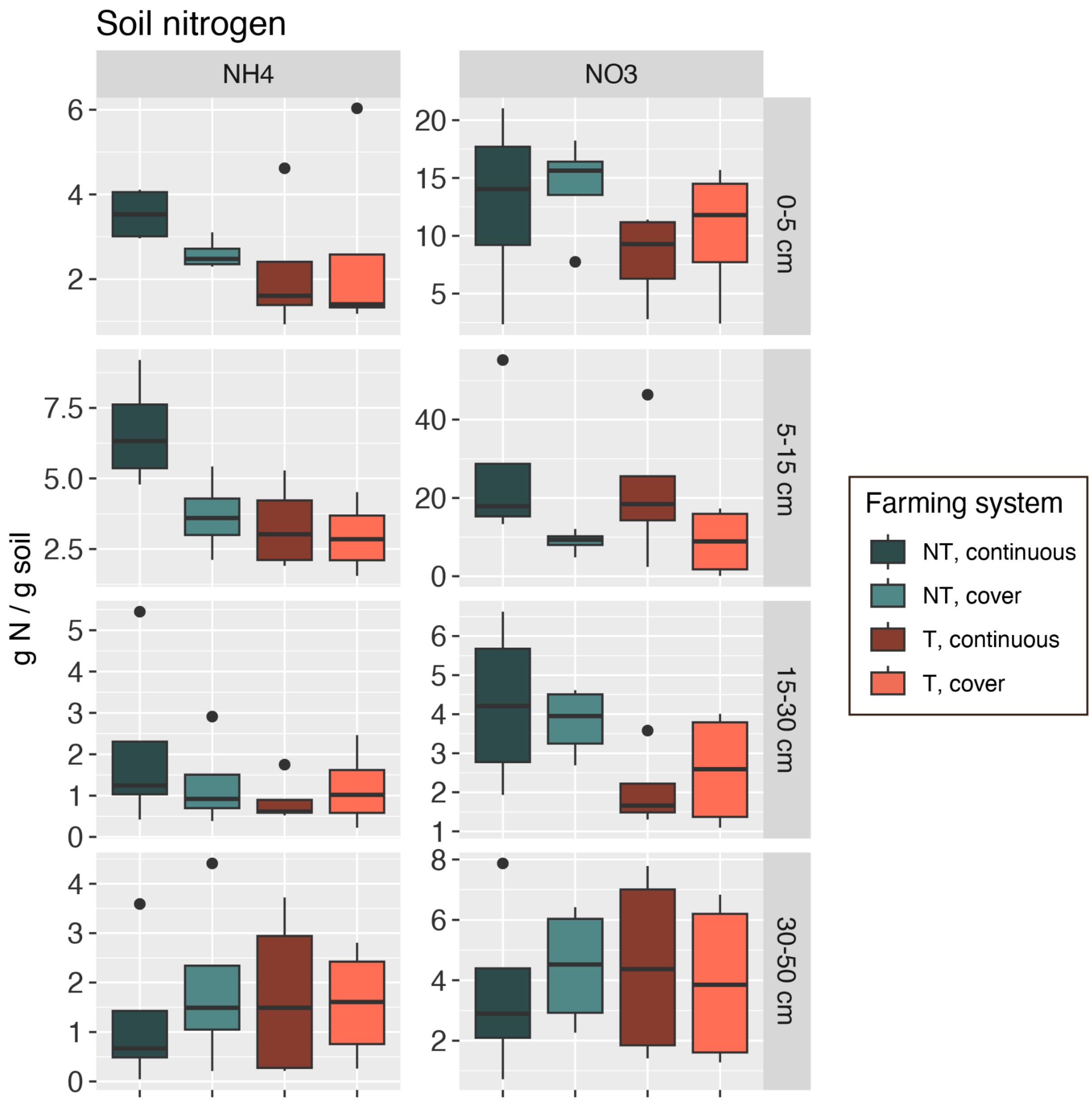
Table 6. Mantel statistics of paired datasets illustrates the matrix correlation between dissimilarity matrices for the datasets listed in the table. This demonstrates a strong relationship between soil properties, soil fungal ASVs, and plant growth under stress, but almost no relationship between those parameters and root fungal communities. This suggests a high selection bias of root fungal communities, regardless of soil management system.



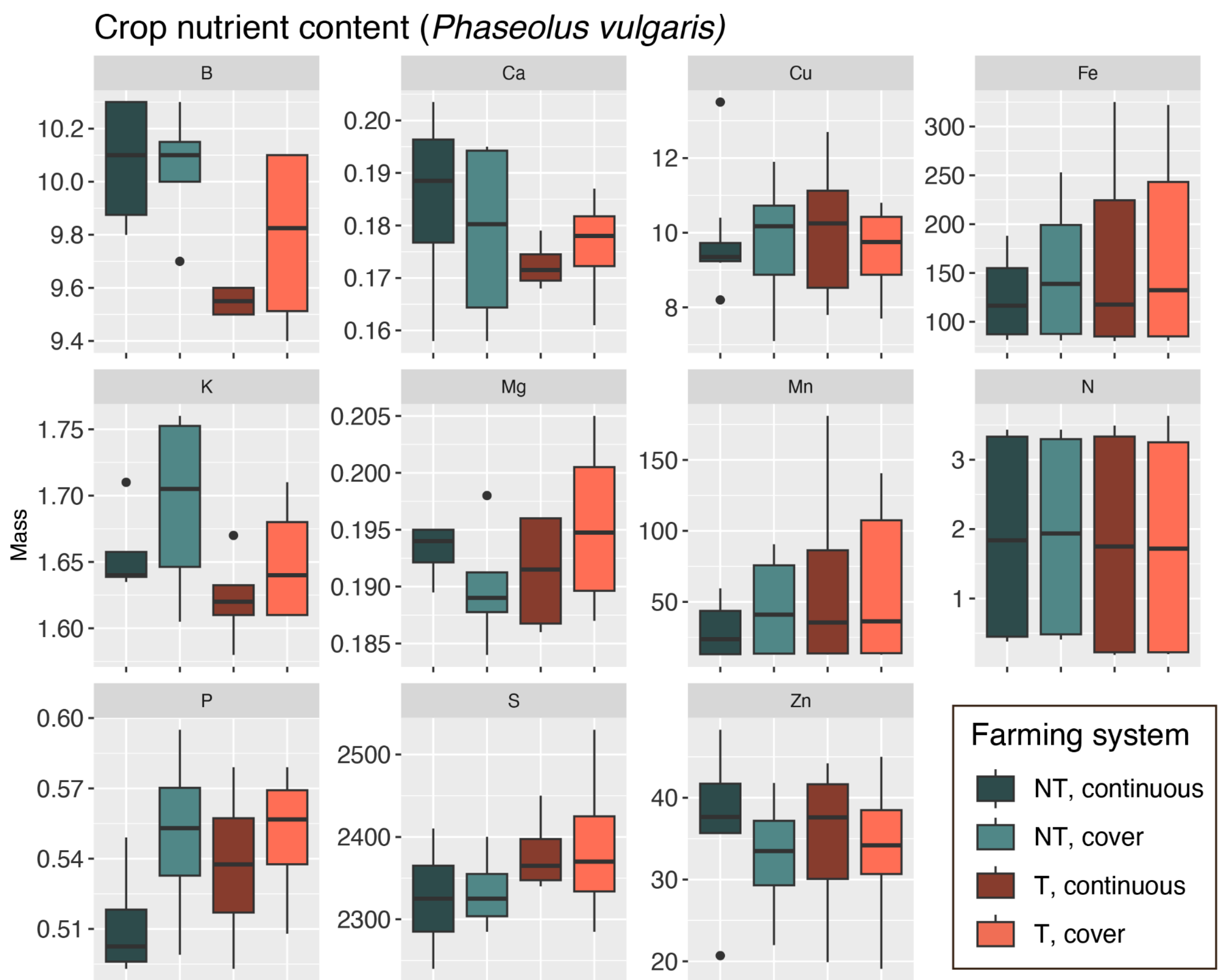
Supplementary Figure 1. Differential abundance of taxa across tillage systems, as determined by linear discriminant analysis (LDA), demonstrating enrichment of no-till and tillage system in particular fungal OTUs. No-till systems had higher differential abundance of thermophilic saprotrophs that aid in cellulose degradation, including genera *Myceliophthora* ($\log_{10}$(LDA)=8.4) and *Thermomyces* ($\log_{10}$(LDA)=8.7). These saptrotrophs, in combination with significantly higher levels of POXC found in no-till systems, suggest Tilled systems were enriched in three main genera of saprotrophic fungi–*Schizothecium* ($\log_{10}$(LDA)=8.5), found in fecal matter, *Spizellomyces* ($\log_{10}$(LDA)=8.4), a pollen-degrading family of fungus, and *Mortierella alpina* ($\log_{10}$(LDA)=7.6), a soil-dwelling and chitin-degrading fungal species.



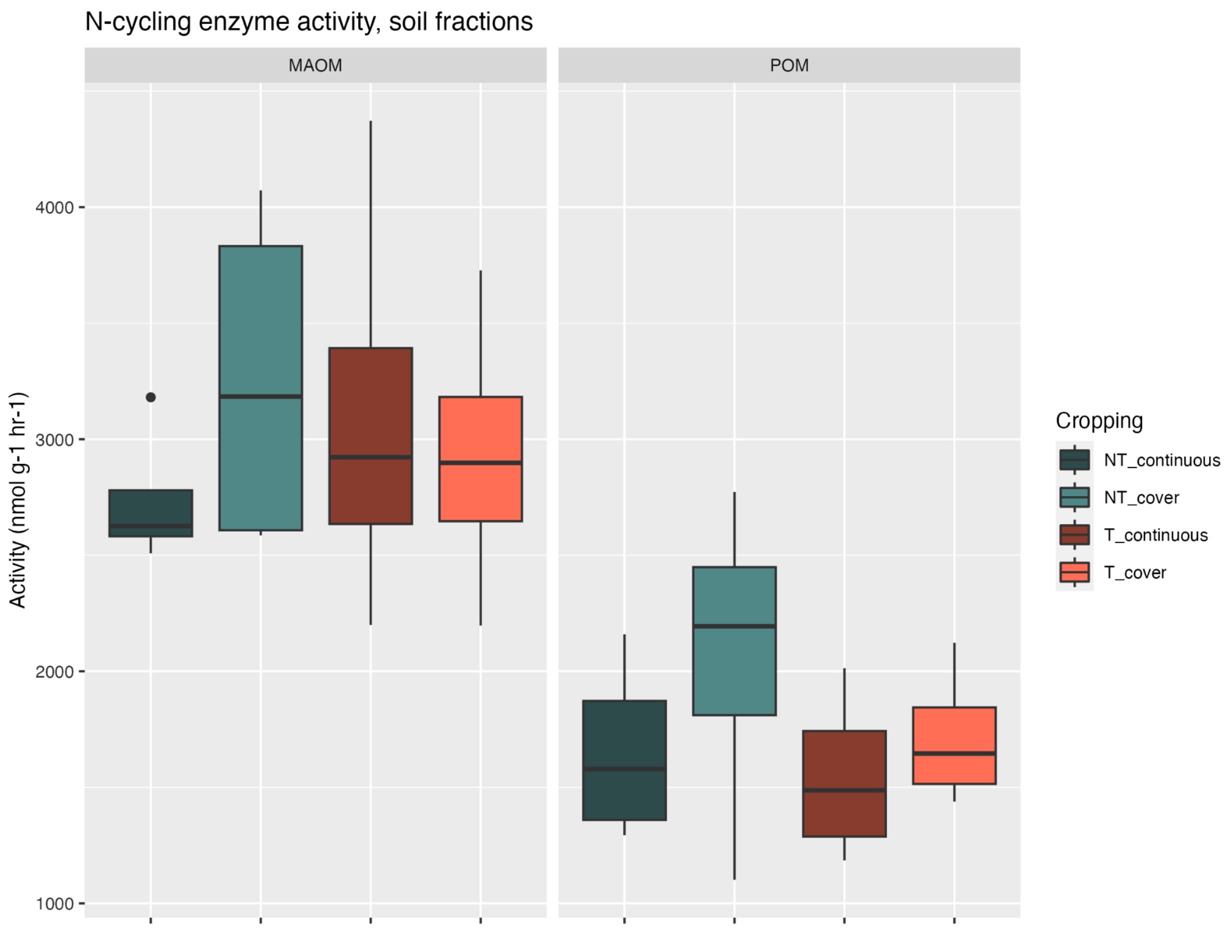
Supplementary Figure 2.



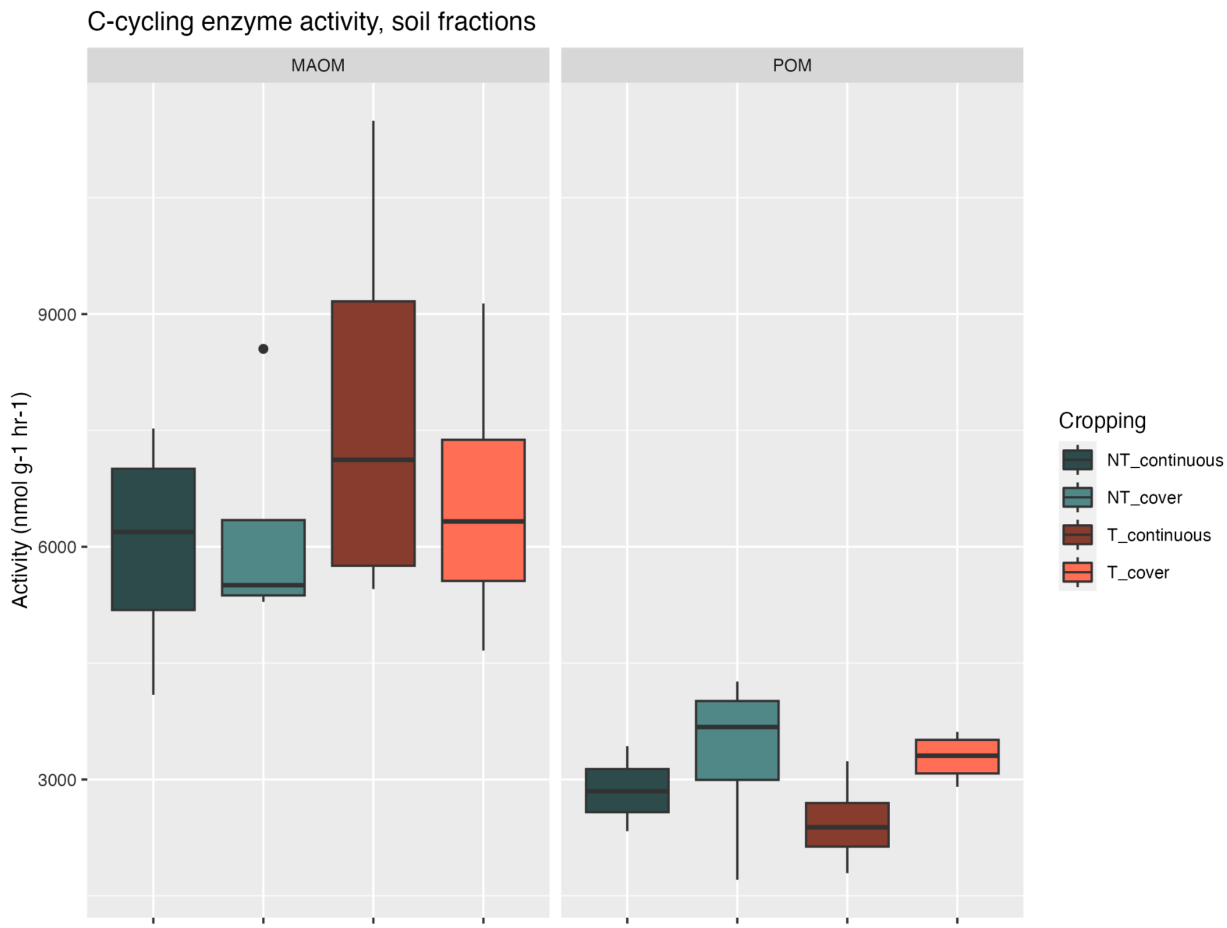
Supplementary Figure 3



Supplementary Figure 4



Supplementary Figure 5



Supplementary Figure 6

A community approach to nourishment: the material and social conditions integrating anti-hunger and food sovereignty in the San Francisco East Bay[3]

Abstract

In the United States, hunger relief is increasingly tasked to massive federal food relief programs that link industrial farms, shelf-stable and processed food products, and regional food banks. As this system further entrenches corporate consolidation and the financialization of the food system alongside ecological collapse and labor exploitation, it threatens movements for food sovereignty. Food sovereignty is a framework for enacting self-determination through the cultivation of vibrant foodways, agroecological transitions, and agrarian life. Yet implementation of these methodologies is relatively rare in the US. Urban agriculture is a possible exception, and offers a case study of how community-led efforts to enact agroecological transitions and nourish people may embody principles of food sovereignty. During the height of the COVID-19 pandemic (2020-2022), urban farms became vital to the anti-hunger movement. This study explores the direct integration of small-scale, local agriculture with anti-hunger efforts in the San Francisco East Bay before, during, and after the height of the pandemic. The author—comprising academic researchers, students, and community partners—uncovered the diverse relations and networks that attempt to decommodify locally-produced food and ensure access for marginalized communities. Our team conducted 46 interviews within this community of practice, engaged in six years of participant observation, and tracked food distribution from two local farms and two food distributors. These mixed methods sought to illuminate how this community of practice articulates the relationships, networks, strategies, and practices necessary to realize anti-hunger objectives in alignment with the principles of food sovereignty. From the perspective of this community of practice, integration of hunger relief and agriculture can occur by attending to: 1) personal, reciprocal, and intimate relationships, 2) cycles, circularity, and reciprocity, 3) agency and self-determination, 4) holistic nourishment (social, emotional, spiritual), 5) local and solidarity-based economies, and 6) awareness of precarity, power, and privilege. These principles, both in theory and practice, may offer new pathways for the food sovereignty movement in the United States. This study highlights the kinship networks, local organization, solidarity, volunteerism, mutual aid networks, and informal relationships that nourish communities in need. Overall, the community of practice described in this study articulates a vision of networked care that prefigures a world where the nourishment of human communities and landscapes are intricately linked.

[3] Intended co-auhtors for publication are Arianna Hee, Stan Byias, Aaron De La Cerda, Lekeisha Simpson, Annika Levaggi, Natalia Semeraro, Effie Rawlings, Tiffany Lwin, Tommaso Bulfone, Carly Finkle, Satchi Thockchom, Gisel De La Cerda, willow holiday, Jennifer Sowerwine, Charisma Acey, and Timothy Bowles

Introduction

The global food system is broken. While over 800 million individuals experience hunger and a billion suffer from malnourishment, obesity affects another billion people (1). Meanwhile, despite the capacity to produce food above the world's population needs, one-third of all food produced globally is wasted (2). The financialization and market-based structure of the global food system drive these tragic contradictions—where a handful of corporations serve as middlemen dictating pricing and distribution between producers and consumers (1). Ecological devastation, chemical intensification, industrialization, and labor exploitation are globally employed to produce unhealthy and wasted food (3–6).

In the US, efforts to address hunger are increasingly integrated into a corporatized system linking chemical and industrial agriculture to regional food banks (7). Across the US, a "nutrition transition" towards industrially produced, processed, high-fat, high-sugar diets is visible in the foods that stock regional food banks (8). Highly refined or processed edible oils, sweeteners, ultra-processed foods, and animal-source foods are pushed as calorie delivery systems for food insecurity (9). This process is driven by financialization, corporate consolidation of grocery suppliers and outlets, broken subsidy programs, mass media advertising, and diminishing agricultural self-sufficiency (10). Hunger and obesity are also issues of racial and environmental justice in the US. Both are more prominent in communities of color due to long-perpetuated racial segregation and economic violence (11–13). Increased rates of obesity and other diet-related chronic diseases often overlap with malnutrition among low-income populations whose economic conditions drive them toward purchasing cheap foods (13–17).

Understanding the continuum between hunger and nourishment requires us to see them as both affective and structural phenomena. Affect refers to the material encounter of bodies (including impulses, passions, wishes, and traumas) that draw human and non-human agents into webs of relationships that constitute and construct their being (18). Hunger and nourishment are "affective" to the degree that they are embodied, experiential, biological, and profoundly intimate. Food tastes are materially shaped by the body, brain, and tongue, *and* are articulated through "complex assemblages of past opportunities and vacancies, personal memories, social histories, and random events" (19). Social anthropology and political ecology increasingly view nourishment as not only a biological phenomenon, but also including the act of preparing food, eating with others, and sharing food (20). In this way, the continuum from hunger to nourishment is a visceral experience that has critical emotional dimensions.

On the other hand, hunger is "structural" to the degree that it is socially determined—economically, politically, and culturally. People's experiences, knowledge, and value of food are determined by structures of power that dictate their choices and shape their desires (21,22). There also exists a crucial link between the structural and the affective. Emotional responses to food "arise out of the power-laden social networks", which are "central to the development of our (always social) bodies" (19,23,24). Poverty and structural violence impose immense restrictions on how people can access and desire nourishment (6,12,17,20,25). An authentic response to hunger cannot be achieved without acknowledging and understanding the complex interplay between its exterior and interior dimensions.

Yet even framing "hunger" as a broad social problem obscures deeper economic, political, and social challenges. In his book *Big Hunger: The unholy alliance between corporate America and anti-hunger groups*, Andy Fisher examines the dangerous ideologies, structural challenges, and systemic exploitation embedded within the "hunger" concept in the US. Charity models that position food aid and food distribution as the solution to hunger obscure its structural causes: poverty, systemic racism, domestic or institutional violence, gentrification, and corporate control of the food system (7). Ideologies that position hunger as an isolated social problem allow for the valorization of food charity programs, which have expanded dramatically over the last half-century and dedicate enormous resources to only addressing symptoms—not the root causes. Fisher writes that "at worst, "hunger" provides a watered-down or sanitized framing of a challenging and contentious set of social and economic problems. Though it addresses the symptoms of poverty, the hunger-problem statement fails to establish the necessary justification to build the financial, human, or social capital needed to eliminate the problem on a more permanent basis" (7). Fisher articulates three primary conceptual problems with the concept of hunger: 1) it is subject to political and emotional exploitation because of its ambiguity, 2) it diverts attention away from more politicized, longer-term, and structural solutions, and 3) it creates solutions that *perpetuate* or *entrench* hunger by maintaining structural inequalities and consolidation of power in the food system (7). Whether it is framed as hunger or food insecurity, when we are unable to see hunger as a symptom of poverty we obfuscate its actual causes and limit our collective imagination around what kinds of social change are possible.

In this article, we examine the relationships between hunger and nourishment through the lens of food security and food sovereignty. We ground this analysis in a case study of urban agriculture in the San Francisco East Bay (hereafter, East Bay), where a "community of practice", including local farms, food banks, pantries, churches, schools, non-profits, and grassroots organizations, sourced healthy, locally-produced foods to address hunger (Table 1). This network assembles primarily through the act of sourcing and distributing food; participants share infrastructure, exchange surpluses, coordinate volunteers and deliveries, participate in community engagement around anti-hunger objectives, and convene gatherings around food in the East Bay. A community of practice is typically defined as a group of people who share a common interest or passion for a particular domain of work, and who learn together through collective practice and social exchanges (26). Rooted in feminist scholarship, naming a "community of practice" conveys the idea that learning is always situated in a particular social context. This group of organizations, institutions, and grassroots initiatives engages in collective practice; they do not achieve anti-hunger initiatives in isolation. Rather, they collaborate materially and socially through the sharing of food, linking each organization in the community of practice to many others in the network. With this practice, they iterate, transform, change, and grow, learning to better nourish their communities and support one another in their anti-hunger efforts.

We argue that this community of practice provides an illustrative example of community food production that can achieve both anti-hunger objectives and nourishment in ways that align with the principles of food sovereignty. The community of practice that engaged in this study was specifically engaged in sourcing from small, regional, and urban farms practicing forms of agroecology for their anti-hunger initiatives. Organizations in the network can be classified into a series of categories based on their role, as outlined in Table 1. This study took place before, during, and after the height of the COVID-19 pandemic, and so also offers insights into how the integration of small-scale agriculture with anti-hunger objectives can respond to crises. This article begins with a theoretical grounding in the concepts of hunger, food security, and food sovereignty. It then introduces those concepts in the context of the East Bay and examines the key themes that emerged from interviews and food distribution data collected within this network. Taken together, the study offers insights into how anti-hunger initiatives might be better coupled with agroecological transitions. It also serves as an exposition of the relationship between nourishment and food sovereignty.

Food security to food sovereignty

Hunger and nourishment are broadly approached using two frameworks: food security and food sovereignty. Food security first emerged with the creation of the United Nations and the Food and Agriculture Organization (FAO), then came to the fore in response to the food crises of the 1970s (27). Rather than acknowledging how global markets had undercut local self-sufficiency, organizations like the World Bank and FAO pushed for further financialization, mechanization, and competitive advantage for industrial farming internationally (28). Food security aims to supply sufficient calories to people regardless of how the calories are produced or where they come from (3,29). Power lies with large-scale producers (corporate and industrial farms, manufacturers) and distributors (multinational food companies). Broadly, consumers have little control over what foods are available for them to eat.

Food sovereignty, on the other hand, emerged from agrarian social movements predominantly in Central America, taking hold in international peasant organizations like *La Via Campesina*, and ultimately breaking onto the international stage in the 2000s (30,31). Since then, food sovereignty has become a mobilizing frame for social movements around the world. Food sovereignty is defined as "the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems" (32). Food sovereignty seeks to dismantle the hegemony of corporate-controlled food chains that often disregard social and environmental costs, advocating instead for local autonomy or bottom-up global food governance (Canfield 2020). Standing in opposition to imperialism, neoliberalism, neocolonialism, and patriarchy, food sovereignty elevates the roles of women and Indigenous peoples as custodians of agrarian knowledge. Food sovereignty emphasizes the right of food producers over natural resources such as land, water, seeds, livestock, and biodiversity. Advocates from colonized Indigenous communities, the descendants of enslaved people, and landless farmers have consistently argued that the realization of food sovereignty is inseparable from the struggle for land sovereignty, anti-racism, and cultural resurgence (Meek and Tarlau 2020, Myers 2015, NBFJA 2022, Trauger 2018, Williams et al. 2017, Angarova 2020, LaDuke 2005, Peña et al. 2017). Yet in the US, food sovereignty has not been widely adopted as a framework for agricultural change. Their political and anti-capitalist nature make them broadly incompatible with neoliberal movements for food systems change, the non-profit industrial complex, and corporate integration with agricultural innovation (33–35).

Urban agriculture offers possible models for the coordination between anti-hunger initiatives and food sovereignty. The politics and practice of urban agriculture are among the most dynamic community-led food systems interventions in the US, and often embody principles of self-determination and food sovereignty (36). Urban agriculture is often led by low-income communities of color and is focused on actualizing principles of sovereignty, justice, and food systems transition that align with food sovereignty (33). In this inquiry, we hypothesize that urban agriculture is a critical site of integrating food sovereignty and anti-hunger initiatives.

In the United States, the potential for meaningfully addressing the structural and affective dimensions of hunger through urban food production is often dismissed. Yet there is strong evidence that urban agriculture emerges as an important source of food during times of crisis (37–40). When social and political will was mobilized through the military-funded Victory Gardens program of WWII, over 50% of the country's fruits and vegetables were being produced by small-scale, suburban gardens (37). Further, urban systems have been shown to produce more food per unit area than conventional agricultural production (41). Uncertainty remains, however, regarding the capacity of urban agriculture to meaningfully address hunger, especially in low-income and vulnerable communities (42). This is questioned largely on account of urban agriculture's role in perpetuating gentrification, attracting venture capital investment, "green-washing", and forms of self-exploitation (43), patterns that often lead to a predominance of white bodies in urban food production spaces (44). The production capacity of urban agriculture, especially to produce calorically-dense products (grains, meat), is also limited due to spatial constraints (45).

The East Bay is home to a robust network of community gardens, farms, food banks, churches, non-profits, mutual aid networks, and social movements that work to address hunger, build community, and nourish the soul. These organizations collaborate in a vast and dynamic web to bring food to those who otherwise might not have access. Few studies have worked to illuminate the specific mechanisms that allow urban agriculture to integrate with anti-hunger initiatives and offer nourishment through enactments of sovereignty. This study seeks to address this gap by investigating the mechanisms by which urban and city-regional agroecological farms engage with anti-hunger initiatives. Our central question: How do members of this community of practice articulate the relationships, networks, strategies, and infrastructure necessary to realize anti-hunger objectives in alignment with food sovereignty principles? By exploring the urban agroecological landscape of the East Bay as a case study, we seek to illuminate specific examples of how anti-hunger initiatives can be coupled with agroecological principles and the struggle for food sovereignty. What cultural, ethical, and spiritual practices do these communities use to prefigure a future where all can be nourished? What's more, they are connected through a patchwork of farms practicing forms of agroecology—an action-oriented framework integrating diverse forms of knowledge to promote ecologically vibrant and socially just agricultural systems (46–48). At these sites, agroecological practices and social movements work to create more ecologically sound and socially just farms. In this study, we attempt to bring various voices, stories, and materialities from this network to life. Through participant observation, photo-journaling, interviews, and food distribution tracking, we seek to evoke the life of these efforts for nourishment and care through food.

Grounding in place

The East Bay is a region often celebrated for its diverse and vibrant local food system, and as a leader in urban agriculture and food sovereignty movements (35, 36). The region is the ancestral and unceded land of the Chochenyo speaking Ohlone people, known as xučyun (Huichin). Ohlone people stewarded highly productive agroecosystems using prescribed fire, rotational foraging, complex ethnobotanical knowledge, and a cosmovision that connected them to the landscape (51–54). Freshwater creeks ran from the hills of sequoia down to oak woodland and grassland, finally draining in the seasonal marshes of the flatlands that were marked by massive sacred sites now called shellmounds (55). For Ohlone people, there were no concepts of homelessness or poverty, but a rich tradition of mutual aid, community care, and abundance rooted in a reciprocal relationship with the East Bay landscape (56).

This relationship was severed by Spanish colonization, which brought the capture, enslavement, and murder of Ohlone people. The missions were agricultural settlements, cultivating European crops and livestock by exploiting the labor of enslaved California Native people (57,58). This created the conditions for California rancherias, and ultimately the plantation economy of California's industrial agriculture (59–61). Ohlone shellmounds, sacred ceremonial, and burial sites were desecrated and used to fertilize settler farms and pave the streets of the East Bay (55).

These violent histories haunt the East Bay's struggle to create a nourishing, vibrant, and just food system. Efforts towards food justice are additionally complicated by the region's high levels of wealth inequality, severe gentrification, ongoing police violence, and a housing crisis that threatens the integrity of food justice initiatives (62–66). According to a 2020 report, 31% of neighborhoods (census tracts) in the San Francisco Bay Area were sites of displacement, making it the highest ranking region in the country for gentrification (67). Income inequality in the Bay Area is the highest in California, and thus highest in the entire country, with the top 10% of incomes over 12 times greater than the bottom 10% (68) and 8 households holding more wealth than 50% of the population. This has major effects on hunger, nutrition, and food access across the Bay Area. Since the COVID-19 pandemic, food insecurity has risen to 33% of Bay Area residents, meaning that 1 in 3 people regularly skip meals, remain hungry, or refrain from purchasing nutritious or desirable food due to prohibitive costs (65). In 2014, the Alameda County Food Bank (ACFB) reported that 1 in 5 county residents relies on the food bank to meet their food needs (69). Food banks like ACFB largely rely on packaged and processed foods, as well as foods sourced from farms with industrial and chemical-based operations, revealing an entrenched system that often delivers low-quality and environmentally-damaging food to anti-hunger programs (7).

It is in this context that urban agriculture, food justice, and food sovereignty initiatives emerge. In the Bay Area, many trace the lineage of this work to the Black Panthers and their free breakfast and grocery programs (70). From these roots, the Bay Area has seen a proliferation of efforts that claim to alleviate hunger through urban agriculture or food justice (49,62,71,72).

However, many scholars, activists, and community organizers have been quick to highlight the very real contradictions embedded in attempts by external actors to improve, help, or alleviate the struggle of urban communities. Scholars have demonstrated how urban agriculture and food justice initiatives in the United States can cater to affluent white communities and often center a culture of whiteness while perpetuating systemic oppressions due to poverty, racism, and heteropatriarchy (73,74). Rhetoric such as "getting your hands in the soil" or "paying the full cost for food" used in white-led alternative food movements ignore painful and violent histories of enslavement and dispossession at the root of agriculture in the United States (75,76). In their detailed study on gentrification and urban agriculture in the East Bay, Elissa M. Mann documents how the introduction of urban agriculture is often intricately linked with luxury real estate development companies, rising local property values, and large volumes of property transfers (64). Mann demonstrates how "forces of racial capital … work to remove and strip long term community members of their access and right to their own neighborhood," and how a "well-intentioned urban agriculture project truly can be appropriated by investors and city planners to extract profit from a neighborhood." Lisa "Tiny" Gray-Garcia, an Oakland-based "formerly unhoused, incarcerated, revolutionary journalist, lecturer, poet, visionary, teacher and single mama," writes about how efforts to alleviate poverty, houselessness, or hunger are often rooted in saviorism that only perpetuates those conditions. In her book *Poverty Scholarship: Poverty scholarship: Poor People-Led Theory, Art, Words, and Tears Across Mama Earth,* Gray-Garcia writes:

> At its most benign, [the] arrogance of pseudo-corporate non-profiteer or NGO or Poverty industry movements fuels the movement of peoples with class privilege into neighborhoods they aren't from (gentriFUKation) or to launch teaching programs in poor, indigenous communities without asking. At its most deadly it creates media, art, and messages about worlds and peoples who haven't given their permission to be media subjects, the multi-million dollar tourism movement, constant and incessant "devil-opment." We are constantly told that this is what we as poor people need to get up and out of poverty. We are told this by the people who want to excavate our resources, sell us useless products, poison our land, our air, our water and our bodies. Perhaps, if we began to decolonize all of this so-called economic development, help, crumbs, programs, and services we could begin to

> speak about land, language, and resource reclamation. We could begin to lead ourselves, our families, and our communities out from under the heel of the oppressor. (77)

Many of the very programs, non-profits, and institutions that supposedly work to address food insecurity use hunger to accumulate wealth and power as part of their organizing logic (78,79). What is lauded as charity are actually crumbs. As Yoruba scholar and post-activist Bayo Akomolafe says, "What if the way we respond to the crisis is part of the crisis?" (80) With this contradiction in mind, how can efforts to feed and nourish our communities shift from charity to solidarity?

Critically, the class and educational privilege of the study's academic-affiliated authors are implicated here as well. Academia is part of a power structure that reproduces inequalities, exacerbates wealth disparity, drives displacement, and limits sovereignty and self-determination (77,81–84). UC Berkeley is no different. The university has been driving displacement in Berkeley for years due to growing enrollment, intense property development, and high rents, with a recent study demonstrating that these exact tactics primarily benefit the most affluent (85,86). The destruction of People's Park—a historic site of street life, mutual aid, community uplift, art, and organizing—demonstrates how UC Berkeley panders to private industry and real estate profits over community-based systems of care (87). The privatization of the so-called public university has been bolstered by massive financial backing from corporations deeply invested in the industrial food system, including Bayer, Syngenta, and Novartis (88–90). As the authors and participants in this study experience a range of wealth, class, and educational privileges, we must critically examine how our actions may be reinforcing existing inequalities and power imbalances.

The East Bay is the birthplace of so many movements for self-determination and sovereignty. From the labor movements of the early 20th century, to the Black Panther Party, to the Red Power movement, the Bay Area has been a rich landscape where oppressed people have reclaimed power for themselves. Food and land have been central to these efforts, and are at the center of many projects to reclaim sovereignty. The first point of the Black Panther Party's 10-Point Program is "We Want Freedom," and the last is "We Want Land, Bread, Housing, Education, Clothing, Justice And Peace." This is the soil from which today's East Bay food sovereignty initiatives grow, and their efforts to find freedom through land and food is at the center of our inquiry.

While this study began before the COVID-19 pandemic, the conditions of the pandemic and the associated breakdown of the food supply chain influenced this study as well as the general landscape of anti-hunger efforts, all of which were centered in community, food sovereignty, and the importance of localizing food systems. Since the beginning of the pandemic, several innovative programs have emerged linking anti-hunger efforts with local, small-scale farms—many of which are linked to the organizations interviewed and featured in this article. A host of produce prescription services have been created in Alameda and San Francisco Counties, where fruits and vegetables are prescribed alongside behavioral health support from local clinics. With programmatic names like Recipe4Heatlh and VeggiesRx, these programs offer patients prescriptions for fresh fruits and vegetables that are sourced from regional farmers. "Farm to food bank" programs have also been supported by the US Department of Agriculture (USDA) and California Department of Food and Agriculture (CDFA) through grant programs and other funding sources that allow food banks to source more of their inventory directly from local farmers. These programs mark shifts in public consciousness about how agriculture and anti-hunger efforts can be linked, driven by the precarity in supply chains during COVID-19.

Our methodology

We employed a participatory mixed-methods approach alongside a community of practice in the East Bay from 2016 to 2021, investigating the relationships, networks, strategies, and practices that sustained initiatives for nourishment and food sovereignty. To understand how participants in this dynamic and relational community made meaning of their efforts, a significant portion of our methodology included ethnographic data garnered through participant observation. Between 2017 and 2023, the authors participated in growing fruits and vegetables, washing and packaging produce, delivering produce, cooking prepared meals, and distributing food. By participating directly in these mutual aid activities and networks, we were able to engage with farmers, organizers, distributors, drivers, volunteers, and many members of our community whose pantries and fridges were supplemented through these efforts. During such encounters, the lead author maintained field notes and a photojournal in an attempt to understand the daily practices, meaning-making, identity formation, and narrative creation of anti-hunger initiatives in the East Bay. Through years of growing, distributing, sharing, and cooking food, a wide range of flavors, textures, smells, and characters emerge. Thus, a large part of this article centers on the voices and stories of the people who make up this vibrant web of nourishment, care, and solidarity. We hope that this piece serves as a vehicle for sharing their stories in ways that serve their sovereignty and amplify their message to a wider audience.

In particular, we will follow a single crop—the humble collard green—as a way of uplifting the agency of food and the power of non-human beings in constituting networks of care. This draws inspiration from Donna Harraway's concept of "companion species" in reference to the co-constitutive existence of humans and non-human beings (91). We propose that collard greens (*Brassica oleraceae*), changed and shaped by centuries of cultivation across the globe and adopted by a wide range of cultures, might serve as a good companion species in an exploration of nourishment from the soil to the belly and back again. Networks of nourishment are dependent on more than just human actors—they are wild, emergent, enmeshed, entangled, alive. Gilles Deleuze and Félix Guattari wrote of such co-constitutive and emergent systems as *rhizomatic*. Without a body plan, "a rhizome ceaselessly establishes connections between semiotic chains, organizations of power, and circumstances relative to the arts, sciences, and social struggles" (18). In other words, the transformation of symbols, power, and material conditions are living systems, and so are the work of a multiplicity of beings and unending series of semiotic events. Non-human actors are key to understanding their development. Like the matsutake mushroom of Anna Tsing's *The Mushroom at the*

End of the World, we propose that following the collard green (an abundant, nutrient dense, culturally mutable, easy to grow, long-season crop) might expand and deepen our sense of "community" in this community of practice (92).

Our team conducted 46 semi-structured interviews with food producers, distributors, and consumers involved in this community of practice. Interviews were designed to illustrate the participants' experiences, motivations, and challenges in accessing and distributing food in ways that aligned with food sovereignty principles. These interviews were conducted under IRB protocol 2019-10-12688. All interviews were anonymized and transcribed in full. Our team employed qualitative coding on interview transcripts to identify recurring themes, patterns, and narratives using Taguette, a free and open-source software. All transcripts were coded by two different individuals and a total of 44 codes were generated through the coding process. Codes were aggregated to produce six key themes (Table 2).

Quantitative tracking of food distribution was carried out using a combination of manual logging and smartphone-based forms linked via QR-codes at two sites owned by the University of California: Oxford Tract and Gill Tract Community Farm[4]. Produce type, weight, and destination were collected at delivery over a six-year period. This data collection aimed to quantify the scale and scope of food distribution efforts, identifying trends and patterns over the study period.

Taken together, these diverse methods offer a rich understanding of how communities engaged in linking mutual aid with local agriculture understood themselves, their projects, and the communities they were embedded within. Six key themes that speak to successful integration of hunger relief and agriculture emerged from our analysis of the data as follows: 1) personal, reciprocal, and intimate relationships, 2) cycles and circularity, 3) agency and self-determination, 4) holistic nourishment (social, emotional, spiritual), (5) local and solidarity-based economies, and 6) awareness of precarity, power, and privilege.

Results

Personal, Informal and Intimate Relationships

Personal or intimate relationships emerged as a critical aspect of hunger relief in this community of practice. A majority of these local organizations rely on informal and reciprocal relationships in order to understand the specific stories and intersectional struggles that people face in their

[4] It is important to mention that both of these sites are highly contested. Their inclusion in this study brings in a complex web of power relations between the academy and the community. While the University of California owns the land, there are subtle and complex power dynamics at play involving land occupation, community development, bureaucratic gate-keeping, cultural practices that center whiteness, and more. For land occupation at Gill Tract, see Antonio Roman-Alcalá's work (93–95). For more about the contested nature of the Oxford Tract, see Rainey et al. and this housing report from 2018 (96,97). That these sites continue to be made available for self determination projects by and for QTBIPOC, low-income communities is critical.

communities. These relationships constitute a system of care, which can begin to address the complexities of hunger. Our interviews offered many examples of how local knowledge and informal relationships allowed this community of practice to shorten supply chains, strengthen alternative food networks, and personalize approaches to addressing hunger.

Notions of personal and trusting relationships were seen as essential to addressing the intersectional causes of hunger, as a staff member at the Women's Drop-In Daytime Center describes:

> For a lot of people, they want to learn you, learn about you, trust you, see what you offer, and then eventually may sign up for services. So that's the beauty of what we do, and hospitality is a great way to start that relationship and build trust. And that should never be undervalued... you got to start somewhere and it's a beautiful way to start. That's why you got to start with their belly, among other things, which is great. (Client Distributor 4)

This individual is demonstrating that food, hospitality, and housing are all parts of a deeper investment in relationship in order to be with someone as they seek to transform their own lives. While trust takes time, deep, reciprocal relationships are necessary to begin the holistic changes needed to address hunger's roots—housing instability, poverty, inequality, and domestic abuse. These root causes of hunger will not be addressed by a single meal or a bag of produce. Tending and uprooting them requires an ongoing relationship.

Informal and personal relationships were understood as critical to maintaining the dynamism and flexibility required to minimize food waste and address hunger. For Daily Bread—a grassroots effort that organizes volunteers to deliver food between different locations—informal and personal relationships make the entire operation run. One of their organizers described the nature of these relationships:

> Most of our arrangements are very casual, very informal. So there's a phone call, "Can you use this?" So I spoke with the nutritionist at both Berkeley and Albany School District, and I said, "What are you doing? Can we bring these items?" And so we worked out an arrangement and so now we do that. So there's nothing formal about any of them. (Aggregator Distributor 4)

The informal nature of their operations is made possible by close relationships. Through the ongoing exchange of food, trust is established. Members of this community of practice establish trusting relationships that allow them to pick up the phone and mitigate the dynamic nature of food sourcing and recovery. Their ability to assess who needs food and how that food can be quickly redistributed reveals the importance of informal relationships as a strategy for shortening supply chains. Many interviewees used phrases such as "word of mouth," as they explained the networked way that people found out about their services—whether they were farmers supplying vegetables, volunteers coming to help aggregate food, or clients receiving food for their families. This "word of mouth" spirit and the informality of people's engagement was emphasized repeatedly.

Staff from the Women's Drop-in Daytime Center also articulated an informal practice to account for the structural barriers that intersect with hunger—getting to know their families, their living situation, and their way of life. This includes access to infrastructure for food preparation, food storage, and housing. The integration of these additional barriers to nourishment into strategies for care was clearly articulated:

> So I really think that personalized care is a big part. And it's really more like, "Tell me... How many people are in your family? … Do you have secure housing?" Because if someone's living in a car, it's a little different because they're going to be using a camping stove or they're not going to have a refrigerator. They're not going to have a freezer. So you're going to want certain types of food for them and in a certain way. Maybe they don't have a can opener so then you flip-flop. Or if they're living in a shelter, they might have access to a microwave, but not others, or no freezer, but a refrigerator. (Client Distributor 4)

This individual has clearly engaged in many conversations of this kind and understands how poverty restricts access to the tools required to prepare and store certain foods. They adjust their care accordingly. Knowing the intimate details of people's lives, and creating conditions where they can be visibilized and held in community, are essential to that person's ultimate ability to feed themselves.

Personal relationships also help shape feelings of belonging and camaraderie that can support nourishment. The following testimony from a farmer illustrates the complicated relationships with hunger that shape their efforts:

> People don't want to have a soup kitchen experience… It's often very undignified. I grew up really poor. My family would rather have either gone hunting or grown their own food or gone to some discount place and gotten cheaper stuff, even if nicer stuff is available, as a handout from a church or something because of the dignity part of it. So that's why embedded folks who are culturally literate, the people who are doing their own thing already that we connect with and partner with, is really important so that people can just be like, "Oh, I'm just in my community doing my thing. Yeah, I helped this person out with their car the other day, and, oh yeah. Okay. They're hooking me up with some groceries. Cool." I don't have to have this experience the same as like a dejected person that has to go down to the food bank and stand in line for half an hour and fill out a bunch of forms, and you see where I'm going with it. (Farm Distributor 7)

Here, a person is "embedded" when they establish relationships of trust in the community. Trusting relationships are understood as offering a sense of dignity, mutuality, and respect to the act of food distribution and mutual aid. This person understands the soup kitchen to be a cold and impersonal space, with long lines and paperwork that leads people to feel undignified. There is some fundamental anonymity to the idea of a "handout." When there is a reciprocal relationship, then receiving food feels more dignified. These emotional qualities of food distribution are essential to understanding how hunger can and must be addressed in our communities. They are also foundational to a more transformative approach to hunger and nourishment that includes agroecological transitions and agrarian life. This perspective was shared by an organizer at the Gill Tract Community Farm (Gill Tract), which works to bring people of diverse identities, cultures, and experiences to farming. The farm was founded by an occupation in 2011 and is a site of agroecological practice, collective governance, popular education, and equitable access to healthy foods. Yet notions of dignity and respect complicate this vision. Racial harm and conflicts around racial justice, moments of BIPOC farmers feeling "surveilled," and gender-based harms all challenged the farm's commitment to bringing diverse communities together on the farm. Even within contexts that prioritize racial justice, sovereignty, and equal access, significant barriers to participation in agriculture remain. Histories of enslavement and colonization, present-day labor exploitation and abuse, and prevailing power imbalances in land access trouble efforts to create racially and culturally diverse farming initiatives.

The importance of personal or intimate relationships was also reinforced by larger organizations with higher levels of funding. Berkeley Food Network is a food hub that opened in 2020, and operates with community partnerships through sourcing and distribution programs to ensure people can receive high-quality food in ways that maximize dignity, respect, and choice. Berkeley Food Network is reliant on partnerships with community social service organizations that already have existing, intimate relationships with their local communities. One of their staff spoke to the importance of partnering with "community social service organizations who already have existing touch points and relationships with community members," since Berkeley Food Network did not have the relationships required to support unhoused communities. They did not know how or where to meet those needs, so they partnered with those who had existing relationships in the community to bring nourishment to unhoused community members. Another organization that relied heavily on informal practice and personal relationships was Planting Justice. Planting Justice is a non-profit that has been working at the intersection of food justice and holistic re-entry for individuals coming out of incarceration since 2009. Meaningful employment and vocational training are central to their approach. PJ operates several initiatives, including a plant and tree nursery, a tree farm, an edible landscaping service, vocational training, and political advocacy. One of their staff described the "first name basis" relationships that underpinned many of their programs, including smoothie making and distribution from urban farms and gardens. Critical to the success of the program was the team's long-standing relationships with food recipients, having known "some of these young people since they were freshmen and now they're seniors." These personal relationships are essential to the effective distribution of food.

Agency and self-determination necessary for nourishment

Agency and self determination were also key principles within this community of practice. One volunteer at the Berkeley Food Network offered this insight:

> The solutions to fit the dietary needs of different people is so different. Is so different. So if there are all these varying needs and desires but you have a linear production, there's just going to be so much waste inherent within that because there will be a lot of "No's". People say no to food all the time and that's okay. That's agency and that's choice and it's so intimate what we're putting in our bodies. So you should be allowed to say no without feeling guilt. But the way our system has evolved right now is that, well, if you care about the world and about humans, you will feel guilt if you're wasting something because of the resources that are used within it and then the potential that food could feed someone else.

It is important to this volunteer that people maintain the right to refuse certain foods, and to choose what they put in their bodies because the act of nourishment is intimate. One way of removing the guilt or shame around these moments of refusal is the creation of spaces and communities where individuals can enact their agency. According to the quote above, the intimacy of hunger and eating is threatened by the structural realities of a system that wants to dictate what people should eat. What's more, they express that an individual might feel guilt for *not* eating or wasting food that has been offered to them. Celebrating agency and allowing people to say "no" is positioned here as a crucial element of culture around hunger relief. This volunteer went on to say that the organization's "goal is to establish choice and give people agency." Self-determination is not only right—it is effective. By allowing people to "establish choice" and enact their agency, they are more likely to be nourished. Expanding the choices available to members of their community was central to the practice of this food hub, and was a commitment shared by many members of this network. This is an expression of the value of holistic nourishment and occurs at physical, spiritual, and communal levels.

The importance of agency also extended to farmers in this network. The organization of Acta Non Verba's Community Supported Agriculture (CSA) box demonstrates this. Acta Non Verba is a BIPOC-led non-profit working at the intersections of youth education, urban agriculture, and food distribution. Their CSA aggregates produce from their four urban farms as well as regional growers, and offers it on a sliding scale. Then, any "proceeds go to the bank accounts for the kids" in their youth programs. This highlights moves towards uplifting agency on both ends of production and distribution. On the production side, their staff emphasized how cooperative systems increased the agency of both farmers and their communities. "Cooperatives have been a saving grace throughout all this," the farmer shared in their interview. "They're the most economically resilient in any form, not just farms, but whether it's cooperative distribution, cooperative processing." Cooperating with other regional farmers, distributors, restaurants, and non-profit organizations allowed Acta Non Verba to dramatically grow their operations during the COVID-19 pandemic. Comparing themselves to the industrial farms with broken supply chains that had food rotting in fields, Acta Non Verba staff noted that they were able to meet *more* need during the COVID-19 crisis. "Smaller, more diverse and more localized systems… we were able to pivot. All these smaller scales are able to really shift and serve the community where it's needed," the farmer shared. From their vantage point, it was smaller, diversified, and localized food systems were able to better pivot and address the crisis of COVID-19. Cooperating and collectively building power were key to creating self-determination for Oakland residents in the heart of a low-income and low food access community. Supporting youth in the community financially and offering them the opportunity to use those funds as they saw fit is yet another expression of Acta Non Verba's commitment to sovereignty. Centering forms of self-determination in their production, distribution, partnerships, and financial planning have made Acta Non Verba a model for how urban agriculture can avoid the pitfalls of green gentrification (64).

Food sovereignty has become a potent organizing principle internationally because food, agriculture, and land strongly govern self-determination. As Fannie Lou Hamer said, "When you've got 400 quarts of greens and gumbo soup canned for the winter, nobody can push you around or tell you what to say or do" (98). This power was referenced by a volunteer with Berkeley Student Farms, a student-led program practicing agroecology and land-based education with a coalition of farms and gardens at UC Berkeley. They articulated how growing food can serve as a response to the "trauma" embedded within the food system and embody the sincerity and power of people's interconnection:

> There's a lot of trauma in the food system, right? There's a lot of stored ancestral and societal trauma around forced labor, around displacement, around exploitation. And people don't want to think of themselves as the beholden to those structures of power. So there's something that's so empowering, so restoring of sovereignty, about growing one's own food… I think that's also what connects this moment to COVID and to the pandemic, is that people are having a heightened awareness of how interconnected we all are and how what one of us does affects others. And I really believe that community-based farming projects like the ones in the East Bay do the same thing. They highlight how we're connected, and they bring people together and show the way that our wellbeing and our nourishment and our sovereignty are tied up in one another. And they allow us to act on that truth in a way that feels empowering and in a way that feels right. And so is also a direct response to this sort of isolation and the sort of degenerate nature of this virus, saying, "Oh, well, we can still feed ourselves. We can still take care of the earth. And we can envision a different future.

This individual makes clear the view that people's wellbeing, nourishment, and sovereignty are "tied up in one another." Food and agriculture are understood as a site of intersecting violences: forced labor, displacement, and exploitation are named as part of the embedded trauma within the food system. From the volunteer's perspective, crises (like the COVID-19 pandemic) and responses to them (in this case, the growth of community-based farming projects) are embodiments of interconnectedness. Enacting sovereignty through growing food is an opportunity to act on the truth of our interconnectedness in a way that is empowering, rather than degenerate. Community farms are positioned as a response to the traumatic aspects of the food system, but not because they heal histories of forced labor, displacement, or exploitation. Rather, they visibilize how our ability to enact sovereignty is mutually dependent. They allow members of a community to embody forms of nourishment and care that make possible a different vision of the future.

The connection between agency and nourishment was particularly important for Essential Food and Medicine, a collective based out of West Oakland founded in 2020. Essential Food and Medicine is a grassroots effort and collaboration between unhoused and housed residents of the East Bay. Their mutual aid practices included distributing handmade juices and herbal medicine, hosting community events, establishing gardens and mutual aid centers in houseless encampments, political advocacy, a radio program, and more. The range of modalities that this organization engaged in reveals the complexity of healing and reconciliation practiced by its members. Much of their work was centered around the Wood Street encampment in West Oakland and the Wood Street Commons, a houseless-led collective. Central to Essential Food and Medicine's methodology prioritized uplifting the agency and self-determination of unhoused residents. While describing their work with a particular individual at Wood Street (an encampment that once had 250 people living there) one member of Essential Food and Medicine explained their relationship involving much more than just food but mental health, holistic healing, counseling, and social support.

> That's how we like to work, more one-on-one. We can go deep with a couple people… It's challenging. There are a lot of different levels of addiction and mental health. It's being patient and let things not be all the way together for a while… They're all our relatives. It's not even like we're serving them. We're just offering our medicine and they're offering their medicine and we're combining to make something fresh. Certain things we can assist on and certain things they assist us on. It's beautiful.

This quote centers the sovereignty of every individual involved in exchanges of care. It emphasizes non-hierarchical service, medicine, and assistance. Essential Food and Medicine was distributing hundreds of fresh juices, herbal medicines, and prepared foods alongside unhoused communities. This work would not have been possible without their "medicine"—their intelligence, relationships, ingenuity, and community building. A mutual respect is fostered between members of this community of practice, where each individual has something to contribute. From this foundation of mutual respect—where each individual's sovereignty is acknowledged and honored—a more meaningful kind of nourishment can be found.

One particularly vibrant site for enacting this form of collective agency is People's Park, where wild stands of collard greens stood for years (Figure 1). The long-fought-for gardens stood vibrant against the militarized violence and extractive efforts of the University of California (87,99,100). The collards at People's Park were a testament to the wild, fervent, and biodiverse resistance to police violence and dispossession at the hands of the state. Meanwhile, daily food distribution from Food Not Bombs and live-saving medical supplies from partners like Punks With Lunch and Do No Harm Coalition exemplified the Park's spirit of "user development."

Finally, a commitment to sovereignty and self-determination was seen as a remedy for forms of saviorism that plague many efforts to address hunger. A staff person from Food Shift, a vocational training and food waste recovery organization, spoke about their commitment to solidarity in this way:

> Rather than us being front and center being able to provide the food to our constituents directly, instead we will uplift and help scale the organizations that are already feeding people from vulnerable communities, marginalized groups and help them instead… Our motto is having solution for the people rather than serving the existence system. For the people, by the people… and with the people. Meaning, the people we train are going to be part of the solution to get rid of the illusion—or minimize the illusion—and the practice of the savior complex where we're giving to redeem ourselves. Versus we are doing our work to help them not be marginalized because we are the ones who marginalize them in the first place. So after our work if they're not better off than we were just doing our selfish work of redeeming ourselves.

This individual echoes a common refrain regarding the importance of moving away from saviorism and towards solidarity. While dominant philanthropic and non-profit ideologies about hunger entrench savior narratives that are often for the benefit of anti-hunger organizations and food corporations, this network sought the opposite. Vocational training designed to offer meaningful employment in the food system is seen as a (partial) remedy for the more charity-based handouts of other hunger-relief efforts. Uplifting existing organizations by supporting community-led movements was also named as a strategy for avoiding saviorism. This individual is expressing that a commitment to self-determination means avoiding the replication of harmful patterns of saviorism that reinforce existing power dynamics and inequalities.

Nourishment is social, emotional, spiritual, and place-based

Nourishment is often understood as a purely biological or nutritional phenomenon—give someone the right mix of vitamins, minerals, protein, and fiber, and they'll be nourished (10,14,17). Yet this community of practice routinely emphasized the rich emotional, spiritual, and place-based roots of nourishment. Nourishment was understood as emerging from social and cultural contexts where people could receive more holistic forms of care.

Food distribution was rarely performed in isolation in this community of practice. Almost every individual we interviewed mentioned programs that surrounded and augmented their food distribution, many of which attempted to address the social or economic roots of hunger and malnourishment. They include: a free diaper program, cooking classes, job training program for those coming out of incarceration, veterans, or victims of domestic abuse, visits from the City of Berkeley nutrition department, acupuncture, blood pressure screening, sign ups for Cal Fresh, catering services, racial justice study groups, and more. These activities demonstrate a broader commitment to addressing the roots of hunger and poverty than the charity model of food handouts. Integration with small farms also meant that seeding, composting, planting, harvesting, and other principles of horticulture and agroecology were routinely mentioned aspects of this community practice.

One staff member at PJ spoke to this directly, highlighting how their organization tried to address economic disparities and systemic violence:

> What does it cost the county of Alameda County Public Health Department, for example. What does it cost us as a society to not have access to affordable [food] for low income people? You know, like what is actually if you want to get on the dollars and cents question, like how much money going out the door to respond to, like the impacts of food apartheid. But also beyond the economic piece what is the physical, emotional, psychological and spiritual impacts of urban agriculture on the people who are able to participate in it, to the people who are able to benefit from it? … You can speak to any member [our] nursery right now, and each of them will have their own personal story of how … the ability to even just do plant work and earth-based work, and to be paid well for it, or paid enough for it, is really just life-saving beyond the economic piece…

This individual uses the term "food apartheid," a term that captures the interlocking economic and political violences that maintain a social order where some are starved of nourishing foods while others have unfettered access (101). In this quotation, they make an appeal to the multiple forms of nourishment that people receive from working in urban agriculture—the physical, emotional, psychological and spiritual benefits. And yet, this individual ultimately names those benefits as building upon economic opportunities. "Earth-based work" is positioned as "life-saving" beyond just a living wage. The contradictions embedded within this quotation should not be overlooked. This person claims a legitimate economic intervention at the roots of hunger (poverty), and appeals to the broad societal and economic costs of limited food access. Yet at the same time, they claim that the work is meaningful or *nourishing* along a series of other dimensions (physical, emotional, spiritual). Holding these truths in dynamic tension generates new modes for tending the deeper roots of hunger.

At the Gill Tract, a volunteer described how acts of nourishment during their time at the community farm created a strong spiritual connection. Speaking about an experience playing music at the farm one day after volunteering, they shared this:

> She came over from the [farm stand] and she said, "This is what church feels like." And she was so inspired and so happy because we were playing and she was able to connect with spirit and just to tune in and to be present… To honor the land for me is to pay reverence, to respect, to give, to nourish. And I honor the land by pouring libations for the ancestors, for the ancestors of this land, for my ancestors. The way that I honor the land is by planting and giving to others. Another way I honor the land is just to be in connection and activate it

> through music. You know because the land needs activation too. And I think the vibration of the drums actually activates the land and gives back to the land…

References to "pouring libations," and "ancestors" indicate a set of cultural practices that this individual is bringing to bear on their agricultural work. The community farm has given them a place to perform these cultural practices in ways that feel connective and nourishing. And in turn, they are about "to nourish" the land through reverence, respect, and offerings—in this case, music. The person continued:

> Remember that childlike essence, you know, that we are all connected to nature and that we are all part of it. And when we take care of the land, we're taking care of ourselves. That type of reciprocity. It's like a very holistic experience… And the land is very healing. And sometimes I don't want to I want to just be by myself. So I can be in communion with the land so I can heal and the land can heal because I have something to give the land as well as the land has something to give me. And so I think that's another layer of healing you know because we can have a bad day and we can just come and connect with a certain plant or smell a flower or rose. And it just changes the frequency of our spirit…

The collard greens offer us an illustrative glimpse into these woven and alive senses of food and place. An altar at the Gill Tract (Figure 2B) features the collard greens laid out on the ground, surrounded by a sword, flags, corn, and other objects. The collard greens, some of the most prolific and important crops at the community farm, are offered back to the Earth and the altar. Their large palms face upwards like plates or bowls, cradling one another. At GRIP, a volunteer cooks collard greens from another local farm for the families at the shelter (Figure 2A). This facility offers medical and counseling services, an address for mail, a shower, and place of gathering. Collard greens are there, stripped and washed. They are ready to be cooked alongside fried chicken and yams in the background, serving culturally relevant soul food for people in transitional housing—reaching across place, across time, across culture.

The integration of food sovereignty and anti-hunger efforts in the US must be attuned to the spiritual dimensions of transforming agriculture. Indigenous and traditional worldviews of land (expressed through relationship seeds, soil, plants, and the like) affirm the living quality of land. This closely resembles emerging understandings of soil and soil health that view the soil as a dynamic, living being (102,103). To transition agriculture towards more ecologically and just forms while also addressing hunger, this community of practice returned to forms of spiritual practice (reciprocity, prayer, etc.) with frequency.

This was echoed by other participants in this network. One volunteer from Essential Food and Medicine described how working at the intersection of food and farming was contextualized by the COVID-19 pandemic:

> Whenever there are crises, I think there's something built into our DNA that wants to respond like, "Oh, actually we need to reconnect with the earth and actually put our hands in and start planting seeds for our own security, because that's the roots of our health." … It's just important to recognize these roots and never forget the roots. I think certain crises bring us to the point of remembering like, "Oh yeah, food, land, water, what are the essential things before we get too far off on what we should or should not do in terms of our health?

This offers another dimension to nourishment and the "roots of our health." This person offers that the foundation of our wellbeing is a connection to the Earth—food, land, and water are named specifically. Seeds become a metaphor for self-determination and agency, where individuals are cultivating their own wellbeing through conscious action. This quotation contextualizes the work that Essential Food and Medicine was doing with unhoused community members, pairing juices, herbal medicines, and hot meals with transformative justice, holistic healing, and gardening in the Wood Street encampment:

> People were like, "Well, why is it at [Wood Street]?" Because of prayers and it's because of listening, that's it. Actually, it takes some energy to do that. It takes some dedication and courage because the whole world can be going this direction and you got to stand in the truth of who you are. Then you see the results. Yeah, that's really the teaching behind the organization. The food is the best way to communicate…

This highlights the spiritual and emotional qualities of solidarity required to establish care in places where dehumanization, disenfranchisement, and disempowerment are rampant. The Wood Street encampment was the site of systemic harassment by the City of Oakland and violence from CalTrans and local police (85), yet it was also a node of mutual aid, care, self-determination, and hope. In a press release dated March 17, 2023, members of the Wood Street Commons (a houseless-led collective of Wood Street residents) protested the city's so-called solutions that left houseless communities with "no collective voice, and no power to govern themselves" (105). For this housed person working in solidarity with this community, "standing in the truth of who you are" requires prayer, dedication, and courage. Food is positioned as the bridge, the mode of communication. And nourishment and care are seen as something far beyond a single juice or hot meal.

Another volunteer from the Gill Tract shared a perspective from their life that offers additional insight into the social and emotional dimensions of nourishment. They share about their life experience working in anti-hunger work before coming to the community farm:

> I'm from Inglewood. And for much of my life, I grew up in a food desert where it was like, you know, 7-Elevens and … Jack in the Box, and … there wasn't like a ton of fresh food, but the fresh food that was there was like all these old abuelas and stuff who had their little gardens. And you know so before this, I was working at Compton Community Garden for a while. And then I also was working at Altadena Farmers Market for a bit. And they have a

> program there where they actually distribute food to elders in the area. And that was super, super special to be a part of because of you know I think often our elders really fall to the wayside in you know contemporary culture or whatever. We really don't care for our elders. We kind of just put them away and wait for them to die. And you just see the faces of these elders, like especially native elders getting delivered food that was their ancestral food and just seeing the joy and the memories and just that connection in real time, right there… It's like nothing else. And it's like even seeing the kids here today, there's something very similar about these young children who are doing this work and these older folks who have been torn away from … the land and from the food and you know to see all of that kind of come together is just like the best thing in the world.

For this individual, acts of nourishment are touched by a wider set of social and cultural needs. This individual is speaking to more communal and collective ways of living—in many ways, reflective of forms of social cohesion that have been lost in the United States (106). Caring for elders, especially using ancestral foods and social connection, is an important social goal that can be met (in part) with food. And reconnecting children with land, food, and their elders is also seen as a critical aspect of the community farming experience. Thus, even after this individual had just shared their own personal experiences with hunger and food deserts, the solution is posed in terms of forms of social and emotional care. It is caring for children and elders that takes center stage when it comes to a more holistic sense of nourishment and nurturance.

Circularity, Cycles, Reciprocity

Circularity and reciprocity were another key area of focus within this community of practice. Symbolic or metaphoric appeals to circles and cycles were an important way that this community of practice articulated their values. At the same time, circles and cycles were also routinely cultivated in material and practical ways.

Circles and reciprocity show up both materially and symbolically. FrutaGift is a grassroots project in the Fruitvale district of Oakland, California where members of the community pick up food from a farmer’s market in a wealthier neighborhood in Oakland that would otherwise be composted, and bring it to a low-income, predominantly Black and Brown neighborhood to distribute for free. FrutaGift has been operating for years as a purely volunteer-based, grassroots initiative, yet it is rooted in personal relationships of trust that allow for it to continue. One volunteer with FrutaGift described some of their basic practices in this way:

> Every Sunday, an opening circle happens at 3. We bless the food. People start showing up at 2:30 to receive numbers and help set up. The whole operation starts earlier, bringing hot food to the farmers at the Temescal Farmers Market. We meet at the farmers market, help the farmers break down their stand, return containers that we’ve borrowed.

From gathering and grounding themselves in an opening circle to cooking for farmers at the market, these reciprocal formations and exchanges were a common form found throughout this community of practice. Practices of regularly forming and actualizing feedback through circles and cycles offer modes of being that embody principles of reciprocity and solidarity. In other words, by viewing circularity and cycling as a part of their practice, members of this network prefigure a world where those values are manifest. The volunteer went on to describe their understanding of reciprocity.

> All the food is a gift. A gift holds greater value than just "free." We have to think about all the labor and care that went into this food. We have to think about what these farmers are giving us. It is such an amazing gift what we are receiving. There is no distinguishing between the giver and the receiver, we are all receiving some sort of gift, people who come to the farm stand get the gift of food, but the whole process warms my heart and that too is a gift…

This individual invites us to embrace the idea that all food is a gift, and that gifting is a cyclical and broadly transformative process. All the dimensions that encompass food (e.g., agricultural labor, care, the act of giving and receiving) the entire process are rooted in reciprocity. They also distinguish between something being free and something being a gift, shifting the ways value is assigned within this community of practice. Additionally, this quotation brings in a nuance in regards to the "savior" complex that we've encountered in quotations above. There is a genuine sense in which those who offer support, who organize and offer nourishment to their neighbors, are being given a gift through their service.

Another organizer with Essential Food and Medicine—the collective who recovers, transforms, and distributes surplus food and natural medicines alongside the unhoused community—shared their aspiration to work with compost:

> One thing we're excited about, I'm excited about, but haven't really cracked the code on yet within this particular model is how to transform the extra food that we don't use when we salvage it and actually create compost out of that. We can actually take that and redistribute that back to local farms, local gardeners, so we can keep that circle going. It's all about that circle. We want to use everything and keep the circle going back around again. That's going to create currency because compost is gold. That can be a project and a micro business for the folks we work with if we crack that code because good compost is really good. We just want to figure out how to get the circle going.

Many of the farms interviewed for this project had some kind of on-farm composting system where food waste from volunteers, neighbors, local restaurants, or similar sources were brought on-site and composted. Essential Food and Medicine's aspiration to recycle nutrients and food through composting expresses an ethic shared by the broader community of praxtice. Composting is itself a practice that restores cycles of carbon and nutrients. This quotation also suggests other forms of reciprocity and cycling that would be built into a composting system—a microbusiness or project that would redistribute compost to local growers, that would "keep the circle going." This emphasis on creating the circle, on keeping cycles in motion, was a kind of refrain for members in this community of practice. This volunteer from Essential Food and Medicine (EFAM) went on:

> I think with EFAM, what our mission is, is to create community immunity through providing the essentials and the roots of health through redistributing food. But I think, ultimately it's the ritual of it. For example, compost, it's the ritual of just, "Man, this is actually sacred and there's no such thing as waste in the system. There's no such thing as throwaway." It's important to utilize that as a lot of Indigenous cultures would utilize every piece of an animal or every piece of a tree. None of these things are throwaway or things that are disposable.

Circularity here is elevated to the level of ritual. The idea that nothing is disposable applies not just to food, but to human beings, cultures, ways of life, and cosmologies. This individual brings the idea that the restoration of cycles of nourishment, decomposition, and new life is a ritualized form of a broader ideology or ideal. Thus, a return to cycles and circularity continues to offer this community of practice not only pragmatism and a set of practices, but a broader ethical and ideological framework that offers a kind of symbolic resonance.

It is not only nourishment and care that rely on cycles. One person spoke to the cyclical nature of our crises and the political movements that respond to these challenges. They worked at the Basic Needs Center, a program on UC Berkeley's campus that provides a range of services to students, staff, and faculty on the university's campus. Their services include financial advising and emergency relief funds, housing assistance and tenants rights advocacy, support for undocumented students, and a food pantry. During the COVID-19 pandemic, the pantry became a node for mutual aid and food waste recovery. It served as a critical emergency food relief hub, which included hosting a large USDA-sponsored food box delivery program. One of their staff spoke to the nature of crisis in this way:

> The issue is that there's so many who are already in a personal crisis, or perpetual crisis, because of the situation and the systems that they've been trying to survive in. And then, you have crisis of COVID, or the crisis of the fires that happens to their community on top of their individual personal crisis. And so, I see our programs as thinking about being prepared and preemptively trying to stop crises. But also, supporting someone through a personal crisis and giving them some tools and resources to prevent or support and make sure that they're okay, like have what they basically need to survive for crisis… With COVID, I thought about all the people working in these spaces… everyone is very good at responding to crisis, it seems. And it's like—this is my time, let's go. I'm energized by this, which is a weird thing to think about, why are you energized by crisis? But I think it's good… But I hope that it could turn more political, just as a pathway to being part of this a bigger political movement… doing stuff for people, and with people, and by people.

This offers another avenue through which to understand cycles of care. It is not only efforts to nourish communities that have a cyclical quality. Crises—be they individual or collective—also arise periodically. And often, collective crises like COVID-19, wildfire, genocide, or mass uprising are layered over existing personal crises. Programs to meaningfully address hunger must recognize the episodic and cyclical nature of these crises. They must also be conscious of how individuals can meet these episodic moments of crisis. For this individual, the presence of crisis increased their resourcefulness, which led to expanded capacity for their organization. A look at the food distribution from the Basic Needs Center between 2019 and 2020 demonstrates the unprecedented increase in the scale of their distribution with the onset of the pandemic (Figure 3). Crisis offered this person a purpose, and their positionality allowed them to act decisively. At the end of the quotation, however, they note the limitation of this perspective. In order to affect real change, crises must create meaningful "political movements" or movements for social change. This aligns closely with the perspective common in food sovereignty circles, where social movements are typically viewed as a critical component of food systems change.

The experience and perspective of those involved in the Berkeley Food Network, a food hub in Berkeley that opened during the pandemic, sheds light on the limitations of the highly linear production and distribution models of industrial agriculture. One employee at Berkeley Food Network describes how the emerging interest in food hubs contribute to a movement towards reciprocity and increased circularity:

> "It's like this idea of circularity, the food hub is just what allows that circle to come together and what allows that linear cycle of production to waste to be bridged back towards distribution. So it's really just about having a space in which folks can bring their waste and in which other folks know that they can come and receive food. And most of the time … partners are doing both. Partners are bringing us waste while also getting food … And in a linear model, one instance of not desiring something equals waste unless there are systems in place to recapture and distribute that and manipulate that food. So the food hub is really just what can accommodate a circular production system or continuous circles, right, in the sense that "waste" can be regenerated into food and then that food…"

This employee at Berkeley Food Network demonstrates a critical way in which participants in this network view themselves. Networks of care are not composed of individuals in 1-1 transactional exchanges, but rather nodes or hubs where a diverse of interactions can occur in the same space, e.g., people who come to donate food also receive food. This composition, once again, blurs the line between 'giver' and 'receiver,' between those who are 'serving' and those who are 'benefitting'— at least in its ideal form. There was a recognition of, and commitment to visibilizing the ways that *everyone* involved in the food hub benefitted and received food from the experience. This "node-based" or "hub-based" structure within the community or practice seems essential to enacting food sovereignty. Many critical nodes in the network served as sites not just of transaction or linear exchange, but the vibrant, complex, and circular closing of a range of cycles: transforming seeming "waste," building relationships, receiving nourishment, cooking, preservation, re-making value, and on.

Yet these commitments to non-hierarchy are aspirational rather than fully realized. The staff person from Berkeley Food Network spoke to some of the complexities of power when they discussed volunteerism, adding depth to the notion of reciprocity. Volunteers, and the work of food waste recovery more generally, were seen as closing loops that have been systematically degraded by industrial agriculture. This was accomplished by re-assigning value based on a commitment to the human right to food rather than the oscillations of markets.

> "It's something like the 12 pack of yogurt, one bursts, so it's unsellable... But what is their incentive, then, to find a belly for it, right? It doesn't exist. So what we do in terms of food recovery is identify that despite things not having a financial price on them, there is still so much nutrients within that item and so much potential health benefit downstream. So it's like, okay, how do we bridge that gap? How do we acknowledge that something has no cost or financial value? And it's through volunteers. So it's through these folks willingness to just come in and give their time and energy and effort towards sorting through a 50% spoiled, 500 pound thing of oranges, right? And it's like, is that economically viable? For sure not, but an economically viable production system leads to incredible amounts of waste and incredible amounts of people going undernourished. So that's how our volunteers are able to fill that gap and to be that workforce that allows for a lot of this work that the market economy simply hasn't accounted for."

Our current industrial food system operates according to a model where waste is *guaranteed* because there aren't systems in place for food recuperation, transformation, and redistribution. What's more, a market-based economy shapes desires, tastes, and preferences. Desirability serves to sever individuals from the legitimate cycles of food, where scrounging through a 500 pound case of oranges is an embodied and direct encounter with the true rot and spoilage that is enacted by a food system. Who would want such an experience when compared with the neat and tidy ailes of a U.S. grocery store? Berkeley Food Network is creating a space where assigning and understanding "value" can transform, closing loops and recuperating the desirability of certain foods. And all the while, these individuals are also bringing food home, finding material nourishment for themselves and their families through the restoration of these cycles.

At the same time, however, this reliance on volunteerism deserves scrutiny. A valorization of volunteerism as an answer to the failures of capitalist, market-based systems can limit our ability to make more meaningful structural or governmental changes (107). This individual is uplifting the way in which labor—in this case volunteers—when given the right incentives, can close loops and restore value to food where market-based capitalism fails. It invites a deeper critique of the current food system, now supported by many activists, scholars, and movements: food must change from being a commodity to a human right (107–109).

Finally, a commitment to circularity and restoring cycles invited a connection between the cycles of ecosystems and the healing cycles of the human experience. Agroecology views ecological relationships and enhancing nutrient and resource cycling as key to creating vibrant and productive agricultural ecosystems (46). There are also fundamental cycles of human healing and wellbeing that come together through land and agriculture that this community of practice prioritized highly. Another volunteer at the Gill Tract spoke to how this manifests at the community farm:

> What I can say is that the places where I find magic on this land shift constantly. And I think that speaks to the way that the land is moving, even though it seems stationary. It's not. It goes back to the conversation we were having about cycles earlier, especially with grief and joy and it all coming in and out. I'm like, "Oh, yeah, like the nitrogen and carbon cycle." You know it's all moving… But having access to this land, I think, is what speaks to me the most because spaces like this are few and far between… And the main reason I'm here, I think, is … to facilitate my own healing as an individual. Both individually, and as a person whose family and ancestors have experienced land-based trauma. And I'm personally divorced from the land, or at least I was… And I feel like that's a really dangerous place to operate because if we are of the land and we are divorced from it, separate from it, it's kind of like, you know, an umbilical cord. Then how can we operate? How can we do anything if we're not grounded, if we're not rooted the way that we should be?

As a racially and culturally diverse community of practice, a commitment to the long cycles of healing is understood as critical. The land is seen as a bridge—a place where the memory of past traumas, violence, and painful histories is stored, but also a place where healing is possible. As a community committed to healing the paired wounds of poverty-driven hunger and agricultural exploitation, a commitment to the long arc of healing allows people to move forward together. Historically dispossessed of land, this person was now reclaiming autonomy and healing themselves through a relationship with the community farm. Their relationship to the farm shifted and transformed as they sought to right historical injustices that the Earth was witness to. And while past generations were divorced from the land, they see that new generations can take up the mantle. Cycles of loss and reconnection create an *intergenerational* healing process that cannot be overlooked when thinking about how food sovereignty might take hold in the US agricultural system. The metaphor of the umbilical cord is particularly potent here. The cord that ties mother to child, linking generations through nourishment and care, is likened to the "land". Movements for food sovereignty—fundamentally about changing relationships with land—offer visions of nourishment that are as intimate, intergenerational, and as maternal as the umbilical cord.

Creating local and solidarity-based economies

A core theme that emerged from interviews was a commitment to integrating anti-hunger initiatives and food sovereignty through the creation of new economies. One way members of this network imagined creating new, solidarity-based economies was through the creation of market opportunities for farmers who are often left behind in traditional agricultural markets: small and local farms, BIPOC farmers, and women or LGBTQ2S+ farmers. Fresh Approach is a Bay Area non-profit that runs a series of food access programs, including traditional and mobile farmers markets with savings programs for low-income residents. According to our interview, one of their commitments is “supporting local farmers,” and pairing them with low-income communities through market programs:

> “We do really put a priority on focusing our sourcing from small and beginning farmers and farms that are either woman-owned or woman-operated or those that are operated by different communities of color. [We’re] really trying to provide a steady marketplace for farmers that are just getting started or farms that don't really have access to a lot of the kind of traditional CSA channels that some other farms have… And so really trying to find those farms that may struggle otherwise and provide them with a really regular purchase amount that they can rely on, and quick and easy payments as well. So really trying to support our more vulnerable farmers…”

“Supporting local farms” is enacted through the creation of reliable markets that support BIPOC, women, and beginning farmers. This is poised as a central part of Fresh Approach’s food access programs. Often, discourse connecting agriculture and hunger are situated as agronomic, ecological, or climate change issues—with a particular focus on whether we can grow enough food without destroying the biosphere or accelerating climate change (110,111). Members of this community of practice had a very different approach. Many in this network had a clearly articulated belief that poverty, structural inequality, displacement, and political instability were the key drivers of hunger. An employee at another food aggregator and non-profit, Food Shift, echoes this belief. They described Food Shift as “a food recovery organization with a social enterprise kitchen,” and explained their understanding of the causes of hunger.

> “We don't believe that… hunger is caused by lack of food as much. Really the root cause of it is that there is financial insecurity. Because… we don't have lack of food to buy it's just that they don't have the money to buy it, so that's very different than drought conditions in the middle of Africa that all of their crops die. And we also don't necessarily believe that food ecosystems problem have to do with the lack … of food. That of course exists. But again the root causes are in the system itself… and in the financial insecurity.”

For these individuals, hunger is described as primarily economic and structural. According to them, in the Bay Area there *is* enough food to feed everyone. To address economic inequalities that lead to hunger, groups within this community of practice actuated several programs. Fresh Approach created voucher programs and nutrition classes' that create incentives for “lower-income and more vulnerable communities” to “find as much produce as they can” and “incorporate [it] into their diet.” Vouchers for produce are integrated with support for “vulnerable farmers” who have limited access to markets, and with farmers markets and mobile markets. Food Shift hosts vocational training in food careers for formerly houseless or incarcerated people, individuals suffering from domestic abuse, and those who encounter other forms of systemic oppression. Many other organizations in this network ran programs for economic uplift and meaningful employment as a means of social transformation. PJ employs up to 40 full-time staff, with a focus on employing people exiting incarceration. They have a focus on 'holistic re-entry' for incarcerated individuals that includes a community of peers, meaningful employment, living wages, and more. Through these programmatic approaches, many of these organizations seek to create alternative markets or non-market solutions that address hunger in holistic ways.

Given this focus on distribution and economics rather than the volume of agricultural production, how did organizations integrate their efforts with those of small-scale and urban agriculture in the region? Many named specific challenges working with small-scale and urban farmers, especially in regards to supply and distribution. One volunteer working with DB mentioned the challenges with sourcing from small-scale and urban farms this way:

> "We were picking up a lot of produce [at the farm]. The challenge was that it was very erratic, and it was like massive amounts on one day, and then I never knew when it would happen again. So I would say overall, both, during the pandemic, and for all the years before that, the biggest challenge is uncertainty with some groups about whether or not they will have donations. And the variability. And so some of the places that we bring to can only take a small amount, they might be, say, 15 residents within a house, I can't bring them 30 boxes of produce, or whatever. They can only use relatively small amounts. So then we're left with, "Okay, it's a last minute, where do we bring the other stuff?" So there's a little scurrying around. So that's a challenge."

These organizations do everything they can to work within a highly variable and dynamic alternative food system. One staff member at Berkeley Food Pantry, a neighborhood food pantry and non-profit, discussed local agriculture in this way:

> 'It would be great if there were more local farms. Because grocery recovery is not really consistent, and you essentially are getting people's leftovers. Whole Foods is just unloading onto food banks with things they order too much of. If there was a body… that could facilitate transitions between pantries and social service spaces and urban farms…"

This individual is speaking to both the desire for and logistical challenges of sourcing produce from local farmers. Local farms are seen as more desirable than food recovery from grocery stores—which are essentially "leftovers" and inconsistent. However, this organization has not found a successful mechanism by which pantries or other anti-hunger initiatives can interface more with small farmers. This issue of distribution, ironically, mirrors some of the critiques of the dominant industrial food system. While there is sufficient food supply from local farms, this individual recognizes that the problem lies in a lack of economic incentives or structures for sufficient and equitable distribution of that supply. Given that this individual was already collaborating with many small farms, this reveals a key reason to create infrastructure for alternative, local economies.

This emphasis on transforming local economies was evident in the range of programs and methods that this community of practice utilizes to actualize their anti-hunger goals. This quotation from staff at Acta Non Verba illustrates the diversity of strategies that this network was employing:

> It's a strong community, and there's a community center right in the middle of all the housing. We hold a food pantry, we host the food pantry there… [We] also offer on-farm produce pickups. So, people they know when they see the farm's open or even when it's not, if they see that the office is open here, if they see me or another staff member, they know that they can wave us down and get food from the farm… And then lastly is our CSA… What we're doing is ordering what we don't have on our farms, we get it from the other farms. So we're sourcing now…But it's key, because in the Bay, there's a wider market for this stuff still. Income levels are higher, so people can afford to pay for the produce. Whereas in Central Valley, a lot of their markets… they've closed cause it was farmer markets, or direct restaurant sales, and that's not happening. Farmers are still getting paid, plus our food in the CSA, and making sure our community is still getting fed… It's great that we help these farmers, but it's even better that we're helping our own community. And because part of the center is grant funded, this whole program for the next six months, we'll be able to provide up to 20 CSA boxes for our community, free of charge. But we ask for money donations, and… any proceeds go to the bank accounts for the kids."

This organization engages in an impressive range of activities as they work towards agroecology and against hunger in the East Bay. They distribute food from a food pantry within a low-income housing complex, operate a series of small farms, and run a community-supported agriculture (CSA) box that sources from regional farmers. In particular, the CSA program illustrates a strong commitment to solidarity economies. By sourcing from farmers whose markets collapsed during COVID-19, Acta Non Verba has been able to support farmers in their region. At the same time, they're able to offer their CSA box for free to some community members and continue a program that is a core commitment of the organization: proceeds from their CSA are distributed back to bank accounts for students participating in their youth programming. Taken together, a picture emerges of complex, overlapping economies within this community of practice: engaging with existing markets, shoring up failing ones, and imagining new economic futures.

The food distribution from the Oxford Tract offers insights into this theme as well (Figure 2). The Oxford Tract's food distribution was carried out by a series of partnerships and agreements across organizations within this community of practice. These partnerships developed over four years as the project was initiated, grew, and matured. Critically, many of the key partnerships transformed as economic relationships shifted between the farm site and distribution partners. A look at three key partners (Basic Needs Center, Black Earth Farms, and Berkeley Food Network) is illustrative here. In 2018, as the project was beginning, there were no economic relationships between any of the partners and food was distributed more erratically. 2018 had the largest number of distribution partners and the lowest overall production. As the project developed, partnerships began to shape the nature and quantity of distribution. Basic Needs Center began to offer volunteer and communications support to the farm, solidifying a solidarity relationship that ensured a steady portion of food distribution to their operation. Black Earth Farms was an Afro-Indigenous farming collective that stewarded a diverse patchwork of land bases in the East Bay to produce and deliver food directly to the community, in particular Black and Indigenous families. Black Earth Farms began to cultivate produce on the Oxford Tract, which allowed for the collectivization of tools, cold storage, seeds, and production schedules. This also ensured that distribution between the two projects was coordinated, and Black Earth Farms emerged in the data as a steady distribution partner through 2021. Finally, with the establishment of Berkeley Food Network in 2020, the food hub offered funding to the Oxford Tract in exchange for produce deliveries. Their philanthropic funding model made it possible for Berkeley Food Network to pay small farmers for their produce, then distribute that produce for free. This partnership made Berkeley Food Network a large partner in 2021. Taken together, 2021 was the highest production year with the fewest number of partners. Critically, it was the established relationships of solidarity and mutual support that crystallized the distribution pathways for this fledgling farming initiative. This highlights the importance of solidarity and local economies. In the precarious and uncertain work of agriculture, relationships that shore up precarity and establish value outside of markets are essential to combining food sovereignty with anti-hunger initiatives.

Precarity, power, and privilege

Wrestling with power, privilege, and precarity was the last key feature of this community of practice. Power and privilege have already been named and acknowledged in various forms throughout reflections from members of this community—from restoring sovereignty, to volunteerism, to solidarity economies. But explicitly naming, subverting, and challenging power dynamics came forward in the principles and practices of many individuals in this community of practice.

One key aspect of this practice came in regard to labor and volunteerism. While volunteerism was important to the functioning of this community of practice (indeed, many of those interviewed in this study were volunteers) it was also critiqued and nuanced. One paid staff from the Gill Tract spoke to this, especially in relation to agricultural production and the costs associated with skilled labor :

> "Cost is a challenge. Whether it's cost of in our case, supporting unskilled labor, to be able to meaningfully contribute. We need skilled labor to help the unskilled so that we can operate and those people need to make a living most of the time. So that has been a challenge trying to square our social justice values of wanting to help people, pay people fairly… A lot of people are willing to sacrifice, make personal sacrifices… and then there's all the people that are not even dreaming of getting any compensation financially. So that's just where we're relying on a lot of goodwill and faith and belief in the project. That's super beautiful, but when we're trying to be a holistically just organization, it creates some contradictions for us, so that's a challenge."

Agricultural labor, especially for farms practicing agroecology, is skilled labor (112,113). And while such labor can be viewed as meaningful or worthwhile in alternative food movements, self-exploitation is common among small farmers (114). This quotation highlights those conditions when this individual says "people are willing to sacrifice" and "are not even dreaming" of compensation. Yet people's vulnerability to self-exploitation intersects with race, class, gender, and culture. Often a culture of self-exploitation in agriculture privileges white bodies, for whom traumas of land-based exploitation and dispossession are less present (115). In this quotation, the willingness of people to "sacrifice" themselves for the community farm expresses a fundamental "contradiction". The project is "relying" on this form of "goodwill and faith". Yet such a reliance on volunteerism can also obscure the diverse *forms* of sacrifice that individuals are making. Is their sacrifice time, money, and resources? Or are their sacrifices more subtle and woven into structures of supremacy and violence—sacrificing safety, senses of self, a connection with ancestors and cultural practices, a sense of justice or the sacred? Without grappling with the deeper undercurrents of labor and agriculture, the specter of exploitation is perhaps a kind of haunting; present but unseen, powerful but obscured (116). Movements to transform agriculture and enact food sovereignty in the United States must confront this challenge head on, especially as actors within these movements work within diverse communities to create networks of nourishment and care.

Brothers of International Faith is a non-profit that operates in Richmond, CA, organizing a series of food distribution programs with a focus on uplifting men and bringing faith communities together. The organization facilitates support circles for men that address critical issues like addiction, incarceration, and abuse, with the goal of creating healthy families. Brothers of International Faith is organized by individuals who have experienced incarceration, homelessness, addiction, and poverty themselves. They work with a group of small farms in the East Bay to source their produce, alongside grocery outlets like Trader Joe's and Whole Foods. The founder of Brothers of International Faith spoke from experience to outline some of the ways that power moves:

> [Our program] is about putting the old things behind you and taking your rightful position as a man… We have a lot of good men in the street. I was a good man in the street. I went through my addiction. I've spoken with all kinds of men who want to put their past behind them and take up a meaningful role as a man… When men come together, families come together. Kids come together when their fathers are in the program. I worked at a place… in the 70's… It had all the services: school, church, mental health, psych unit. A lot of the kids never made it out of the psych unit. We had to put a lot of them under restraint and medicate them in order to calm them down. They would be calling for their mom and their dad, and even if their mom and dad were sitting in front of them, they wouldn't recognize them. And you see the results of this in the stress... I was once at a food giveaway, and there was a man who was waiting for me and anxious. And he said, "I'm so glad you got here. I have a wife and four children. They're hungry. I was going to rob someone to feed my family." And so I was able to respond, "We are going to have dinner tonight." That's powerful.

This perspective demonstrates how power and precarity complicate efforts to address hunger. For this community, where the stress of poverty and systemic violence is so prevalent and systemically rooted, programs center on creating healthy families and home environments for children. This quote speaks to the complexities of doing so. Even with their parents there in the room, a child may be restrained and medicated as they express the grief and longing they feel. It is hard to locate where food or hunger might fit into this story of loss? Yet in the same breath, this individual from Brothers of International Faith shares a story where food makes all the difference to a man about to rob someone—caught between a moment of desperation and feeding his family. For people who are uplifting themselves and their communities, the opportunity to bring families together over food is not theoretical or riddled with contradictions. It is an expression of dignity and sovereignty.

Brothers of International Faith is ambitious. One of their organizers went on to explain their desire to increase their operations:

> I want to serve more people. I want to expand. I like to build on a scale where the whole city, all of Richmond, is transformed. I am making connections with the pantries, with the churches, going out to all kinds of people. But if we had a facility, people would be able to come to us. It is something that I have to do… We are a 100% volunteer-run organization. For right now, this works. But long term we want to be able to pay our help, to give them a stipend. Because it is hard work. Volunteers come and go. For the most part, if I don't have volunteers, then things fall to me. Because the show has to go on. But that's part of being committed.

This person feels that a lack of infrastructure and labor hinders their work. They would like to reach more people, to expand—it is something they feel they have to do. However they are limited without more physical space to do their work and more labor to support it. This is another dimension of how power and privilege move in anti-hunger efforts. Many organizations in this community of practice, especially those that are more grassroots, are systematically underfunded, under resourced, and undersupported.

One of the organizers of Black Earth Farms spoke to how this affected their work and the people involved. They spoke to the issue of housing insecurity among the young farmers and organizers who were supporting the project:

> One of the biggest things with land sovereignty is housing insecurity, most people in the collective are housing insecure. And so the ability to grow food and be food secure and to put on these events for the community but then not be able to live.

Throughout the interview, this individual from Black Earth Farms spoke of their work supporting unhoused community members and ensuring that they could benefit from the agroecological projects that their collective was developing. Black Earth Farms was involved in political education, sharing about eating food "free of chemicals" and about "what companies to avoid" when going to the grocery store. They provided culturally relevant herbs and medicines to their community. And yet housing insecurity threatened their ability to continue these programs. At the same time, Black Earth Farms lacked stable land tenure as farmers, explaining that they "don't have full autonomy in the places that we grow," because "a lot of the food comes from rows we're given" and "there are rules around what we can and cannot grow."

Even with uncertain land tenure and a lack of affordable housing, Black Earth Farms persevered and delivered hundreds of boxes of fresh fruits and vegetables to families in the East Bay. These stories highlight that if this work is rooted in solidarity and not charity, individuals engaged in anti-hunger work may be in precarious financial, housing or medical situations themselves. A very real sense of precarity was present for many of the organizations in this community of practice, especially those that are led by BIPOC, poor, LGBTQ2S+, or otherwise oppressed peoples. This precarity—itself the result of violent and dehumanizing systems—reveals another shadow that hangs over anti-hunger initiatives: in their selfless mission to provide nourishment for their neighbors and communities, many people risk hunger, poverty, housing instability, and other forms of precarity *themselves* in order to continue feeding their neighbors. Running small farms and mutual aid programs are not lucrative by any means. Anti-hunger work may only address the symptoms of poverty, inequality, racism, and structural violence, but many are willing to sacrifice their lives to treat those symptoms. This expresses a fundamental commitment to harm reduction in this community of practice. One individual who "spent time houseless" expressed how good it felt to "be on the other end" and to be "helping," lamenting that "we're just a couple things away at any given time from not having enough food to eat."

Though the "we" they are referencing is ambiguous, a sense of precarity invades the entire frame. Is "we", the global food system? Or "we", those who struggle in Oakland? Whoever the "we", we are just a few wrong steps away from not eating, they claim. This sense of precarity, and the life experiences that shape that sense, imbues the work of anti-hunger with a more radical posture of humility, purpose, and solidarity.

One of the organizers of Food Shift shared a story of how precarity and power plays out between grassroots or mutual aid efforts and more institutionalized forms of anti-hunger work. They shared a story about the COVID-19 pandemic and some of the community-based initiatives that began during that time:

> Feeding people is an extremely local activity, especially feeding people of marginalized communities, because they don't necessarily have transportation, they don't necessarily have a place to store food or refrigeration and so things have to be very local and immediate. So that's a very different skill set and optimization than having long-term relationships with wholesalers and big corporations and all of that versus grassroots effort where true families got together and started feeding people in this particular encampment or work with that

> particular church… Those are very different levels of activity. And so when they relied on maybe small donors and then that stopped—that didn't work. They couldn't just make their personal relationship work with for example, San Francisco Produce Market or Imperfect Foods…

Here we catch a glimpse (and just a glimpse) of how the non-profit and charity model of addressing hungerperpetuates inequalities. During the COVID-19 pandemic, a string of grassroots efforts popped up to help families and neighbors feed one another. They worked in encampments and in churches. These efforts relied on small-scale food donors like restaurants, caterers, small grocers, and other local businesses. But when those small businesses began to operate normally again as the peak of the COVID-19 passed, smaller grassroots efforts found themselves unable to continue their anti-hunger efforts. Meanwhile, those organizations that could navigate relationships with large "wholesalers" and "corporations" like Imperfect Foods could continue operating.

The food distribution from the Gill Tract illuminates some of how this precarity plays out on small, urban farms (Figure 5). Between 2016 and 2018, the farm produced nearly 8,000 pounds of vegetables, distributed to dozens of partners across the East Bay. The majority of this production was distributed through the farm's weekly farmstand, which primarily serves the city of Albany, CA. Beyond this, primary distribution partners included institutions like the Harriet Tubman Terrace, a low-income housing complex for seniors, or the Basic Needs Center, the food pantry on UC Berkeley's campus. In 2020, however, a dramatic shift occurs. The recorded levels of food production dropped dramatically. Although the farm did continue to distribute food, it appears to be in much lower quantities. This change was multifaceted—food safety concerns, administrative oversight, and fears over liability pushed the university to limit the farm's activities. The Gill Tract was open to only a small team during most of 2020. It is difficult to square this with participant observation on the ground at the time (Figure 6). Major food distribution was happening at the Gill Tract during the height of the pandemic. Collard greens are stacked high, alongside other greens, donated bread, medicinal herbs, and more. The Gill Tract became a hub for mutual aid in 2020, with Black Earth Farm's produce boxes and other food relief deliveries being packed and distributed from the farm. What emerges is a possible alternative explanation: in the first year of the COVID-19 pandemic farming continued, but was rendered illegible to data collection. In other words, food production became fugitive (117). Without record, without documentation, a site of land occupation and power struggle that was not supposed to operate continued to do so anyway (93). Whether food production really did plummet, or administrative oversight rendered that production invisible, both instances express different forms of precarity that the Gill Tract embodies.

Power imbalance and precarity motivate individuals to take up the mantle of food sovereignty. Typically, movements for food sovereignty center the voices of farmers and land-based communities. But in the East Bay, and the US more broadly, these movements are complicated by incredible disparities in access to land. One of the organizers of Brothers of International Faith described the complexities and contradictions that arise from these inequalities, layering his perspective with religious references:

> If we were all to come together on the land, we would realize that we all bleed, we all cry, we all life. I don't look at the color of a person. If we just come together with food, music, celebration, we can serve those that need us most. We were told in the Bible, we were told that we were going to work this land. The idea that we've gotta reconnect with the land… Folks are waking up to this. My friend is working out in her organic garden, barefooted, wanting to get back into the land. There's something to it, but it's something that we need to learn. I see it all the time, but never really got into it and connected to it. I'm afraid to be there… To be in the dirt. That's something that a lot of folks are afraid to do; but also a lot of people are waking up to this reconnection."

The fear expressed here is poignant. While this individual shares the Biblical conviction that people will "work the land," they also express an unfamiliarity with the soil and fear of engaging in agriculture. There is power in connection with the Earth—but it is confused or inaccessible. Fear inhibits a connection that would otherwise be a great equalizer. This person's invocation—that "we all life"—stands against the reality that the land is laden with power imbalances and haunted by a long and brutal history of dispossession. This community of practice is a body struggling with power, wrestling with the contradictions that lie between the poles of fear and celebration.

Discussion

Our study helps contextualize food sovereignty in the US context by offering concrete examples of how a community of practice in the East Bay is struggling to transform their material conditions in the face of hunger. From the stories, commitments, and struggles of this community of practice, some of the textures of the fight for food sovereignty in the US come alive. Transforming agricultural systems and addressing hunger are linked through personal, economic, political, and collective action. Participants in this network articulated a series of core organizing principles through their actions, words, and social organization. They demonstrated a commitment to personal relationships, agency, holistic nourishment, circularity or reciprocity, solidarity economies, and a reckoning with power and privilege. These organizing principles allowed this network of farms, non-profits, food pantries, mutual aid organizations, and grassroots projects to nourish their communities. Together, they enrich and expand a sense of the food sovereignty movement in the US. Participant observation, interviews, and tracking of food donations from farms and food pantries allowed for a rich and complex picture to emerge in the unique geopolitical and social context of the East Bay.

Food sovereignty is an international framework for centering the rights of people to determine their own food and agricultural systems. The political and cultural conditions of the US, however, appear broadly incompatible with movements for land and food sovereignty. Both land and food are broadly understood through the frameworks of capital (markets, property, commodities) in the US. Private property is heavily reinforced in US legal and cultural structures, and systems of property enforcement are valorized and highly functional. The idea of private property is linked closely with the ideals of liberty and freedom. Any political action that threatens private property or the power of business is viewed with skepticism. Ultimately, a strong cultural addiction to individualism constrains efforts to imagine and create more collective or socialized forms of property rights.

These dynamics are countered strongly within this community as they practice forms of reciprocity, communalism, and mutual uplift. In both theory and practice, this network would blur the lines between giver and receiver in ways that subvert pervasive notions of US individualism. Rather than understanding themselves as individual actors, appeals to circularity, cycles of healing and regeneration, and reciprocity reinforced more collective forms of action. Sites in the network were not places of transaction, but vibrant spaces of relationship and mutual exchange. Each person in the network had their "medicine" or "gift"—their contribution that made the whole possible. Food was decommodified and value (re)assigned through forms of kinship, hard work, and relationship building. Taken together, the principles enacted by this community of practice offer glimpses into how to begin deconstructing the monolith of individualism, consumerism, and private property in the US. Facing these ideological challenges head-on seems foundational for any movement for food sovereignty to proceed in the United States.

In other parts of the world, food sovereignty is tied to land-based culture, agrarian life, and the social (re)production of farming communities (32). Scholars like Raúl Zibechi have argued that the mass, grassroots, and farmer-based social movements constituting historic land reform struggles and *La Via Campesina* member organizations are rooted in ongoing and close relationships with land (118). In the US, where such relationships are broadly severed, food sovereignty requires different discursive modes. Agarian life in the US is intimately tied to legacies of enslavement, incarceration, Indigenous genocide, and ecological devastation (43,44,103–105). The mythic imaginary of US agrarian life and the American farmer as a white, male individualist is a pervasive one (106). The condition of farmers, farmer movements, and national land politics deter any coherent movement for agrarian reform or food sovereignty—particularly in regards to issues of race, class, gender, culture, and religion. Smallholder farms are the most common farm type in the US but constitute a small percentage of farm income; and most of these farms do not make a living from farming (119). Farmers make up less than 1% of the population, yet significant racial disparities exist among them: white farmers own 96% of
and 98% of farm acreage (119). The culture of farming that remains is highly shaped by corporate politics, neoliberal economic policies, intense market pressures, the valorization of private property, and a strong cultural trend away from agrarian ways of life driven by the historical processes of industrialization, urbanization, and mechanization.

These conditions frame the complex relationship between members of this community of practice, land, and food sovereignty. Many of those interviewed in this study made a direct link between nourishment and forms of reciprocity with "land." Land is a complex and politicized concept in the US, intersecting with issues of identity, trauma, capital, intergenerational wealth, agency, and sovereignty. Entrenched ideas about private property and land ownership—supported by libertarian and political ideologies that valorize the individual—complicate national conversations about land access and tenure. For members of this community of practice, a more universalizing relationship to land was a key part of how they understood their efforts. Regenerating, restoring, or otherwise stewarding land was seen as one of the ultimate goals of their practice. For those operating food hubs and larger institutions—broadly divorced from direct relationship to agriculture or agroecological practice—small-scale and local farmers were positioned as maintaining those relationships. Meanwhile, for farmers and participants in farming initiatives, appeals to land were made in a range of social, political, cultural, spiritual, and emotional terms.

It is worth investigating the complex and overlapping meaning of the word "land" that were employed by this community of practice. Clearly, land is a site of contestation and political struggle. References to "land tenure," "land access," "supporting local farmers," and ongoing struggles over land access made this evident. Yet there were other layers of meaning attributed to land in this community of practice. According to *Kanien'kehá:ka* scholar Sandra Styres, land is "more than physical geographic space. Land expresses a duality that refers not only to place as a physical geographic space but also to the underlying conceptual principles, philosophies, and ontologies of that space." Styres goes on, explaining:

> Land is spiritual, emotional, and relational; Land is experiential, (re)membered, and storied; Land is consciousness—Land is sentient. Land refers to the ways we honor and respect her as a sentient and conscious being.

For this diverse community of practice, land is not just capital or space. Land is alive, and deserves respect and ongoing relationships based in reciprocity. This perception of sentience shapes and informs agroecological practice that many farmers implement. Cherrie Moraga, Xicana feminist, writer, and activist, expands on this framing of land in *This Bridge Called My Back,* saying

> land remains the common ground for all radical action. But land is more than the rocks and trees, the animal and plant life that make up the territory of Aztlán or Navajo Nation or Maya Mesoamerica. For immigrant and native alike, land is also the factories where we work, the water our children drink, and the housing project where we live. For women, lesbians, and gay men, land is that physical mass called our bodies. Throughout las Americas, all these "lands" remain under occupation by an Anglo-centric patriarchal, imperialist United States. (120)

Moraga echoes Malcolm X when he said that "Revolution is based on land. Land is the basis of all independence. Land is the basis of freedom, justice, and equality." Yet while land is the source of political mobilization and radical action, it also intimate, embodied, and complicated. Land is gendered, paved, stolen, polluted. Taken together, "land" emerges as a potent and powerful symbol that contains a wide range of material, emotional, political, and spiritual modes of being. It is a rhizomatic concept, budding and growing in moments of meaning-making that defy neat categorization or control. In this way, land contains a superabundance of significance, relationships, and possibilities. Critically, it seems that *this is why the term is used*. The idea of "land" is utilized by this community of practice to contain perspectives emanating from a diversity of bodies, cultures, and spiritualities. Land (as a symbol, a relationship, and ongoing semiotic event) allows for difference to be negotiated, deferred, and composted—transforming difference into new, life-giving possibilities (121).

Movements for food sovereignty are further limited by a fragmented food culture in the US. Culinary norms and food preferences are shaped by corporate power in the US, driven by a trillion-dollar food industry that profits from creating cheap and addictive foods (107). There is no shared food culture untouched by corporations. What does exist is warped by domains of fragmented identity and unequal power (43). Attempts to address this system through the "alternative food movement" often center whiteness, cultural elitism, and class privilege in ways that leave people behind (73,122). The Bay Area is one of the epicenters of this "foodie" discourse, with the likes of Michael Pollan and Alice Waters moralizing about what kind of food people should or shouldn't eat (123).

The community of practice in this study addressed a convoluted and harmful food culture by focusing on agency, self-determination, and solidarity. People were celebrated for refusing foods and for saying no. Food was understood as intimate, and a personal decision that should be protected and honored. Agroecological practice and local farming initiatives allowed anti-hunger efforts to offer cultural foods, care for elders and children, and nourishment for landscapes. Ongoing dialogue about how power shapes experiences of food and farming allowed individuals in this network a mode of celebrating difference and navigating trauma.

It must be acknowledged that commitments to reducing power imbalances and transforming privilege are aspirational. As noted above, food banks, pantries, or hubs can be traumatic, undignified, classist, racist, patronizing spaces (78,79,124,125). Power imbalances between those managing or volunteering within these institutions and those who come to receive food persist. This community of practice actively sought to combat these inequalities through a wide range of programs, relationship-building processes, and entry points to allow community members to step into leadership—many of which are mentioned above. These interventions were viewed as effective depending on the organizational structure, sources of funding, and degree of institutionalization. A critical self awareness of the role of power imbalances and privilege along lines of race, class, gender, age, and culture were shared widely across the community of practice, and are the subject of the last thematic section in this study.

Many members of this community of practice also faced forms of precarity in their own lives. Precarity, here, describes a broader social phenomenon in which employment, housing, health, and other social determinants of well-being exist in states of uncertainty. Some scholars have argued that widespread precarity is an inevitable outcome of neoliberalism. They argue that "free market" capitalism and increasingly privatized global interests have created a "fragmentation of national class structure" that leaves a vast underclass without "stable or predictable salary" or other forms of reliable employment (126). These phenomena are certainly familiar in the Bay Area, where wealth inequality is among the highest in the country (68). These conditions color the work of agroecology and anti-hunger work in the East Bay and bring these regional efforts for food sovereignty into solidarity with land-based struggles around the world. Many of the organizations in this community of practice are explicitly inspired by peasant and land reform movements across the world, especially in Africa, the Caribbean, and Latin America.

The cultural and material conditions in the US heavily constrain movements for food sovereignty. What efforts that *do* exist are complicated by dominant neoliberal and philanthropic approaches to social change on the one hand (127), and violent state repression on the other (70,128–130). Neoliberalism compromises efforts towards land and food sovereignty by constantly (re)positioning potentially radical or transformative movements back into relationship with markets in ways that territorialize and constrain them. The US food movement is a loose assemblage including non-profits, the small and family farm sector, grassroots movements, business and consumer advocacy groups, and social enterprise (131). These different sectors often have diverging goals, tactics, and visions of the food system, making a coherent movement challenging.

Meanwhile, the state actively represses movements that reclaim land, capital, or power for common people, especially when those movements are led by Black, Indigenous, LGBTQ2S+, or poor people. People's Park was the site of ongoing police repression and violence, as working class and unhoused people reclaimed land from the state as a home of free speech, mutual aid, and refuge for street life. The most recent wave of this violence came on January 3, 2024, when 1,400 police officers were stationed in riot gear across South Berkeley and 130 shipping containers were used to wall off the public space, costing over $7.8 million (132). This militarized police force was sourced not just from University of California Police Department (UCPD), but "California Highway Patrol, Sheriff's Departments for Alameda and San Francisco counties and from nine other UC and Cal State University police departments" (133).

This brand of state violence has been used consistently against Black and Brown communities trying to establish agricultural or land-based movements in the US. In Los Angeles, the South Central Farm was home to 350 plots for families in the low-income neighborhood. The farm was destroyed in June of 2006 when "more than forty-four activists and farmers were arrested" as "authorities moved to seize and close the farm with an army of 385 sheriff deputies and LAPD storm troopers" (134). Standing Rock was the site of intense state violence against Indigenous land defenders as they sought to protect their lands from environmental destruction by the installation of the Dakota Access Pipeline (128). That struggle was deeply intertwined with issues of food sovereignty, as the Standing Rock Reservation had seen generations of land theft, flooding of arable lands, cultural genocide, and the extermination of keystone species like the buffalo. In the East Bay, this community of practice also faced militarized police presence at Wood Street and the Gill

Tract—both sites of struggles over the control and use of public land (95). The violence and repression of land-based struggle is not unique to the US by any means, however the US is the progenitor and peddler of many of the technologies, tactics, and policies that structure police states internationally (135).

Many radical movements to address hunger have also been met by repression. The Black Panthers were harassed, surveilled, incarcerated, and killed during the FBI's COINTELPRO operation—while the majority of their programs were designed to address hunger and malnutrition in Black community (136,137). The free breakfast program launched by the Black Panthers is the basis for national school breakfast programs today. Grassroots anti-hunger programs and mutual aid efforts are often saddled with fines, permits, and other regulatory challenges that hinder their work (138). Food Not Bombs—a loose-knit group of independent collectives sharing free food in over 1,000 cities worldwide—has a long history of arrests as volunteers attempt to feed their neighbors (139). Many of those arrests occurred in the Bay Area – in Golden Gate Park and People's Park. This is part of the very real context—within which this community of practice is operating, one where state repression heightens precarity and danger.

Many scholars have astutely noted that the concept of hunger can become myopic when it draws our analysis away from the economic, political, and social conditions that cause hunger to arise in the first place. Seeking to address "hunger" as an isolated event depoliticizes the issue, actively reinforcing the economic and political conditions that perpetuate hunger through neglect. Canadian scholar Graham Riches, who has written extensively on food banks, hunger, and the right to food, has argued that the privatization of hunger through corporate "food banking" has effectively funneled corporate food waste into charity in ways that undercut meaningful governmental and structural changes that might realize the right to food (107). In the United States, hunger is primarily episodic and a symptom of poverty, alongside misogyny, racism, domestic violence, high costs of living, and broader issues related to systemic suppression of human rights (108,125). In the charity model of food provision, hunger is the problem and food is the medicine; food handouts and emergency food relief constitute a singular and legitimate response to the conditions of hunger. The community of practice in this study challenged those assumptions with repeated reference to the concepts of agency, self determination, and sovereignty as central to addressing the deeper roots of hunger and producing lasting forms of nourishment. One framework that has been adopted by agroecologists and some food sovereignty advocates is the Five As of Food Security (developed by Cecilia Rocha and the Centre for Studies in Food Security), which includes *agency* as one of the five core pillars of creating food security (140). Notions of self-determination and agency were routinely named as essential to addressing hunger in a lasting way.

At the same time, these critiques are divorced from the material conditions and lived realities of communities that feel hunger acutely. In the face of systemic racism, police repression, corporate capitalism, and economic violence, concrete acts of social uplift are a lifeline. Sharing food and practicing mutual aid constitute a call for freedom and a statement of one's dignity. Often, this is why it is those suffering from forms of oppression and hunger themselves who are leading efforts to nourish their neighbors. Ironically, massive food banks and corporate charities rely on the efforts of poor and marginalized peoples working in their neighborhoods to implement their programs. The stories contained in the interviews above—whether concerning family land theft, childhood trauma, robbery, or houselessness—give a glimpse into the everyday realities that people face in the East Bay. These stories are not theoretical or intellectual, and debates about whether "hunger" is the right issue to tackle do not concern them. If the deeper, structural causes of hunger *cannot* be addressed (if we can't solve, for example, poverty) then the belly is a good place to start. It is the place that some of the most radical movements in the East Bay and across the world have started.

This brings us back to the dual nature of food—how experiences of food are both structural (socially determined, constrained by systems of power) and affective (embodied, emotional, expansive, material). These distinct but interwoven modes of relationship to food (and land) might be best understood as part of the *political ecology of the body*, a framework put forward by Allison and Jessica Hayes-Conroy. A political ecology of the body "facilitates an analysis of the always affective/emotive body that is simultaneously structural and post-structural, material and discursive; it is a framework that offers attentiveness to the rigidities of our socio-political world and yet remains open to the new possibilities that affective encounters may allow" (19). Emotional and embodied experiences with food are shaped by race, class, gender, age, and other social determinants (6,17,141,142), but also offer the possibility of new encounters, new experiences, and new domains of sovereignty. These new domains are, in many ways, the foundation of the global food sovereignty movement, where calls for self determination and agency rest on a politic of bodily and material autonomy (31,32). By placing an affective or emotive body at the center of our analysis, "we can then begin to ask how all of these forces, at a variety of scales, become translated into movement or (re)action within and between physical bodies, in partially explainable but never predetermined ways." (19)

From the vantage point of the body, the work of this community of practice becomes legible in new ways. In their collective effort to address hunger, individuals in this network were constantly confronting the reality of other (human and more-than-human) bodies—rotting oranges, the constrained body of a teenager, broken packs of yogurt, collard greens, police batons. The land is a body that feels, heals, and senses. For farmers and eaters alike, the body of the Earth is understood as an entity deserving respect and reciprocity. This reciprocity is complicated and confused by trauma, intergenerational loss, racism, and power, yet the body constantly offers new pathways, new ways of being. The rhythm of the drum and pouring of libations might just transform someone's day as they approach the farmstand. A couple bags of groceries might be the difference between a body desperate enough to rob someone, and a body feeling settled and safe as they provide for their family. When it comes to joining the transformative power of food and agriculture in communities of practice like this one, the ultimate sight of transformation is the body itself. What is nourishing, what is healthy, what is desired, what is valued—is ultimately an embodied question for the tongue, nose, belly, and heart. The community of practice involved in this study practiced forms of nourishment that went beyond simply material need. By including emotional, social, and spiritual dimensions of nourishment in their efforts, they invoke the power of bodies to have new experiences that make *something else* possible. The affective body is the site of renewal and imagination. As Assata Shakur said, "We need to be weapons of mass construction, weapons of mass love. It's not enough just to change the system. We need to change ourselves" (143). In the US, movements for food sovereignty that link agriculture and anti-hunger work face great obstacles. They will only be realized through the transformative and discursive future that a liberated body—nourished, grounded, and held in a web of reciprocity—can enact.

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Theme	**Codes**
Personal, intimate, and informal relationships	“Distribution networks”, “gender issues and food”, “mental health”, “physical health”, “informal practice”, “partnerships”
Cycles, circularity, and reciprocity	“Environmental impact”, “infrastructure”, “localism”, “reciprocity”, “sourcing”
Agency and self-determination	“Equity and food justice”, “land tenure”, “resilience”, “solidarity”, “sovereignty”
Holistic nourishment (social, emotional, spiritual)	“Services and activities beyond food”, “cooking or food preparation”, “educational programming”, “food quality”, “housing”, “food production”, “spiritual connections”
Local and solidarity-based economies	“Economic viability”, “food security”, “geography”, “income”, “labor”, “organizations”, “planning (land use)”, “revenue generation”, “technology”
Precarity, power, and privilege	“COVID-19 response”, “institutional practices”, “language justice”, “organizational response to crisis”, “policy”, “race, ethnicity, and culture”, “structural barriers”, “vulnerability and precarity”

Table 2: A table showing the 44 codes that were generated through our qualitative coding protocol, and the six key themes that the codes were grouped into. Interviews were designed to understand the

Figure 1. (A) Food distribution from Food Not Bombs at People's Park's historic stage. This distribution has happened for years at the Park, with both groceries and hot meals brought five times a week. (B) A view of the western gardens in the Park before UC contractors destroyed them. The collard greens and radish stand triumphantly among calla lilies and mallow. These are in the foreground, while a mutual aid distribution project is set up in the background.

Figure 2. (A) Cooking collard greens with a member of Brothers of International Faith. Collard greens are stripped and washed in the foreground. The individual in the background is preparing fried chicken. Collards are part of cuisine from the United States South and African diaspora. This picture was from a night cooking a soul food menu for those staying at a family shelter in Richmond. Collard greens

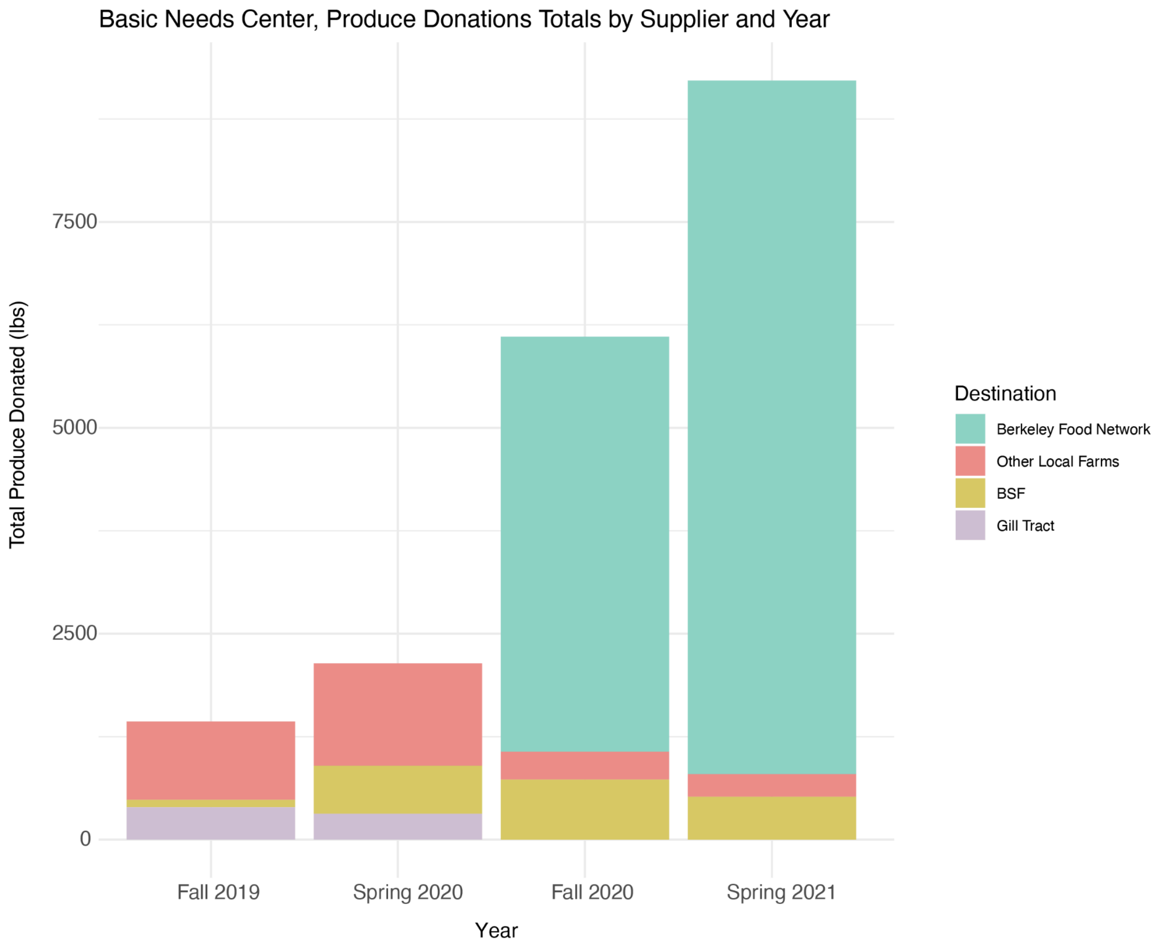

Figure 3. Food distribution from the Basic Needs Center, the food pantry on UC Berkeley's campus founded by students. Note the incredible increase in distribution, from just below 2,500 pounds of food in the spring of 2020 to over 8,000 pounds the following spring. The vast majority of this increased capacity (at least in regards to distributing fresh produce) came from their partnership with Berkeley Food Network. Distribution from local farms stayed about the same throughout the crisis. In fact, during the onset of the COVID-19 crisis, local farms constituted the entirety of their produce distribution. In order to meet the needs of the moment, the Basic Needs Center turned to a source that could meet the high levels of demand.

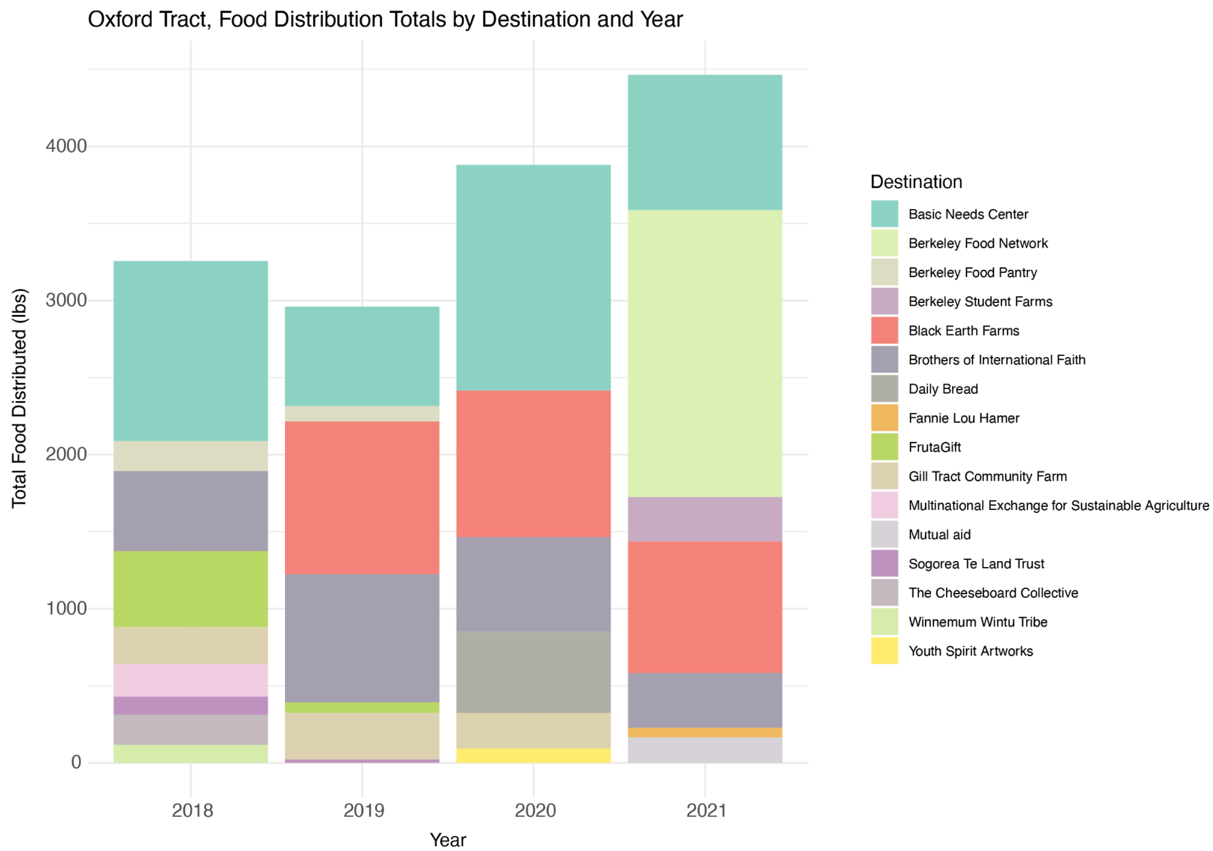

Figure 4. The distribution of food from one participating urban farm, known as the "Oxford Tract," between 2018 - 2021. This quantification of food distributed from the farm demonstrates how personal and informal relationships constitute important linkages between members of the network.

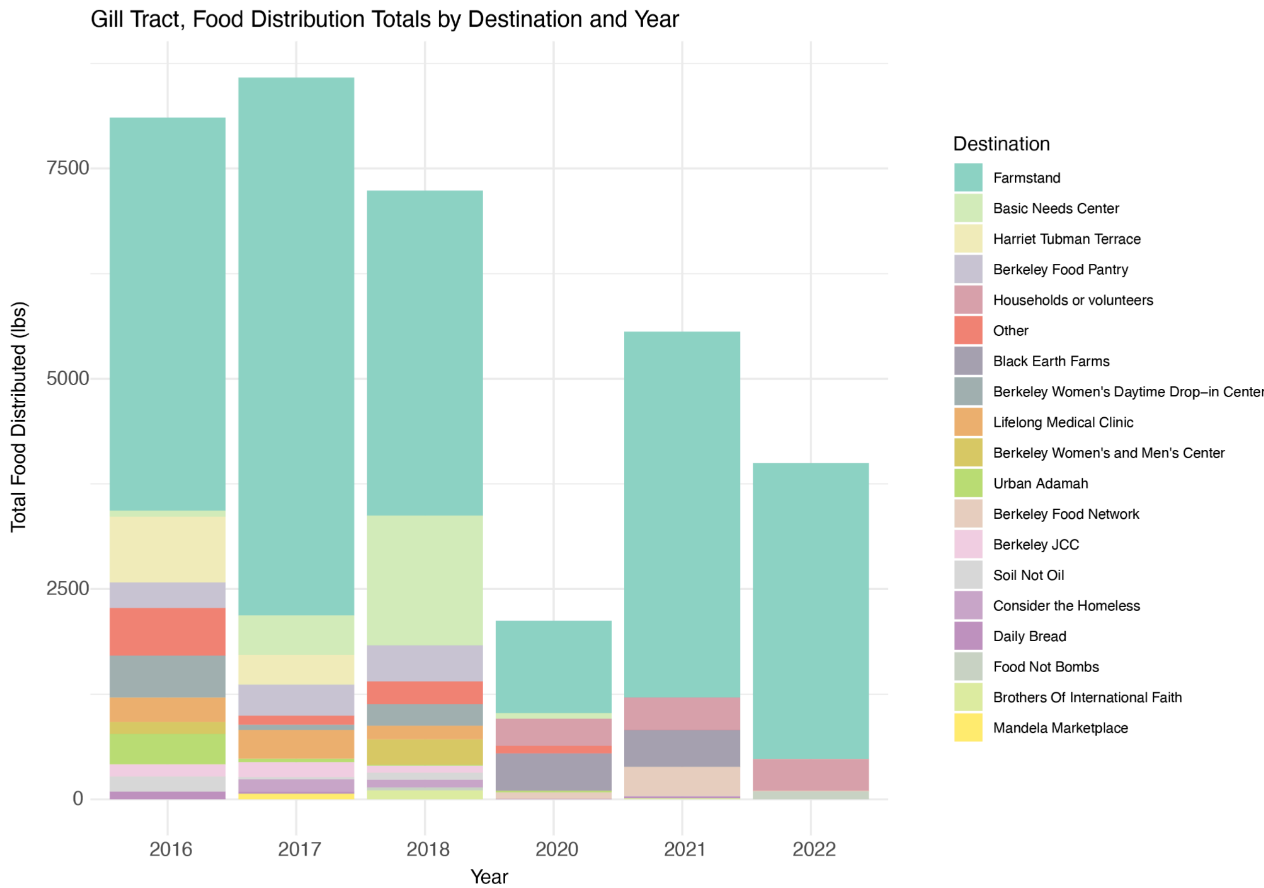

Figure 5. Food distribution from the Gill Tract Community Farm between the years 2016-2022. This illustrates some of the transformations that food distribution went through over the COVID-19 crisis.

Figure 6. The farmstand at the Gill Tract Community Farm, stacked high with collard greens, chard, and lettuce in the foreground. In the background, we see other produce (tomatoes, tomatillos, herbs) and donated bread. The collards glisten and sweat, piled neatly with all their stems pointing together. Their many shapes, colors, edges, and sizes are a kind of invitation—to delight in the variety of how nourishment happens here.

Figure 7. (A) The final stages of destruction of the Wood Street encampment on April 20, 2023. The lead author was onsite bringing food and water to partners and collaborators working in the encampment when hundreds of riot police and demolition crews swept into the camp. At one point, an estimated 250 people lived at the site. (B) A photo from under the freeway overpass where the "Cob On Wood" community project was constructed, taken during a community celebration. The lights from the party warmly frame the cob kitchen, free store, and health clinic. The overpass acts as a kind of great hall, echoing and uplifting the sounds of music alongside the clatter of food, laughter, and conversation.

"How we treat the land comes down to how we view our spirit": thresholds in soil health and agroecology from the cracks of California agricultural system[5]

Abstract

A movement of small-scale (<10 acres) farmers and community organizers across California are putting soil health and land stewardship at the center of their efforts to enact agroecological transitions—strategic processes of collective action that create more socially just and ecologically sound food systems. In particular, this study focuses on a network practicing a "hand-scale no-till" farming system. Practitioners bridge racial, cultural, economic, and geographic differences, but share a common stewardship ethic that emphasizes both social and ecological wellbeing. This ethic informs a common set of principles that define hand-scale no-till: minimizing tillage, maximizing crop density, utilizing cover crops, recycling on-farm resources, and maximizing on-farm biodiversity. In partnership with this network, we facilitated a participatory action research (PAR) project to understand the impacts of this farming system on soil health and agroecological transitions. Through interviews, field days, farmer-to-farmer exchanges, educational programs, on-farm research, and participant observation, our team was able to document two interrelated phenomena: 1) how farmers' hand-scale no-till practice changes soil health outcomes on working farms across a range of social and geographic contexts, and 2) how, in turn, differences in soil health conditions shift farmers' agroecological practice. This article focuses on two soil health outcomes of particular interest to farmers in this network. First is soil carbon, a governing property of soils critical to crop health, adaptive capacity, and climate mitigation. Second is soil food web structure, relevant to understanding soil biodiversity and ecological functioning—of significant interest to farmers. Soil carbon concentrations and stocks were both significantly higher under hand-scale no-till at the soil surface (15 cm), but carbon at deeper depths (50 cm) was undifferentiated by land use. Soil food web analysis (via nematode community analysis) found evidence of more enriched and structured food webs under hand-scale no-till, with higher degrees of bacterial-mediated soil webs and a decrease in fungal activity. Our team also modeled changes in soil health along geographic (degree of urbanization) and agronomic (years of implementation) gradients, motivated by interest in understanding differences in agroecological transitions across farmers' diverse contexts. Tracing soil carbon changes with years of practicing hand-scale no-till revealed that long-term implementation of the system may lead to decreases in soil carbon concentrations and stocks at depth (60 cm). Meanwhile, both carbon and food web structure increased on farms embedded in more urban environments. Taken together, these trends suggest that changes in soil health are constrained by challenges ranging from soil inherent properties and sourcing organic amendments, to maintaining farm labor and supporting farmer livelihoods. Personal, emotional, and spiritual connections to land were found to be essential to the success of these farming systems, organizations, and initiatives.

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[5] Intended co-authors for publication are Tanamá Varas, Yvonne Socolar, Catherine De La Peña, willow holiday, Annika Levaggi, Moe Sumino, Gustavo Gutierrez, Arianna Hee, Lauren Pong, ameia smith, Rogelio Chavez, Rose Curley, Sara Tiffany, Jennifer Sowerwine, Charisma Acey, Paul Roge, Amanda Hodson, and Timothy Bowles

These connections contributed to a shared ethic of stewardship in this network. Overall, our study demonstrated how agroecological transitions can occur both ecologically and socially across a wide range of geographic, cultural, racial, and institutional contexts in the United States. This offers possible pathways for scaling agroecological transitions and food sovereignty in the US.

Introduction

Farmers and land stewards are increasingly called to the frontlines of multiple crises. They are tasked with maintaining global biodiversity and feeding communities amidst rising global temperatures, extreme weather events, hunger, pandemics, and constant war. Particularly in communities undergoing structural violence or marginalization, land stewardship is tied to the liberation and sovereignty of peoples, cultures, traditions, and nations. The flourishing, innovation, and agency of the next generation of farmers is increasingly eclipsed, however. Many beginning farmers are marginalized, or structurally excluded, from creating agroecological transitions due to the dominance of free market capitalism, extractive economies, and corporate plantation agriculture. These systems extract value from the bodies and homes of peasant communities, women, LGBTQ2S+, Black, Indigenous, and poor people.

In California, these global challenges take on local forms. For thousands of years, Indigenous communities stewarded California's diverse landscapes through complex ethnobotanical knowledge systems, cultural fire practices, agroforestry, and spiritualities that honored sacred reciprocity with more-than-human beings (1–4). These critical relationships were severed during European colonization. Enslavement of Indigenous people at Spanish missions, and massive land grants through the hacienda system, paved the way for large, conglomerated settler farms that relied on exploited immigrant labor (5–7). The dream of California as a "land of plenty" led to a complete transformation of the state's hydrology, involving massive engineering projects to redistribute and manage water resources across the state—with devastating ecological and human impacts (8). Today, the increased threat of wildfires, drought, floods, and public health crises like COVID-19 are exacerbating challenges for California farmers and farmworkers (9–13). The state's plantation-based and industrial food system is compromised by decreasing water resources, soil degradation, labor exploitation, and broken supply chains (14–17).

It is in this context that communities are actualizing agroecological transitions that address systemic failures of the food system in California, and the US more broadly. Agroecology is a cross-disciplinary, action-oriented, and transformative approach to agricultural and food systems that integrates diverse knowledge systems, social movements, and ecologically-based farming practices (18–23). *Agroecological transitions*, then, are collective and community-based agronomic, ecological, social, economic, and political changes that create more ecologically sound and socially just food systems (24). Agroecological transitions include everything from changing individual agricultural practices to regional "strategic processes of collective action" (25). These transitions utilize "principles of agroecology" and "are driven by the agency of food producers and people living in territories" (25). Such transitions are understood to occur in *territories*—assemblages of geographic, ecological, administrative, and cultural phenomena that define domains of power (26,27). Agroecological transitions describe the social and ecological thresholds that constitute food systems change, and highlight the socio-ecological nature of agroecology. This article seeks lessons from a network enacting agroecological transitions at the margins of California's industrial and plantation-based agricultural system.

A diverse network of small California farmers from a wide range of geographic, cultural, and socioeconomic contexts are stewarding landscapes designed to adapt to these interlocking challenges. In particular, this article is in conversation with farmers adopting a no-till farming system that seeks to achieve ecological, economic, and cultural resilience by foregoing mechanization and implementing hand-scale practices. We call this system "hand-scale no-till". Farmers in this network exhibited a wide range of practices, political formations, organizational structures, economic models, and cultural backgrounds. They span urban and rural landscapes, non-profit and for-profit enterprises, and represent diverse racial backgrounds and cultural traditions. Despite these differences, they all implement hand-scale no-till as a means of building soil health and maximizing local food production while minimizing external inputs. It was in this context that a collaborative project between farmers, researchers, non-profit organizations, and community members emerged, utilizing participatory action research methods to better understand how new agroecological practices emerge at the margins of California agriculture. Through a participatory research process, we learned how farmers link stewardship of soil health to changes in their livelihoods, adaptation, community food sovereignty, and relationships between people and landscapes. Our mixed methods study thus focuses on bringing soil health assessments into direct conversation with farmers' perspectives on soil. We detail the steps in this process below.

Overall, this study attempts to bring soil ecology and social anthropology into a dialectic. It seeks to uncover how key ecological parameters motivate farmers' agroecological practice, while conversely, tracing the social and cultural forces that drive soil health outcomes. These intersections of ecological and social change allow for an examination of how soil mediates agroecological transitions, offering possible lessons for scaling agroecology in the US.

A network of farmers

Participatory Action Research

This project was initiated through conversations between the authors and a group of farmers from across Northern California and the San Francisco Bay Area engaged in hand-scale no-till. Over eight years, the project included hundreds of participants in a wide network that included dozens of farms, non-profits, land trusts, and other community organizations. Participants entered the project in a variety of ways: attending workshops and field days, hosting educational events or programs, participating in soil health testing, and organizing farmer-to-farmer exchanges (Figure 1). Through these forms of engagement, practitioners engaged in key aspects of the research process, including study design, forming hypotheses, defining research questions, analyzing data, and sharing results.

All participants were connected to agroecological projects that sought to build soil health through hand-scale methods, especially in small plots and marginal lands with limited access to capital. Throughout the research process, farmers discussed challenges and shared knowledge about their engagement with soil, they swapped seeds, shared food, and discussed everything from land ownership to mutual aid. Farmers, community members, students, university staff, and researchers alike took part in these activities.

These methods are inspired by the principles of participatory action research, a democratic and participatory orientation to knowledge creation (28–30). Participatory action research attempts to center the design, implementation, analysis, and sharing of scientific inquiry in community-driven processes with the goal of uplifting social movements (31). In its ideal, this is achieved through iterative, practical, and action-oriented forms of collective experience that transform consciousness and create new forms of knowledge (32). Our implementation of PAR within this project was aspirational. While there are many aspects of community participation and governance we are proud of in this project, there is still much work to be done. There is always room for improvement in how power, ownership, and agency are negotiated in research.

Twenty different farms and community organizations were directly involved in the development and implementation of this project. Of these 20 organizations, 13 were BIPOC-led while 7 were white-led. Meanwhile, 12 were non-profit organizations, while 8 operated as for-profit operations. Taken together, they operated 28 different farming sites. Geographically, participating farms were spread across Northern California from the Central Coast to the Sierra foothills, with a large cluster in the Bay Area (Figure 2). By implementing a soil-first approach, members of this network create productive agroecosystems while facing capital and land limitations in ways that facilitate agroecological transitions. Changes in soil health have led to practitioner observation of enhanced ecological functioning, increased economic resilience, and better adaptive capacity to crises. This is motivated by farmer's goals of nourishing communities, repairing ecosystems, protecting biodiversity, and increasing collective autonomy and self-determination. Farmers in this network articulated a set of shared management principles that include minimizing soil disturbance, maximizing crop density both spatially and temporally, maximizing on-farm biodiversity, recycling on-farm resources, and maximizing soil coverage using mulches and plants. Hand-scale no-till requires no large machinery, utilizes minimal external inputs, and can be successfully implemented on small plots or marginal lands. Importantly, these benefits are accompanied by expanded concepts of labor, kinship, and the relationship between people and landscapes.

The project broadly sought to engage an already existing network. A "network" describes a network of individuals who co-develop knowledge of a shared interest through a common practice (33). Describing the network utilizing hand-scale no-till as a network includes the feminist notion that learning is always socially embedded and situated within a historical and cultural context. This network embodied these principles through a dynamic and ongoing process of knowledge sharing already in progress long before the advent of this project in 2017.

The initial phase of the project involved field research to investigate hand-scale no-till outcomes, both those observed by farmers and those not yet documented (34). The idea for a randomized, controlled field study began through conversations between the authors and members of local farms, community organizations, and advocacy groups. The direct experience of practitioners was clear: they had observed benefits for crop productivity, soil health, ecological functioning, farm management, and economic viability. In the Fall of 2017, our team implemented a field experiment based on farmer-derived principles and practices, comparing hand-scale no-till to other farming systems typically employed by small, organic vegetable growers in California (35). A diverse rotation of vegetable crops was grown every season, and each system managed to adhere to four core soil health principles that were shared among the network: 1) minimize soil disturbance, 2) maximize soil coverage, 3) maximize living roots, and 4) maximize biodiversity. In this way the study was adaptive; our tillage and cover crop treatments were combined in a way that was responsive to these soil health principles, leading to the creation of four distinct farming systems. The field study was implemented for six years, with a portion of the project ongoing as of spring 2024. The study system was designed by visiting collaborating no-till farmers' fields, and modeled after best practices in no-till soil conservation methods. Collaborating farmers visited the study site to advise on the implementation and maintenance of the study. Three community field days were held at the study site to engage both practitioners and the broader public in conversation about the potential benefits of limiting soil disturbance and maximizing local efficiencies.

In parallel with this field study, we sought input from farmers about our initial results and wider community-based research on the farming system. To create a guiding framework for the implementation of this project, a team of community organizers and farmers planned a farmer-to-farmer symposium with 35 farms represented from across the state. The core intention of this symposium was to crystallize an already forming network centered around hand-scale no-till farming practices. In February 2019 in Davis, California, participating farmers engaged in conversations on a range of topics from the ecology of no-till farming systems, to sharing knowledge and resources, to economic resilience.[6] With the consent of participants, all conversations that day were recorded for later transcription and compilation, while key points of discussion from small groups were collected on poster paper and used to create report-backs for the whole group. One group focused on defining a common set of principles of this hand-scale no-till system, which were collected, discussed, distilled, and shared back with participants for discussion. Another group was tasked with defining a series of research questions regarding this type of small-scale farming system, primarily focused on soil health but also touching on broader ecological and social outcomes. Two other groups were focused on knowledge sharing and economic viability, with a focus on supporting participants in actively sharing information and resources. Key summarizing themes and ideas were compiled by each of the focus groups and written onto large pieces of paper for a report-back, which were then written out and shared with the symposium organizers.

[6] For more information on our methods, see Supplementary Information.

Evaluations of agroecological practice

The symposium yielded a guiding framework for the participatory action research project (Figure 3). From the summarizing notes, transcriptions, and group report-backs, five key modes were identified that this community used to evaluate their agroecological practice: 1) economic wellbeing and livelihoods, 2) community food sovereignty, 3) ecological relationships, 4) adaptive capacity, and 5) personal, emotional, and spiritual connections to land.

Our team adopted these five evaluations as pillars of our research process, through ongoing dialogue and action with members of the network. In agroecology, there is a recognition that the scientific, practical, and social movement elements of agricultural transitions are interwoven (18). Thus, while these guiding principles were derived from practitioner systems for evaluating their stewardship practices, we posit that they can be just as meaningfully applied to the social, cultural, and political elements of this network. That is to say that these principles are multidimensional. They can be applied to something as specific as what winter cover crop species to plant, or what kind of tractor implements to use. However, we propose that these principles could be equally applied to evaluating on-farm labor and hiring practices, organizational structure, food distribution methods, and beyond—bridging ecological and social systems through a common set of farmer-defined evaluations.

"Economic wellbeing and livelihoods" represent consideration of the material outcomes of a particular methodology. How does an action impact the economic viability of an individual, their enterprise, their family, or their community? What does a particular action mean for their livelihood, or the means of ensuring that one's material needs are met?

"Community food sovereignty" questions the degree of agency that a course of action offers to the community's food system. Inspired by the international food sovereignty movement, this principle interrogates access to and supply of food, but also the governance systems that control the production and distribution of food. It is concerned with the sovereignty that individuals, families, and communities have in determining their food systems.

"Ecological relationships" invite questions about the health, vibrancy, productivity, and diversity of ecosystems and especially working lands. In this network, there was a particular focus on soil health, a wonderful example of the kinds of frameworks that practitioners were using to evaluate the physical, dynamic, and emergent qualities of "health" as pertains to an ecosystem like soil. This principle explicitly invites attunement to ecological relationships. Farmers were particularly interested in hand-scale no-till's effect on the soil, including: 1) carbon stabilization and carbon storage under different no-till management practices 2) nutrient cycling and availability in no-till, 3) soil biological diversity and food web complexity under no-till, especially in comparison to undisturbed soils or "natural" ecosystems, 4) soil structural differences that facilitate water storage, 5) effect of other soil conservation practices under no-till (e.g. cover cropping, occultation), 6) temporal transformation of soil ecosystems after transitioning from one tillage regime to another.

"Adaptive capacity" examines the degree to which a particular intervention or action increases the capacity to withstand disturbance or crisis. From an ecological standpoint, this includes the degree to which improvements to soil health might help crops survive little to no irrigation in the event of a wildfire or dry well. It could include other forms of adaptive capacity that the soil ecosystem confers such as resistance to soil-born disease or pests. Adaptive capacity can also imply broader social or economic resilience. Many farmers in this network noted that high densities of crops (in both space *and* time) allowed for levels of production that improved their success at the market. Reducing external inputs and the need for machinery allowed practitioners on small or marginal lands to begin farming—conferring a form of adaptation by reducing barriers to entry.

Finally, "*personal, emotional, or spiritual connections to land"* includes all the affective qualities of agroecological stewardship that must be included to understand communities like this one. The term "land" conveys multiple layers of meaning as it is commonly used by this network. Within this network, land is the site of relationship to ecology, to the Earth, and to more-than-human beings; all the forms of life that are left out of an anthropocentric worldview. Land is a living entity that warrants relationship and reciprocity. "Land" is also a political and cultural intervention; it is the site of cultural renewal, resistance, political struggle, and sovereignty. "Land" invites the complications of private property, capital, land tenure, and access. Farmers in this network form deep personal, emotional, and spiritual ties to place—often engaging these different layers of meaning simultaneously. These affective and emotional qualities of agroecology are essential to understanding the possibility of movement massification and territorialization.

These evaluations are used by farmers in this network to understand their agroecological practice. Importantly, these modes of evaluation combine and influence one another in complex feedbacks. For example, some farmers reported that hand-scale no-till's dense crop rotations resulted in improved total production and revenue. This was particularly promising for farmers with limited access to land and capital because of the potential to achieve high yields and access new markets. These improvements in farmers' livelihoods increased security of land tenure, allowing for more stable relationships with the landscape and deeper knowledge of its ecological features. Richer ecological knowledge increased adaptive capacity to challenges such as water deficits, pest pressure, and soil-born diseases. Adaptations to these challenges further improved production which impacts community food sovereignty, and so on.

These evaluating principles informed our research process in a few key ways. First, they helped define the soil health metrics we evaluated as part of this study. Our soil testing focused on soil physical, chemical, and biological properties that were of interest to this network. While a fuller suite of soil health measurements was shared directly with farmers, this study only reports on two key metrics—soil carbon and soil food webs. Second, these principles helped guide our farmer-led experimental design. Farmers defined the sampling areas on their own farms and categorized each sample by key features such as management history, land use type, landscape position, time of management, productivity, tillage intensity, and more. Farmers were particularly interested in how soils under hand-scale no-till compared to other land uses that were integrated into their agricultural landscapes. Thus, comparisons between hand-scale no-till and surrounding grasslands, forested areas, and tilled agricultural fields are a direct response to farmers' interest in landscape-scale domains in soil health. Broadly, how farmers defined sampling areas were influenced by these factors. For example, adaptive capacity to stresses like water shortages or high heat were a key criteria farmers used to decide what areas should be sampled together. Finally, these principles guided the topics discussed during farmer interviews. Semi-structured interviews were designed to explore how farmers navigated these principles as they evaluated their own agroecological practice.

A shared commitment: soil health

Soil health, and the importance of placing soil stewardship at the center of their agroecological practice, was a core commitment among this network. Soil health is a framework that views soil as a living, emergent entity (36). The framework considers the capacity of soils to provision food, fuel, and fiber while also delivering critical ecosystem functioning (37,38). New molecular methods are pushing the boundaries of knowledge about the soil ecosystem, revealing some of the mysteries of soil life that have eluded humans for millenia (39,40). Yet many biological and ecological dimensions of soil still evade clear understanding. Thus, the metaphor of health is employed by a wide range of actors to capture the functional and dynamic qualities of how soil interacts with broader social, cultural, and ecological systems. Soil health has led to wider adoption of practices and policies that promote stewardship and reciprocal relationships with soil (41).

While farmers articulated a range of questions regarding soil health and hand-scale no-till, this study focuses on two key attributes: soil carbon (or soil organic matter) and soil food webs. Soil organic matter, composed primarily of carbon, is a key property that governs much of the structure and function of soil, contributing to key ecosystem services (42,43). Soil organic matter is primarily formed and stabilized through microbial necromass following the decomposition of plants, which eventually becomes bound to the surface of soil minerals or protected in soil particles (44,45). Soil carbon is a particular focus because farmers in this network understood themselves as contributing to climate mitigation by storing higher levels of carbon in their soils (46–48). Forms of no-till have demonstrated the possibility of increasing carbon levels and stocks in soils (49,50), although research on this has primarily focused in industrial farming contexts with high levels of biocide application. In this study we evaluated soil carbon concentrations and stocks due to farmers' interest in how hand-scale no-till might be uniquely positioned to improve carbon storage and organic matter accumulation in soils due to minimal disturbance and high organic matter inputs.

Soil food webs were another area of intense interest for farmers in this network. The network spoke often of the host of life in the soil: microbes, fungi, invertebrates, worms, symphylans, spiders, flea beetles, and more. Many had directly observed changes in macroscopic soil organism populations on their farms after transitioning to hand-scale no-till. Farmers were motivated by their perceptions of soil organisms and their response to particular forms of soil stewardship. Soil food webs have been shown to respond dynamically to management changes such as no-till, solarization, and organic production—all practice utilized by this network of farmers (51–54) Nematodes are an effective bioindicator for studying soil food web composition and structure. Nematodes are ubiquitous in soils and occupy five trophic levels in the soil food web, from bacteriovores to predators (55,56). Nematodes also occupy key niches in the soil food web, regulating nutrient availability for plants (57) and exhibiting diverse life history strategies from opportunist r-strategists to slow-reproducing k-strategists. The abundance of nematodes with different feeding habits and life history strategies can be used to calculate ecological indices that reveal information about the structure, complexity and stability of the soil food web in soil samples (58,59).

In this article, we bring soil health measurements from this network of farms into direct conversation with farmer's perspectives on soil. Within this network, soil health is linked to perceived changes in farmer livelihoods, adaptation, community food sovereignty, and relationships between people and landscapes. This study tracked key changes in soil health across 16 farming sites in this network, including soil physical properties (bulk density, texture), chemical properties (pH, soil carbon, macro and micronutrients), and soil biological properties (soil food webs). Many of these measurements were carried out and reported directly to farmers, but are not included in this study. Instead, this article focuses on how soil carbon and food web structure were transformed across stewardship regimes, or land use types, on farmers fields. As part of a broader land stewardship ethic, hand-scale no-till was compared to other possible stewardship methods—perennialization, tillage-based agriculture, reintroduction of California natives, reforestation, and the like. These indices are also traced alongside farmer-defined characteristics (years of implementation, land use type) and geographies (degree of urbanization).

Soil health measurements are then paired with interviews that contextualize the motivations and aspirations of practitioners within this network. This study reports on some of the reflections and direct quotes from this network of farmers with the goal of illuminating why hand-scale no-till has been adopted by such a diverse group of farmers, organizations, and projects. Overall, this study attempts to bring soil ecology and social anthropology into dialogue. It seeks to uncover how key ecological parameters motivate farmers' agroecological practice, while conversely, tracing the social and cultural forces that drive soil health outcomes. These intersections of ecological and social change allow for an examination of how soil mediates agroecological transitions, offering possible lessons for scaling agroecology in the US.

Our approach

Transect walks and farmer interviews

To evaluate the relationship between farmer perceptions of soil, stewardship practice, landscape dynamics, and soil health metrics, our team conducted on-farm research at 16 different sites across Northern California. These sites ranged from tiny urban farms surrounded by concrete to small rural farms growing amidst oak woodlands. Sites were selected from farmers and practitioners who had already participated in other forms of farmer-to-farmer knowledge sharing within the network.

Our methodology focused on allowing farmers to define the boundaries of each sample area. This accomplished multiple goals simultaneously. First, it allowed us to understand what factors farmers were using to understand perceived differences in soil health. Through the transect walks, farmers converged towards a common set of landscape factors they perceived as important for defining areas with unique soil health outcomes. These factors are explored in the results below. Second, this open-ended approach allowed farmers to collect what information about their farm they were most interested in, shaping the on-farm study to be most useful for their own knowledge production. Third, by sourcing our sample locations from the place-based knowledge of farmers, we believe our study is better positioned to explore the full range of soil health outcomes that were occurring at these sites. The selected soil health measurements were derived from the research questions established at the symposium, field days, and farm visits, and included soil physical, chemical, and biological properties.

We asked farmers to determine the study areas at each site by conducting transect walks. Transect walks are a participatory action research technique designed to source local knowledge of terrain and territory in a way that is guided by the relationships between individuals and the landscape they are embedded within (60). Transect walks were conducted in the fall and winter of 2021, centered around areas where hand-scale no-till farming was being practiced but included the entire landscape. Farmers were asked to walk us through the entirety of the farm, responding to the prompt: *Show us every area with distinct soil health characteristics that can be found on this landscape*. The entirety of the walk was recorded, while the authors took field notes and traced the areas of interest on a map as the farmer led us through the site.

Following the transect walk, the authors and farmers compiled a soil sampling plan based on the walk, field notes, and map of the site. Having the farmers' active leadership in determining the transect route, drafting a site map, and finalizing a sampling plan was key to our methodology. This process yielded an experimental design with farmer-defined sampling areas categorized by management history, landscape position, soil type, soil edaphic properties, productivity, and more. In this context, sample areas or plots were the experimental unit of our on-farm study. We collected metadata on each sampling area, including 1) years since implementation of current management practice, 2) management history (annuals, perennials, cover crops, etc.), 3) landscape position, 4) farmer's perceptions of the area's productivity, resilience, production intensity, and tillage level, and 5) land use type. Land use types for each sampling area were determined by the farmer, with the goal of having points of comparison with the same soil type, or other baselines, to compare with hand-scale no-till. These alternative land use types were comprised of whatever land uses surrounded hand-scale no-till farms, but generally comprised four major categories: forested areas, grassland areas, tillage agricultural areas, and urban areas. Samples from these alternative land uses were taken from areas classified on the same soil type as hand-scale no-till whenever possible.

To classify the landscape context of each farming site, our team utilized the publicly available data from Dynamic World. Dynamic World utilizes a globally consistent, high resolution, near real-time land use land cover (LULC) classification system that leverages deep learning on 10 m resolution Sentinel-2 imagery (61). From this resource, we were able to assign every sample in our dataset a score based on the land use classification from a 2 km radius around the center of the sample area.

In addition to the transect walks that defined our sample areas, we conducted interviews with 19 farmers in this network. These semi-structured interviews were conducted to illicit informations about how hand-scale no-till (and farmers' soil stewardship practice more generally) intersected with the farmer defined evaluations: 1) ecological relationships, 2) adaptive capacity, 3) community food sovereignty, 4) farmer livelihoods, and 5) personal, emotional, and spiritual connections to land. Interviews were conducted on farmers' fields, recorded, and transcribed. Transcriptions underwent a qualitative coding process using Dedoose, a free web application for mixed methods research approaches. Transcripts were coded twice by two different individuals, and those codes aggregated within the five principles listed above.

On-farm soil health measurements

Soil samples were collected in the spring and summer of 2022 from each sampling area. Composite soil samples were taken from each sampling area at depths from 0-15 cm, 15-30 cm, and 30-60 cm using 15 cm dutch augers and homogenized. Unless otherwise noted, soils were air-dried, ground, and sieved to 2 mm before analysis.

The primary soil physical properties evaluated include bulk density, gravimetric soil moisture, and soil texture. Apparent bulk density was evaluated using the equivalent soil mass procedure as outlined by Wendt et al. (62) Soil cores were collected from a known volume and masses recorded in the field, then equivalent masses were calculated using *SimpleESM* (63) following the calculations in Lee et al. (64). Gravimetric soil moisture content was evaluated by weighing soil samples before and after oven-drying at 105 °C for 24 hours. Soil texture was evaluated using a standard pipette-based method (65). Briefly, 5 g of dried soil was added to a 0.5% sodium metaphosphate solution, which was shaken overnight. Then, the sample was allowed to settle for a known amount of time (based on particle size) and dispensed into a tin for weighing and calculation of particle size distribution or the volume percent of sand, silt, and clay particles.

Soil carbon concentrations and stocks were evaluated via gas chromatography and complete sample digestion at 1,200 °C measured on an Elementar varioEL cube (Elementar, Ronkonkoma, NY). Before elemental analysis soils were processed in a ball mill to homogenize the sample and prepare it for combustion. Carbon concentrations (g C / kg soil) were measured directly during elemental analysis. Carbon stocks (tons C / ha) were calculated using the equivalent soil mass approach noted above, which accounts for changes in bulk density across samples and changes in the effective depth of sampling due to soil (de)compaction (64). Other soil chemical analyses included pH, cation exchange capacity (CEC), macro (N, P, K) and micro (Ca, Mg, etc.) nutrients. These analyses were completed by the University of Massachusetts Amherst Soil and Plant Nutrient Testing Laboratory. These results were shared directly with farmers, but are not reported on in this study.

Soil food web analysis was done by evaluating the nematode community structure. Nematodes occupy multiple trophic levels within the soil food web, including root herbivores, bacterial-feeders, fungal-feeders, omnivores and predators, so that the abundances of their feeding guilds reflect those of primary decomposers, such as bacteria and fungi (66). Nematodes can serve as useful indicators of ecosystem functions such as nutrient processing, based on the relative abundances of key groups of bacterial and fungal-feeders (59,66,67) or estimated metabolic footprints of the carbon used for biomass production and respiration (67,68). Nematodes can also serve as indicators of disturbance due to differences in their life history strategies, which can be classified along a gradient between "early succession" and "persister" species (58). Early succession nematodes are r-strategists that thrive in disturbed environments, with shorter life spans, short generation time, small eggs, high fecundity, and high tolerance to adverse conditions. These species feed in enriched media and are mainly bacterivores. Persister nematodes are K-strategists that have the longest generation times, largest body sizes, and the greatest sensitivity to disturbance—mainly comprising omnivores and predators.

Soil samples for nematode community analysis were put on ice immediately and stored at 5 ºC until further processing. Nematodes were isolated from each composite soil core sample (comprising 200 cm^3 of soil) using a combination of sieving, decanting, and Baermann funnel techniques (69). The total nematode count per sample was determined using a Nikon model TMS-F inverted microscope (Tokyo, Japan). The initial 200 nematodes identified on each slide were classified taxonomically to the genus level under 400× magnification (70). Nematodes were further categorized into fungivores, bacterivores, or herbivores based on the feeding classifications provided by Yeates et al. (71). During analysis, nematodes exhibiting internal body cavity degradation, indicative of post-mortem changes, were identified as deceased and excluded from the enumeration to ensure only live nematodes were counted.

The abundances of nematode groups were used to calculate indices measuring the degree of disturbance, structure, nutrient enrichment, and metabolic potential of the soil food web (59,67). In this framework, the *Basal Index* indicates the degree to which a soil food web is "diminished due to stress, including limitation of resources, adverse environmental conditions, or recent contamination" and is characterized by a predominance of early succession nematodes (59). The *Enrichment Index* traces the degree of resource availability, typified by a flush of bacterial activity and bacterivore nematodes. The *Structure Index* increases with the abundance of predators and omnivores, and indicates the degree of "links in the food web" and "multitrophic interactions" (59). Finally, the *Channel Index* represents the ratio of key groups of fungal and bacterial feeders which gives insight into whether decomposition is proceeding more through bacterial or fungal channels and how management may differentially affect these groups (Ferris et al., 2001).

Nematode metabolic footprints estimate the carbon footprint of nematodes performing different ecosystem functions (68). Building on the nematode indices, which take into account sensitivity to disturbance and abundance, nematode metabolic footprints estimate the size dependent contribution of each trophic group (fungivore, bacterivore, omnivore) to C energy flow, incorporating information about nematode lifespan, body size and respiration rate (68). For example, the *Fungal Footprint* represents the estimated amount of carbon that is processed through fungal-mediated decomposition pathways, with greater abundances of larger, longer-lived fungal-feeders increasing the score. Calculations of indices and metabolic footprints were completed using the R, shiny package, NINJA: 'Nematode INdicator Joint Analysis' (72). Nematodes in the family Tylenchidae, can include groups that are typically non-detrimental plant parasites feeding on epidermal root hairs as well as groups that feed on fungi (71,73). Therefore, in calculating nematode indices, the abundance of Tylenchidae was split, with half categorized as plant parasites and half as fungal feeders, reflecting the uncertainty of feeding preferences in this group.

For our statistical analyses, we employed linear mixed-effects models (LMMs) to investigate the effects of land use type, management time, and urbanization score on soil health properties using the *lmer* function from the lme4 package in R. Site was included as a random effect in our models to account for lack of independence of samples within sites. To ensure the robustness of our models, we examined simulation-based diagnostics for hierarchical regression models using the DHARMa package. This included checks for residual normality, homoscedasticity, and the presence of outliers, which are crucial assumptions for the correct interpretation of LMMs. The DHARMa package simulates new residuals from the model's fitted values under the hypothesis of a correctly specified model and compares them to the observed residuals.

For summarizing the model effects, we calculated modeled means and standard errors for each treatment group using the emmeans package. This involved post-hoc analysis to adjust for multiple comparisons and control the family-wise error rate, typically using methods like Tukey's HSD when interpreting the pairwise differences among treatment levels.

Results

On-farm soil health

Soil health surveys across this network of farms revealed strong socio-ecological feedbacks that governed both farmers' practices and soil ecological functioning. Land use type strongly governed total carbon concentrations at the soil surface (Figure 4, Table 1), with hand-scale no-till doubled above 30 cm when compared to other land use types. This effect, however, was not found at deeper depths, with no significant difference in carbon concentrations across land use types at 30-60 cm depth. Soil carbon stocks followed similar trends, doubling in hand-scale no-till relative to nearby tilled sites at 0-15 cm but remaining unchanged by land use at deeper depths.

Transect walks and farmer interviews revealed that farmers in this network had been stewarding hand-scale no-till systems for very different durations: some plots were less than a year old, while the oldest plots were 20 years old. When we compared soil carbon stocks and concentrations across years (Fig. 4), we found a negative relationship between soil carbon and years under no-till, especially below 15 cm. These findings were a surprise. Strong declines in carbon with time would suggest that minimizing disturbance and high compost application were somehow redistributing carbon across the soil profile or leading to carbon losses.

Observed trends in soil texture revealed a more complex socio-ecological explanation for these observed trends. Soil texture was highly correlated with the number of years that hand-scale no-till was implemented ($F = 10.402, p = 0.002$). Soil texture, however, is understood as an inherent property of the soil that is generally unaffected by management even over decades. When soil texture was included in our hierarchical models of soil carbon concentrations and stocks, the explanatory power of years since implementation dropped away.

Soil nematode community analysis revealed distinct food web assemblages in the hand-scale no-till when compared to other land uses in the landscape surrounding no-till plots (Table 1, Figure 5). The spider diagram in Figure 5A indicates these differences. Hand-scale no-till had the highest measured Structure and Maturity Index, which indicates high connectivity between food web trophic levels and the presence of persister nematode species, predators, and omnivores. Grassland exhibited similar levels of these indices as the hand-scale no-till plots. Hand-scale no-till also exhibited a relatively high Enrichment Index, signifying a flush nutrient environment and high bacterial-feeder activity. Compared to grasslands, hand-scale no-till exhibited a similar Structure Index, but had a lover Channel Index indicating greater decomposition throughbacterial relative to fungal pathways. Meanwhile, neighboring tilled systems had more intermediate levels of the Structure, Maturity, and Enrichment indices, but higher Channel indices, indicating greater numbers of fungal-feeders, when compared to no-till. While hierarchical modeling showed no statistically significant effects of land use type on these indices, subjective differences were observed in patterns of indices between land use types (Figure 5).

Looking across plots of different ages, we found that there were significant long-term cumulative effects of hand-scale no-till on the soil food web. Even after accounting for soil texture in our hierarchical models, plots with longer implementation time tended to be more enriched and exhibit less fungal-mediated decomposition pathways than younger plots—they had pronounced Enrichment and Channel Indices (Table 1, Figure 5B). Meanwhile, food webs that were earlier in the implementation of hand-scale no-till were found to have a significantly higher Basal Index, meaning their food webs were constituted by early succession nematodes and opportunistic genera that thrive in more disturbed or nutrient-limited soil ecosystems.

Looking at changes in carbon and soil food web indices with urbanization revealed another set of complex socio-ecological interactions. After classifying every sample by the percent of urban land use (i.e. cement or concrete) within a 2 km radius of the sample area, samples ranged from nearly 100% urban land use for the most urban sites, to nearly 0% at the most rural sites. Thus, the sampling areas in this study comprised a robust urban-rural gradient. Along this gradient, hierarchical models determined that soil carbon was dramatically enriched in more urban areas (Figure 6, Table 1). Soil carbon concentrations and stocks at the surface were both an order of magnitude larger on urban farms than their rural counterparts. At depth, these increases were more moderate but still significant (Table 1). Unlike years of implementation, there was no meaningful relationship between urbanization and texture—soil textural differences were evenly spread across urban and rural farms.

Increases in soil carbon with urbanization were accompanied by changes in the soil food web as well. Total nematode biomass decreased by an order of magnitude moving from the most rural to most urban site; in other words, urbanization land use strongly determined the total number and size of the nematode population (Figure 6). Similarly, the Fungal Footprint—an estimation of the total carbon flux that is processed through fungal decomposition pathways—decreased with urbanization. At the same time, however, urban land use coverage was clearly linked to increases in the Structure Index, suggesting that soil food webs on more urban sites had increased connectivity between trophic levels and greater numbers of omnivores, predators, and more multitrophic interactions.

Taken together, these results demonstrate marked changes in soil ecological functioning with the implementation of hand-scale no-till, *and* ways in which those changes were linked to sociological determinants like urbanization and farmer management decisions.

Farmer perspectives

"It's like a completely built city underground": ecological relationships and soil health

Farmers in this network were highly motivated by the living and dynamic attributes of soil. Soil health, among this community of farmers, is seen as a foundation for the other benefits of hand-scale no-till: promoting adaptive capacity, supporting economic resilience, and allowing for increased food production on small or marginal lands. Farmers in this network were well studied on soil biology, chemistry, hydrology, and more. Farmers were deeply committed to ongoing inquiry and study of their soils through soil testing, self-guided education, observation, and trialing new practices. One farmer described their approach to soil health in this way:

> We just stay in tune with what the soil is looking like. We try not to commit to a procedure just for the sake of having some consistency … Soil doesn't really work that way. Temperatures change, seasons change, and they get hotter sooner and longer. We have to adapt and alter how we respond to it … If I use the same metrics to judge this soil health below our feet now versus the soil in the beds, I would find that maybe this is really unhealthy soil if I'm using the same metrics for these two. But that would just be wildly naive

and incorrect … There's that saying, you can't judge a fish by how it climbs a tree. There's appropriate measures for each thing. For soil health it's just knowing what appropriate metrics you're looking at, what you're measuring and why." (Farmer 10)

This farmer's approach suggests a high level of study and practice. They are conducting evaluation of the soil in a dynamic and adaptive way, only considering "metrics" that are relevant to their end goals as a farmer. Soil health outcomes are highly contextual. They change with climate, as the seasons shift and temperatures rise. They changes based on what the farmer's goals are. This practical, nuanced, and adaptive approach was paired with careful study, as indicated by another farmer's perspective on dealing with a particular soil-born pest:

> I'm sure you know if you look very lightly in the literature it says get rid of them by tillage but if you look more deeply in the literature it says mites and nematodes and things like that will eat them. You just need good healthy biology. So the way we solved it in here was actually to scoop out half the soil and bring soil from [another] field and it disappeared." (Farmer 1)

Soil food webs are leveraged by this farmer to address soil-born pests. The farmer appeals to their study and practice, acknowledging how conventional wisdom suggests tillage is the only solution. This farmer's commitment to studying soil health, and to employing soil biodiversity as a mitigation strategy, demonstrates how soil health is operationalized by farmers in this network.

Farmers were highly motivated by measured changes in soil health. Actions that benefitted the soil, and the farm's broader ecology, were seen as worthwhile in and of themselves. For example, one farmer expressed how soil organic matter measurements influenced their farming practice:

> But the main thing that got me back into cover cropping was I got frustrated with seeing the decline of our organic matter after a few years of success after we switched to no-till. The few years after we switched I was like, "Holy hell!" We're getting that 1% increase that everyone boasts about if you switch to no-till and you do it right. And then it started plateauing … so we're trying to incorporate cover crops into the no-till system and this year we're doing way more than we did the previous year… (Farmer 12)

Building soil organic matter was seen as a meaningful goal, and farmers in this network were involved in ongoing monitoring as they sought to find best practices. Cover crops were added to their stewardship practice with the explicit goal of increasing soil organic matter. Many farmers articulated ongoing evaluation and monitoring they performed on the soil at the farms, and how that, in turn, influenced their agroecological practice. One farmer expressed this process:

> I notice different things each day, different insects, the biodiversity that we've created, and when we don't create enough what happens when we don't ... Soil is a universe of its own …

> it just got me so aware of how important it is and like how much attention it needs and how we gotta balance it. We're still trying to find the balance. And we started learning about no-till, and we're trying to implement new methods and trying to give back to the soil and not just be extracting but … regenerating it and giving back. So we've been experimenting with different methods and like leaving crops in the soil, we started doing our own compost, stuff like that. And we also we might do a carbon sequestration plan for the farm where we sequester carbon with different things around the farm with like hedgerows, or even like the way that we prep our soil, and amend our rows. (Farmer 16)

Practices like no-till, maintaining living roots, and composting were implemented with a clear eye toward the "universe" of the soil. Increasing soil carbon was an actionable goal that this farm planned to establish a stewardship plan around, including hedgerows, soil preparation, and amendments.

Many of the farmers in this network made regular appeals to mimicking nature, seeing hand-scale no-till as more closely aligning with how organic matter is added to the soil in "natural" ecosystems. In particular, tillage and the mechanical turning of the soil were seen as counter to the additive, emergent, and biologically-mediated soil building processes in natural ecosystems. One farmer explained these perceptions in this way:

> I always like to think, what would nature do? … Nature has built the most fertile soil in this world, has turned a rocky volcanic planet into a fertile landscape for all of us. And it doesn't till, you know, it doesn't do that specific action. (Farmer 17)

Comparisons to natural ecosystems motivated farmers to employ a range of principles in the hand-scale no-till system, including the maximizing of on-farm biodiversity, minimizing tillage, and maximizing soil coverage. Farmers were particularly interested in how hand-scale no-till transformed soil health relative to other land uses on their farms—including grasslands, forested areas, urban soils, and tilled agricultural soils. This was a major motivation for comparing soils under hand-scale no-till to other land use types on the same landscape.

At the same time, farmers acknowledged an element of mystery and power inherent in the soil. Despite extensive experience working to build soil health, many farmers readily acknowledged that soil had an agency all its own. One farmer decentered themselves as the "builder" of soil, and afforded agency to the soil organisms instead:

> I don't really necessarily look at myself as somebody who's trying to build soil. I'm just trying to attract the fungi, the bacteria, and the invertebrates and figure out how to get them so that I can put a cover on them so they can do their secret work and magic … That's really what I'm trying to do when I put leaves and, you know, cover cropping and all those different types of things … Is to attract those things, which build. Right? They want to work for you.

> They want to do the work. So let's just provide them everything that they need so they can do their thing and I can go off and do something else. (Farmer 18)

This farmer places the locus of power and agency in the soil with soil organisms, seeing themselves as merely a facilitator—setting the right conditions such that the soil ecology can do their "secret work". This was echoed by another farmer when they said, "When you look at it in the soil perspective, it has kind of been the hidden perspective because it's kind of a mystery down there." This quality of mystery and the unknown structures part of the ethic shared among this network. For this network of farmers, soil is afforded agency. This agency seems to be one of the fundamental assumptions underlying how principles of hand-scale no-till can be applied in such diverse contexts. One farmer, reflecting on the broader network of farmers involved in the project, expressed this sentiment about soil formation across the farms:

> Organic matter came from something. It came from life living upon life and dying upon life and so all soil types are different, but all soil organic matter was built through something … there are universal laws in soil ecology, might be that there are subtleties that are different in areas but the universal law of life grows, its death supports the next life, and keeping things within the cycle, is just a universal fact. It doesn't matter if you're in Santa Rosa, or here, or Berkeley. (Farmer 12)

Soil enacts forms of power through cycles of living and dying. These cycles, while unique to their agroecological context, follow universal principles. Despite their racial, cultural, and geographic diversity, farmers in this network converged on a common set of agroecological practices—in part due to their recognition of the agency of these cycles in the body of the soil.

"Access to land, access to capital": Farmer livelihoods

During our farmer interviews, labor was a key issue mentioned by practitioners in their consideration of this system. Many spoke to the complex trade-offs between farm productivity and profitability, soil health, and labor demands. One farmer shared their experience of these trade-offs in this way:

> "There's a lot of people who have come to this [no-till system]. It is a lot of observation and looking at what the soil needs. I'm really excited about this whole movement that is going forward… In 2018, we increased our produce revenue by eight percent by increasing our planting intensity and decreasing our land space, which was something that we just trialed—partially through increasing labor…So we can do a lot and we can stack a lot of enterprises on top of each other, and that's what we need to do to feed people." (Farmer 1)

This farmer is directly relating their practice of increasing planting intensity and productivity to both soil outcomes and labor demands. They illustrate that to achieve economic success on small, marginal farmland, it is worth building soil health at the expense of increasing labor demands.

Hand-scale no-till systems allow for greater flexibility in the timing and accordance of crop planning with available space. Crops can be cycled out in a single day, with fresh starts or seeds planted immediately into emptied rows. Hand-scale no-till operations can start earlier in the spring and extend later into the winter. Taken together, these differences in the adaptability of no-till systems represent meaningful differences for farmers looking to manage their soils using ecological methods.

The relationship between labor, soil, and agronomic outcomes was not fixed or the same for everyone, however. They changed over time, as illustrated by a farmer who described their experience in this way:

> "At first I thought no-till was a labor saver. But then we lost our composting facility, and now we only have s*** compost because I don't really have the ability to create enough. And now the compost brings in weeds. It brings in disease… So now I feel like the labor is back up again—it's just of different kinds." (Farmer 7)

Access to inputs, changing soil health conditions (in this case weed pressure or disease), labor, and farm viability are being weighed and constantly reevaluated. The realities of how farm labor is achieved were also discussed. Many farmers were integrating their operations with various educational, community, or volunteer labor forces—sometimes in combinations or all at once. One farmer spoke to the dynamics of these systems in this way, acknowledging the clear need for increased labor under hand-scale no-till.

> "What we're discussing here today is a system that requires quite a lot of manual skill and labor, right, so it inherently does involve people… So ensuring the ways that we set up these training opportunities are not exploitative, but to actually be nurturing and beneficial to both the farmer and the learner." (Farmer 6)

No-till farm labor was being understood and discussed in ways that were not embedded within typical schemas of agricultural labor, but rather intersecting with other economic, social, and cultural modes of exchange. The exchange quoted below, between a group of both urban and rural farmers, reveals some of the nuances and questions that these considerations raised in dialogue:

> "People come to me and say, 'Well, aren't you going to get a tractor?" and these different kinds of things. And no, I'm not getting a tractor. I'll get some people! But I'm not going to get a tractor." (Farmer 3)

> "Well if you're like us that's partly because, being very urban, we have a lot of access to volunteer labor… Per square mile, the amount of hand labor is really quite high." (Farmer 4)

> "Well, maybe that gives us an opportunity to start to think about how this [type of] no-till plays into the whole question of what a farm is or where it's located. Because, you know, when you're located farther out, then you don't have access to the labor. So then you have to rely on machines. But as you start to come back home into the cities, then you're going to find that you're going to have a lot more people that want to volunteer…" (Farmer 3)
>
> "But then your cost of land goes up!" (Farmer 5)

Implementing hand-scale no-till requires unique types of labor relations and has a high labor demand. These shifting labor relations have huge implications for farmers in this network. This quote demonstrates how farmers are grappling with the very question of what constitutes a farm, or where a farm can be positioned; geographically, economically, and socially. Hand-scale no-till opens new domains, or territories, for cultivation by expanding the geographies, populations, land bases, economic models, and labor forces that constitute agriculture. These domains or territories become sites for not just achieving farm viability, but building soil health, creating educational opportunities, and realizing food sovereignty. The quotes above suggest that hand-scale no-till farming creates new relationships between agricultural landscapes, soils, and those who perform the labor needed to maintain them. This opens new territories of agroecological practice.

At the same time, these changing labor relations betray differences in class, race, and land tenure. Understanding how issues of racial justice and class difference intersect with alternative forms of agricultural labor is critical. What's more, farm labor is just one small aspect of farmer livelihoods. While our interviews did touch on other issues such as market access, production costs, and collaborations with granting agencies or government programs, these issues will require further investigation.

"What we're really interested in is adaptation": adaptive capacity

Given the marked changes in physical, chemical, and biological functioning observed in the soil under no-till management, it is no wonder that farmers asked how this system might impact agroecosystem adaptation to environmental stressors. The capacity of farmers to respond to changing ecological, social, and political conditions is modulated by adaptations at different scales, from improving crop health, to managing farm operations, to leveraging social networks. Changes in soil health and ecological relationships can dramatically alter farmer livelihoods, their degree of agency, and their capacity to respond to moments of crisis.

Adapting to potential soil contamination and land use legacies was a focus for farmers in this network, affecting urban and rural farmers in different ways. One urban farmer explained the history of their farming site, and how hand-scale no-till farming facilitated the transition from a contaminated urban lot to a productive urban farm:

> It was all one lot, and it used to be dry cleaners, so there was a lot of heavy chemical use and stuff but that was way long ago. This was the parking lot. And then it became a mechanics garage … So we still find sometimes the occasional spark plug that unearths we found entire freaking steering columns when we were redoing the edges … When we have to drill deep down, we found some pretty sizeable car parts. (Farmer 10)

This farmer went on, explaining that the farm had been established for over 20 years. Through the addition of large branches, organic material, mulches, and on-farm compost, the site slowly transformed as their practices began to "lock in carbon" and "increase water holding capacity". The site is now so amended with additions that the original soil is buried deep beneath a thick organic layer. The ability for hand-scale no-till systems to create vibrant and production farms in sites of this kind is emblematic of why the system has taken root in such diverse contexts.

An example from the opposite side of the geographic spectrum illustrates the range of adaptive modes that farms across this network were exploring. One farmer stewarding a forested site in a rural area described how hand-scale no-till, and other forms of forest stewardship, helped the landscape survive a wildfire:

> I affirm that every bird I hear has a nest still because we brush the land, we graze the land, and this annual bed maybe didn't save the forest around us but our net impact on the land being agriculture here and forest management out there … you know, it benefitted the property and if the organic matter in this soil is higher, if there are more earthworms than outside, then we are also helping in the most intensive managed areas of the farm … You see on that mountain, I hiked there a couple of days ago, and you look down and we're in just this bubble of green … and everything around us burned down … Although we're doing agriculture here which is the compromise of living with the land and also controlling the land, we've net-benefited a survival of this acreage because it didn't burn down. Us living here and doing what we're doing here, you could look at it and say, oh, is that natural, is that right? But it saved the forest, at least. So it's doing something. (Farmer 12)

This quote expresses complex layers of adaptation that are enacted by this no-till farming system. Within the agricultural zones of the farm, the farmer is expressing how soil health benefits such as more organic matter and earthworms contribute to the resilience of the ecosystem, creating a "bubble of green" amidst an otherwise scorched landscape. While this agricultural practice is a "compromise" between "living with" and "controlling" the land, this compromise allowed the farm to adapt to drought conditions that burned the rest of the area. Other forest stewardship practices, like brushing and grazing, are in conversation with hand-scale no-till, emphasizing how this farming system is part of a broader land stewardship ethic. Taken together, this farmer evokes a sense of how hand-scale no-till fits into a broader plan to adapt to crises facing California farmers such as fire.

Two of the projects in this network are led by California Native leadership. These projects were utilizing hand-scale no-till, but framing the system in unique ways that centered Indigenous lifeways, rematriation, cultural resurgence, and California native plants. A farmer working with one of these projects explained their efforts in this way:

> We're going to propose a new way of farming with the wild in the management structure of conservation so that bringing the nettles, bringing the willow, bringing the native seeds, bringing the native bunchgrasses, so you look at it and it's being conserved, tended, it's wild, but it's actually being managed through Indigenous land stewardship … Right now all the water comes from the creek and the rain … We're managing the water and planting it and our farming practices are designed to basically rehydrate the landscape first … How do we capture the natural runoff so that the end result of the farm is bringing the salmon back? And the elk? (Farmer 14)

In this project, the adaptive capacity of the landscape is measured by the return of the salmon, elk, willow, and bunchgrass. Increasing the capacity of the soil, and broader landscape, to store water is an essential adaptation for the thriving of native vegetation and food production alike. One benefit of a system that foregoes mechanized tillage and promotes hand-scale practice is that cultivation doesn't have to happen in straight lines. Following the contours of the landscape, promoting water conservation and flow, and promoting native flora and fauna are enhanced by this network's low-disturbance agricultural system.

"Having a relationship": personal, emotional, or spiritual connections to land

Finally, farmers in this network share a common stewardship ethic that centers on relationships between people and land. This ethic meant that personal, emotional, and spiritual connections to land were emphasized throughout the network. This ethic took several forms in practice.

First, it meant that nearly every organization or farm in this network participated in some form of popular education or knowledge sharing. From on-farm apprenticeships, to collaboration with local schools, to field days and courses, farming on small or marginal lands was coupled with pedagogical approaches. Every single farm that participated in our on-farm soil health study had some kind of educational program, class, or apprenticeship that they were hosting or participating in. Education emerged as a critical component of not just how the farming system operated, but part of its *ethos*. One farmer described their relationship to these educational programs in this way:

> "I think of [the farm] as an outdoor classroom, a place where kids can explore and experiment and try things and break and dig and make a mess" (Farmer 10)

Another farmer expressed their understanding of the educational programs happening in the community in this way:

> What we're discussing today is a system that requires quite a lot of manual skill and labor, right, so it inherently does involve people. That's what we're talking about … And young people in particular, you know, so the ways that we set up these training opportunities to not be exploitative, but to actually be nurturing and beneficial to both the farmer and the learner. It is very important. (Farmer 19)

From this farmer's perspective, hand-scale no-till was embedded within educational or training opportunities that needed to be carefully designed. The high levels of labor needed to achieve successful implementation of hand-scale no-till made training programs, internships, and other forms of education essential components of the system. This emphasis on education, however, was held within a larger frame. The connection between humans and land was seen as a vital goal in and of itself. Some of these connections are material in nature, as one farmer described the links between soil and human health:

> How much our own personal biology is the exact same as the biology that's in the soil? So those interconnections between us humans and the soil is something that I think is very important to me.

Another farmer expressed the critical connections between humans and the Earth in terms of spirit and intuition:

> I think a lot of how we treat the land comes down to how we view our spirit, and how we view each other and our connection to the natural world. And a lot of the time we know what is best for the land, based on our intuition. Because we really are connected, and can know what is best by feeling and having a relationship with the land … I mean, you can be a farmer for your whole life and really not be fully connected to the land, and be great at doing what you do, with making a profit and having a deal, but never really feeling connected to the land. (Farmer 2)

This farmer is expressing how connection to land helps activate an intuitive, spiritual ground that allows for a richer relationship. From their view, what is best for the landscape is part of a spiritual and intuitive practice that must flow from a meaningful and reciprocal relationship.

Other farmers spoke of their farms in terms that can only be described as intimate or emotional. One farmer described their land in very anthropocentric terms:

> You know, the land gets tired because there's times when we don't cover crop and grow like all season … It doesn't always work out well to, say, to leave something fallow in the summer and when I do do that it usually means that it's actually bare all summer which hurts my heart." (Farmer 11)

The bareness of the soil hurts the farmer's heart. The land gets tired. These aspects of land stewardship must be incorporated into a broader understanding of how agroecological transitions will be realized.

Yet contradictions and challenges to this intention abound. A farmer reflected on their lifelong commitment to their land, and expressed a poignant sense of permanence and responsibility, saying:

> I plan to die here, so this is going to be a long game. Which is part of why I care so much about this. I'm not going to go off to another piece of land. (Farmer 12)

This statement belies a complicated intersection between privilege and responsibility. It is an immense privilege to be able to maintain land tenure in one place and to know where one is going to die. Against the pain of land theft, dispossession, and forced displacement, it must be acknowledged that this is a privileged position to be in (74). Yet at the same time, this farmer expressed another sentiment, which further troubles the possibility of personal connections to land. They later explained:

> We're on borrowed land in multiple ways—just as humans in agriculture, but also as settlers on native land. (Farmer 12)

These statements, seemingly contradictory, invite us to stay with the trouble. Structural forces (power, wealth, class, race) determine much of our connection to land. Land theft, poverty, structural racism, and economic exploitation—all of these are huge determinants of whether an individual can build a relationship with land. And yet, all of those structurally-determined forces are subject to change. They are transitory. They are borrowed. When individuals can achieve *some* connection to the Earth—whatever means may be necessary to achieve it—it transforms their sense of responsibility and reciprocity to place. Committing to dying somewhere is no small feat. The paradox embedded in this farmer's experience is an expression of why personal, emotional, and spiritual connections to land are so motivating for this network: landscapes materialize the inexpressible, carry histories, translate across differences, and embody the inherent contradictions laden within the human experience. A farmer spoke to these contradictions in this way:

> The main reason I'm here, I think … although I haven't always been able to speak this … it's to facilitate my own healing as an individual. So individually, and as a person whose family and ancestors have experienced land-based trauma. I'm personally divorced from the land, or at least I was. I don't feel that way anymore, but my family certainly was … This space does exist within a city that exists within an area that is populated by other people who aren't me … And some of them have more power than others. And some of us don't speak the same language ... So creating safety for myself has been integral in making sure that this land can be healing because it could be also another opportunity—regardless of how beautiful it is

> and how accessible it is—it could be another opportunity for harm, if you're not careful about it. (Farmer 19)

Land is a witness. It remembers and holds the memory of the past. At the same time, land offers the possibility of restoration, healing, and reclamation through embodied experiences of nourishment and kinship. This paradox leads the farmer to the rich soil of contradictions embedded within land-based work. Personal, emotional, and spiritual connections to land engage with trauma and pain as much as they make space for new life.

These tensions and contradictions did not deter farmers in this network from actualizing beauty and regeneration in their communities. The perspective of one urban farmer expresses this, as they watched an urban lot transform dramatically over several years. They described watching the land change from a dumping site—littered with concrete, trash, and other waste products of a city—to a place where children come to plant seeds and pick apricots from the tree. They spoke to the inner and outer transformation they witnessed as they enacted agroecological transitions in their community.

> "It's life changing. Working here really is life-changing. It's not even work. It's more like growing with the area that you're in. You grow together. Like not only do you grow the vegetables and the fruit, but you grow yourself, you grow your knowledge, you grow your heart, your soul, and then you expand, you give it to other people. As they come through they get a taste of it and they can expand and give it to other people. That's the main issue right there is just to spread the love. Spread our roots." (Farmer 15)

Discussion

This study illuminated how a network of farmers, through the adoption of a hand-scale no-till farming system, navigate the complex interplay between land stewardship, food sovereignty, community empowerment, and ecological resilience amidst the complex challenges of California's agricultural landscape. The integration of hand-scale no-till across diverse California landscapes led to transformations in soil health that were dependent on ecological factors (soil texture, vegetation type) and social factors (urbanization, farmer adoption, land use). In turn, transitions in soil health drove farmers towards particular agroecological practices and motivated their continued adoption of a system intended to create vibrant agroecosystems on marginal lands.

Our results underscore that hand-scale no-till, as practiced by the diverse farmers in this network, is not just about soil conservation or land stewardship. It represents a holistic approach that connects ecological relationships with a strong commitment to social justice, community resilience, and self-determination. Farmers in this network span a wide range of geographic, cultural, racial, and socioeconomic differences, but all exemplify a common stewardship ethic that motivates their adoption of hand-scale no-till. These farmers' agroecological practice is motivated by both ecological *and* social drivers, allowing them to reduce external inputs, leverage limited land and capital resources, increase ecological efficiencies, maximize food production, and bolster their own livelihoods and connections to land. Farmers articulated a shared understanding of agriculture as a deeply relational practice, emphasizing connections to the land, to social movements, and to historical or cultural narratives regarding agriculture. This relationship-oriented approach emerges as a critical element in fostering agroecological transitions in conditions that constrain the creation of thriving agroecosystems.

The participatory action research methodology employed in this study was instrumental in engaging farmers as co-researchers, not merely as subjects of research. This approach allowed for a rich dialogue between scientific inquiry and farmer knowledge, leading to a deeper understanding of how agroecological practices like hand-scale no-till can be effectively implemented in diverse socio-ecological settings. The findings revealed significant improvements in soil health, including increased soil carbon and enhanced soil food web structures, which are indicative of more robust soil ecological functioning (75–77).

The blending of sociological and ecological data is key to this study. For example, preliminary data suggested that soil health benefits of hand-scale no-till may accumulate over longer time scales. Farmers and academic collaborators both hypothesized that years of compost application, minimal disturbance, high planting densities, and high on-farm diversity would have accumulative effects on soil health, accruing slowly over time (78–80). Our team was interested in understanding how the duration of management—measured in years of implementation—might affect long-term soil health trajectories across this network. However, many factors influence how and why farmers adopt and maintain particular practices. Agroecological practice is shaped over many years; it is a complex socio-ecological phenomenon that arises from both human and environmental processes (81). Our findings clearly illustrate that soil edaphic (inherent) properties *and* soil ecological functioning shape the practices adopted by farmers engaged in hand-scale no-till.

For instance, soil texture emerged as a pivotal factor influencing the decision to implement hand-scale no-till practices. Our results suggest that farms with sandier soils tended to be early adopters of the system or maintain implementation of hand-scale no-till over longer periods. Sandier soils typically exhibit quicker drainage, higher erosion rates, and lower nutrient-holding capacity, which would benefit markedly from minimal soil disturbance (82). Such ecological insights are crucial, as they empower farmers to tailor their practices to the specific conditions of their land, thereby optimizing ecological benefits and enhancing the resilience of their crops to environmental stresses. Soil texture was a hidden variable governing changes in soil carbon that *initially* seemed to be attributable to the age of hand-scale no-till plots. Years of implementation do not independently probe the cumulative effects of hand-scale no-till; the texture of a farm's soil has a critical influence on a farmer's decision to adopt and maintain this farming system. As they witness improvements in soil structure and health over time—characterized by increased organic matter and more structured soil food webs—farmers are compelled to continue their no-till practices, thus driving a positive feedback loop that further promotes their practice.

Soil nematode communities and food web structure were also part of complex socio-ecological feedbacks. When compared to other land uses on participating farms, hand-scale no-till exhibited the most structured food webs, signifying greater connectivity between trophic levels and multi-trophic interactions (83). Ongoing compost application, diverse organic mulches and amendments, high levels of root exudates from dense plantings, and minimal soil disturbance likely contributed to these shifting food webs as they provided diverse substrates for soil biological communities to feed on (84). Compared with soils under tillage-based systems in particular, the decrease in fungal-feeding nematodes is surprising but important. Many farmers in this network were explicitly interested in how hand-scale no-till might support the growth of mycorrhizal networks and minimize soil disturbance that physically breaks mycelial threads (85). The opposite effect was demonstrated in our study, however. Long-term implementation of hand-scale no-till led to far fewer fungal-feeding nematodes, suggesting a decrease in fungal biomass under the farming system. This could have been due to bacterial dominance in the system related more to organic matter quality, addition rate, and size (86). The diversity of organic inputs in hand-scale no-till may have also driven a higher Enrichment Index, indicating the presence of a nitrogen-rich environment with periodic flushes of nutrient availability. Taken together, a picture emerges of how hand-scale drove shifts towards nitrogen-rich and bacterially-dominated food webs where bacteriovores thrive, fungal decomposition pathways are downregulated, and periodic nutrient enrichment maintains early succession nematode communities.

This study also offers insights into soil carbon and organic matter dynamics within this farmer network. These findings are crucial, especially considering farmers' interest in how hand-scale no-till and associated practices could serve as strategies for mitigating climate change and sequestering carbon. First, the increase in soil carbon concentrations and stocks observed at the surface level under the no-till system highlights how minimizing disturbance, dense crop plantings, and application of composts and mulches can double carbon stocks and concentrations at the soil surface. The surface soil acts as a crucial interface where organic inputs and microbial activity converge, thus serving as an active zone for carbon accumulation (87). However, the less conclusive results regarding soil carbon at deeper depths (below 15 cm) indicate a complexity that warrants further exploration. The finding that long-term no-till might lead to decreases in soil carbon stocks at greater depths challenges farmers' perceptions of hand-scale no-till farming's benefits for deep soil layers. This could potentially be explained by differences in organic matter decomposition rates between soil layers (88), altered spatial distribution of roots (89,90), and physical redistribution of soil between depth layers (91,92). These dynamics underscore the need for a nuanced understanding of soil carbon accumulation and storage, suggesting that benefits observed at the surface might not uniformly extend deeper without additional management strategies.

The social and cultural environments in which farms operate also play a crucial role in shaping soil health outcomes, as demonstrated by the significant influence of urbanization on soil carbon levels and food web structures. Our study found that farms located in more urbanized areas tended to have higher soil carbon stocks and more complex soil food webs compared to their rural counterparts. This can be attributed to several factors, including higher organic input levels from urban waste materials, such as compost and mulches, and possibly reduced tillage intensity due to smaller plot sizes commonly found in urban settings. Moreover, the social dynamics of urban farming—often characterized by greater community involvement, educational outreach, and innovative resource recycling initiatives—foster practices that enhance soil organic matter. Such practices are not only ecologically beneficial but also culturally resonant, reinforcing community bonds and local sustainability initiatives. This influence of urbanization highlights how cultural and social dynamics can directly impact ecological outcomes, supporting the view that urban agriculture can play a unique role in advancing soil health, agroecological transitions, and food sovereignty (93–95). Because hand-scale no-till can be realized without reliance on significant capital inputs, expensive machinery, purchased fertilizers, or large land acreages, they decrease barriers for producers seeking to achieve a level of sovereignty, or agency, over their community food production.

Importantly, this research highlighted the significant role of socio-political and economic factors in shaping farmers' agroecological practices. Farmers' narratives of their agroecological practice reveal a keen awareness of the systemic barriers that impede the transition to more sustainable agricultural systems, such as land access, capital availability, and the structural violence that disproportionately affects marginalized communities. These insights are crucial for developing agroecological policies and practices that are not only ecologically sustainable but also socially equitable. Land stewardship was understood as materializing complex histories and structural violence while also offering pathways for new experiences of self-determination and self-actualization. Specific stewardship practices were seen as building adaptive capacity to intersecting challenges like the climate crisis, economic hardship, and COVID-19. Meanwhile, soil health was a significant motivating factor in and of itself, with farmers engaged in ongoing soil health monitoring and strategic plans to directly and measurably benefit the soil.

Understanding this network as working at the cracks, margins, or edges of California's industrial agricultural system acknowledges the way that ecological diversity occurs at the boundaries of ecosystems. Ecotones, the generative threshold where multiple ecosystems meet, and edge effects are well-documented phenomena in agroecological contexts (96–98). But margins create more than just novel ecological outcomes. In this context, emerging from the cracks of an industrial agricultural system engenders new social relations, food distribution pathways, and networks of care. By tracking changes from the soil ecosystem to the social relations and community food systems it feeds, this article expands our understanding of how agroecological thresholds might be constituted. It seeks to bring into dialogue the necessary ecological and social conditions for the massification and territorialization of agroecology.

This network might offer insights into the ecological and social conditions necessary for agroecological transitions to occur. By tracing both soil health and social conditions on sites practicing this form of agroecological farming, we hope to offer pathways for the scaling of agroecology in the US. Massification describes the processes of scaling or amplifying agroecology, by which "ever-greater numbers" of farmers "practice agroecology over ever-larger territories and which engages more people in the processing, distribution, and consumption of agroecologically produced food" (99). The word is derived from the Spanish *masificación*, which is used in the Latin American context to describe the expansion of grassroots movements (100). In their examination of agroecology in Cuba, Rosset et al. quoted an anonymous *campesino* from one of their workshops, who wrote:

> To *massify* is to move all the methods and forms possible to promote and multiply any task. Taking the practices of peasants and promoters and spreading them in training workshops, seminars, and conversations on the farm. Learn the practices by doing them. Do them in schools, with the children, in the barrio, with the community, so that all these people carry the word from mouth to mouth, to the men or women they are closest to … The need to build a great movement at the district, municipal, and national level. To consolidate the practices in an organized fashion; demonstrate that something good is happening, is being experimented with, on the farm. That nothing shall be left which hasn't been taught to others; that all of us can learn and can also teach, each according to our role. (101)

Much of the practice and theory of massification of social movement, especially regarding agroecology, has happened in Latin America. Mier Y Terán Giménez Cacho et al. (2018) proposed eight key drivers that allow for the massification of agroecology: (1) crises that drive the search for alternatives, (2) social organization, (3) constructivist teaching–learning processes, (4) effective agroecological practices, (5) mobilizing discourse, (6) external allies, (7) favorable markets, and (8) political opportunities and favorable policies. Another key condition for the massification of agroecology was secure land access for farmers and farming communities.

The movement of farmers practicing hand-scale no-till has already achieved a degree of massification in California—however limited in scale when compared to dominant industrial agriculture in the state. Amplification of the farming system has proceeded without any centralized approach or organizational body. Rather, it has spread in an organic and emergent way. This makes hand-scale no-till, and the network that utilizes it, a meaningful case study in agroecological transitions in the US. A number of the drivers of massification listed above were present in the development and dissemination of this no-till farming system. Crises such as water shortages, wildfires, COVID-19, and land scarcity were motivations for practitioners to adopt this adaptable farming system. Several allies in the non-profit and governmental sectors created opportunities for material support, funding, advocacy, and new markets for farmers in this network. Economic success due to higher production was a critical reason for adoption, as favorable markets and new value-based supply chains afforded some economic success to farmers in this network. Finally, social organization and constructivist learning processes allowed for the information to be shared (and then adopted) through informal networks, farmer-to-farmer exchanges, conferences, and word of mouth. "Constructivist" perspectives on teaching and learning suggest that individuals must always construct their knowledge through a dialectical process, evaluating theories and testing practices within their own changing socio-cultural context (32). Taken together, these conditions seem to align with leading theories of agroecological massification and territorialization.

Some have theorized that the scaling of agroecological movements is a form of territorialization or a mode of creating agroecological territories (26,102–105). Territories are not just delineated by geographic boundaries but are defined by environmental conditions, ecological domains, political and administrative structures, history, and cultural identities. Thus, a territorial approach works at the interface of ecology and culture (25) and allows for a regional analysis of food systems change that meaningfully expands beyond analyses at the farm or landscape level (26). Territorialization describes the simultaneous geographic, ecological, and human processes that govern the material development of agroecological transitions. Key aspects of a territorial approach include "a focus on harnessing local strengths, rights to land, seeds and waters, inter-sectoral development, the recognition and celebration of local identities, sovereignty over 'development processes' and solidarity and democracy" (25).

Due to the flexibility and dynamism of hand-scale no-till farming methods, it has a strong territorializing effect. With minimal capital, machinery, or inputs, new social and ecological relationships can rapidly form. These changing agroecological conditions were described by many of the farmers in this study. They witness the forest become resilient to wildfire, and blighted urban lots become vibrant spaces of biodiversity and nourishment. A strong commitment to creating personal connections between people and land was key to these forms of territorialization. The high labor demands of hand-scale no-till suggest that new social and economic relations are needed to successfully implement the farming method. Every farm that participated in our on-farm soil health study participated in some form of educational programming. This aspect of hand-scale no-till could be seen as a weakness or point of critique; if the farming system relies on volunteerism, temporary labor, students, or interns, it may be replicating systems of (self) exploitation (106–110). What's more, such systems may privilege white people who have the economic security and social safety nets to support these precarious forms of work (106). The racial and cultural diversity of the participants in this network troubles and complicates these critiques. To practice agroecology on the margins of California's industrial agricultural system, to challenge dominant paradigms of food, agriculture, and land—these may have inherent risks in the US context. State repression of land-based movements, especially those led by Black and Brown communities, is a legitimate and ongoing threat to transformative movements for food sovereignty in the US (111–114). Projects that increase the visibility and accessibility of agroecological practice, and engender new relationships between diverse communities and land, must be understood in this context. Perhaps they are prefigurative, necessary modes of survival and capacity building on the road to a more liberated food sovereignty movement.

Bridges between communities and the more-than-human world are also essential to this process. This network explicitly emphasizes and highlights those connections, both through their practices and discourse. We seek questions at the edges or margins. How do notions of structure, enrichment, urbanization, and horizons create new embodied experiences of food, land, and culture? How does the soil act as a medium for social constructivism and collective learning? What role does the soil play in the territorialization of agroecology? This article is a case study that explores some of these edges as they are constituted in the cracks of California's industrial and agricultural landscape.

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Figure 1. This study implemented a Community-Based Participatory Research (CBPR) design, where input from a community of practice was solicited and action taken within the community to engage that community directly. The methods and findings within this publication reflect the insights of these community members, including a farmer-to-farmer symposium, field days, farm visits, and conference calls with farmers and community members.

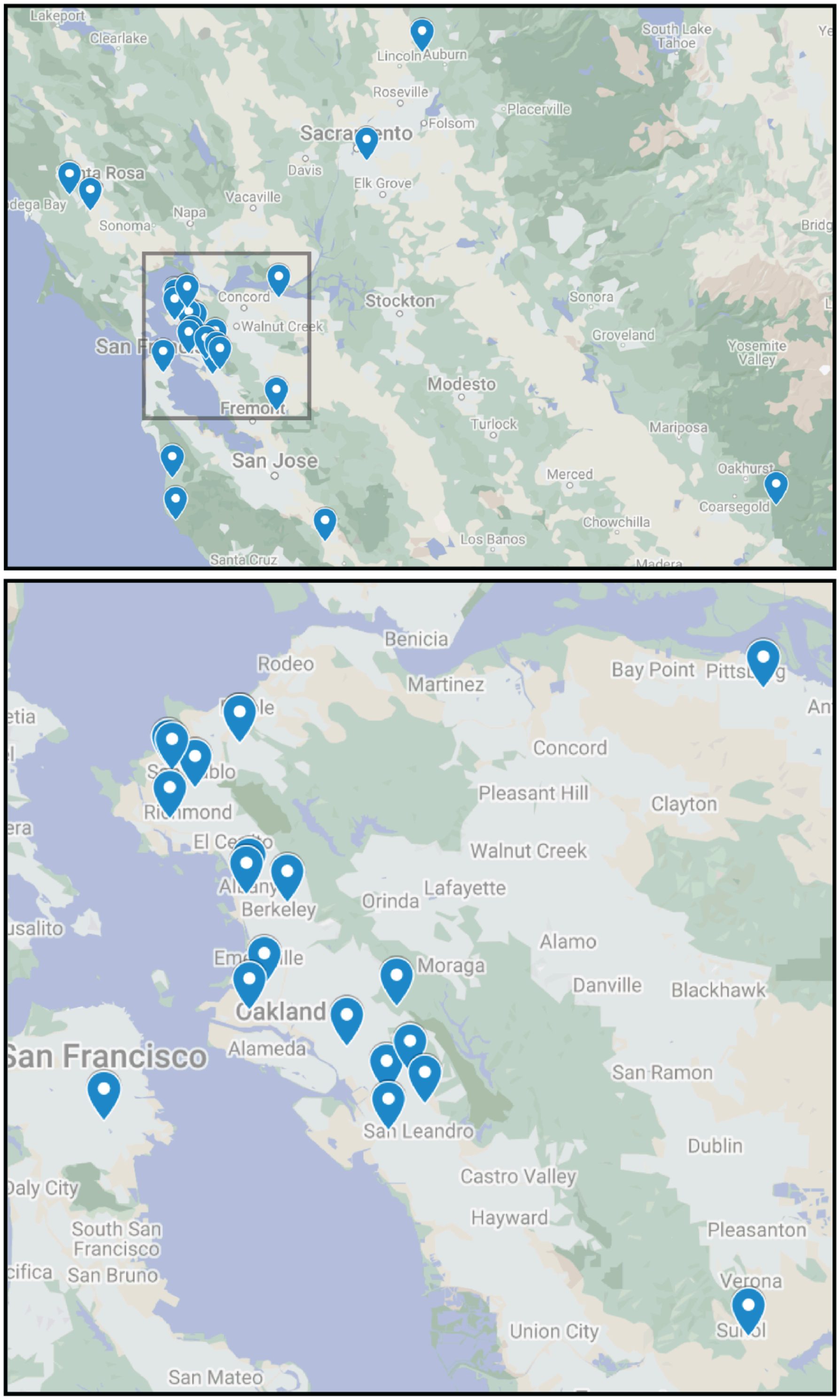


Figure 2. A map showing the 28 farms that participated in this project, representing 21 different organizations.

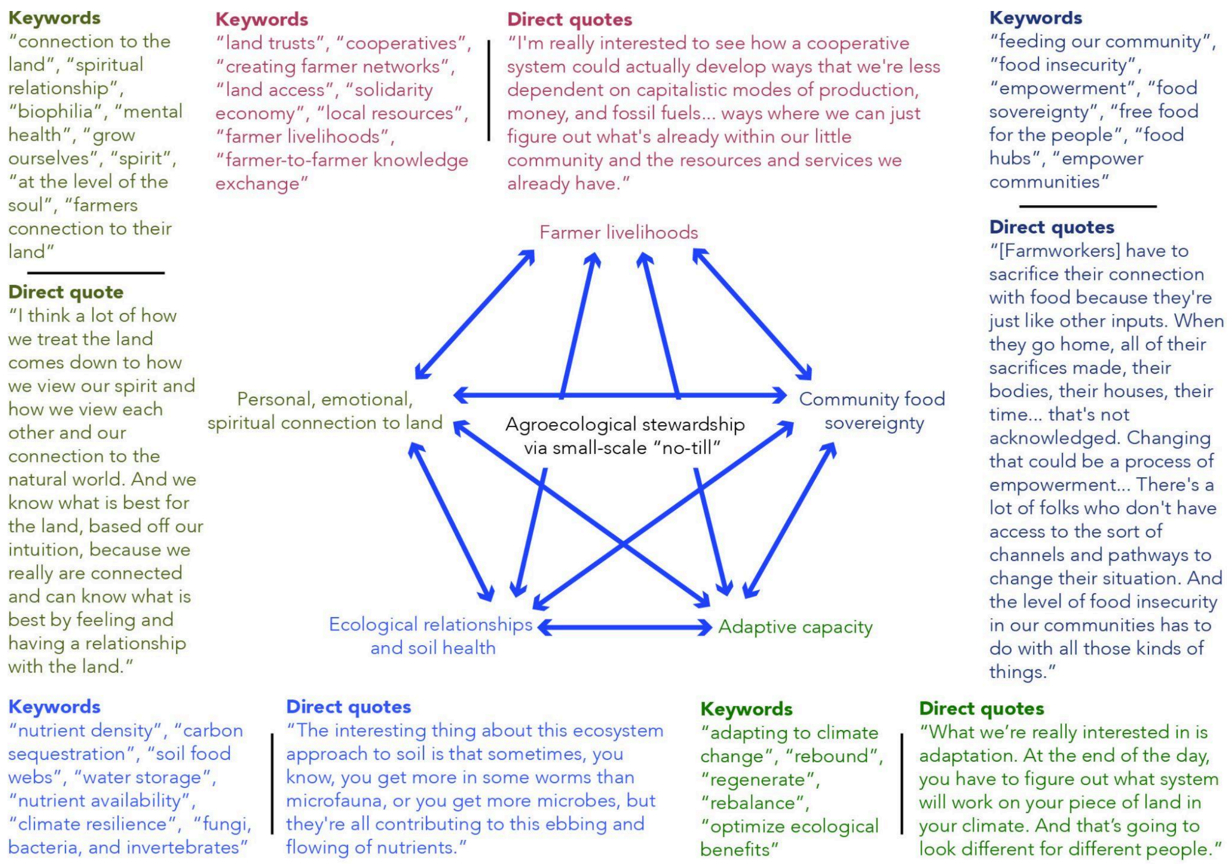


Figure 3. A summary of the central motivations and interests of small farms practicing no-till management in both urban and rural contexts, along with keywords and quotations from our community-based participatory research process. Primary sources are a farmer-to-farmer symposium on no-till in Davis, CA, USA in February 2019 and four field days held in Berkeley, CA between 2018 and 2020. This demonstrates the range of desired cultural, ecological, economic, and practical outcomes for small-scale no-till farmers.

Variable	No-Till		Till		Forest		Grassland	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Total Carbon								
Concentration (g C / kg soil)								
0-15 cm	6.38	0.54	3.16	0.73	3.49	1.45	3.59	0.52
15-30 cm	4.56	0.49	2.44	0.5	2	0.6	1.88	0.26
30-60 cm	2.46	0.3	1.8	0.3	1.53	0.54	1.48	0.26
Stocks (ton C / ha)								
0-15 cm	54.43	4.17	36.07	5.11	35.18	7.93	50.72	6.73
15-30 cm	10.26	1.35	13.16	1.21	9.09	2.57	13.24	2.22
30-60 cm	5.43	0.66	4.09	0.63	3.68	1.07	3.66	0.58
C:N Ratio								
0-15 cm	12.56	0.35	10.55	0.28	12.53	0.51	11.25	0.3
15-30 cm	11.95	0.3	10.76	0.25	12.61	1.09	10.78	0.41
30-60 cm	10.62	0.3	10.08	0.5	11.33	0.96	9.88	0.81
Nematode Indices								
Maturity Index	1.88	0.04	1.93	0.03	1.89	0.04	1.79	0.1
Maturity Index (Sigma)	2.01	0.04	2.09	0.03	1.97	0.05	2.03	0.12
Maturity Index (2-5)	2.15	0.03	2.11	0.02	2.05	0.02	2.13	0.06
Channel Index	27.77	2.95	39.76	4.7	32.9	4.04	37.78	11.24
Basal Index	32.79	1.95	39.69	2.18	45.14	3.71	31.1	5.4
Enrichment Index	61.77	2.13	55.3	2.56	52.23	3.99	65.42	6.34
Structure Index	24.18	3.11	19.76	3.07	9.74	3.6	20.47	8.96
Nematode Biomass (Total)	6.53	1.5	4	0.81	1.95	0.37	6.32	2.32
Composite Footprint	1596.94	323.05	1018.89	191.5	591.75	116.13	1632.57	627.82
Enrichment Footprint	1186.83	269.24	632.34	137.75	393.9	79.7	1163.53	604.3
Structure Footprint	49.34	8.99	50.41	10.18	27.13	12.18	76.95	54.11
Herbivore Footprint	264.52	132.96	218.35	56.82	42.35	12.1	308.36	104.32
Fungal Footprint	27.67	3.25	39.67	5.4	26.51	5.02	51.57	11.1
Bacterial Footprint	1300.41	277.98	747.19	155.76	522.69	115.37	1262.84	613.42
Mites (Total)	2.6	0.73	2.68	0.49	1.29	0.42	3	1.35
Collembola (Total)	0.98	0.21	0.74	0.48	0	0	1.5	0.98
Microarthropods (Total)	3.58	0.76	3.42	0.71	1.29	0.42	4.5	1.54

Variable	Years (In No-till System)			Land Use			Urbanization score		
	F	p	Significance	F	p	Significance	F	p	Significance
Total Carbon									
Concentration (g C / kg soil)									
0-15 cm	7.44	0.01	**	6.3	0.001	***	24.7	0.0004	***
15-30 cm	1.23	0.27		6.53	0.001	***	13.1	0.003	**
30-60 cm	4.55	0.03	*	2.15	0.1		5.9	0.03	*
Stocks (ton C / ha)									
0-15 cm	0.03	0.87		2.82	0.04	*	19.7	0.0009	***
15-30 cm	10.3	0.002	**	2.64	0.05		1.7	0.21	
30-60 cm	5.09	0.03	*	0.35	0.79		9.4	0.009	**
C:N Ratio									
0-15 cm	0.39	0.54		3.03	0.03	*	7.8	0.02	*
15-30 cm	2.21	0.14		2.51	0.06		3.4	0.09	
30-60 cm	3.43	0.07		0.84	0.48		2.7	0.12	
Nematode Indices									
Maturity Index	0.15	0.7		0.57	0.63		1.67	0.2	
Maturity Index (Sigma)	0.35	0.56		0.29	0.83		0.82	0.37	
Maturity Index (2-5)	3.26	0.08		0.28	0.84		4.92	0.03	*
Channel Index	5.76	0.02	*	0.97	0.41		0	1	
Basal Index	8.2	0.01	**	2.45	0.07		1.01	0.32	
Enrichment Index	7.71	0.01	**	1.77	0.16		0.03	0.86	
Structure Index	1.69	0.2		0.29	0.83		5.81	0.02	*
Nematode Biomass (Total)	0.46	0.5		0.88	0.46		3.99	0.05	*
Composite Footprint	0.36	0.55		0.89	0.45		3.15	0.08	
Enrichment Footprint	0.12	0.73		0.82	0.49		0.7	0.41	
Structure Footprint	0	0.98		0.37	0.77		3.25	0.07	
Herbivore Footprint	2.78	0.1		0.2	0.9		4.95	0.03	*
Fungal Footprint	5.31	0.02	*	1.83	0.15		17.99	0.0001	***
Bacterial Footprint	0.15	0.7		0.75	0.53		0.91	0.34	
Mites (Total)	1.73	0.19		1.07	0.36		0.34	0.56	
Collembola (Total)	1.47	0.23		0.26	0.86		1.59	0.21	
Microarthropods (Total)	0.27	0.61		2.38	0.07		2.75	0.1	

Table 1. Estimated marginal means, standard errors, and hierarchical model results for soil carbon concentrations, carbon stocks, carbon:nitrogen ratios, and soil food web indices. Nematode metabolic footprints are expressed in units of s μg C (200 ml soil)$^{-1}$ and total nematode biomass in mg.

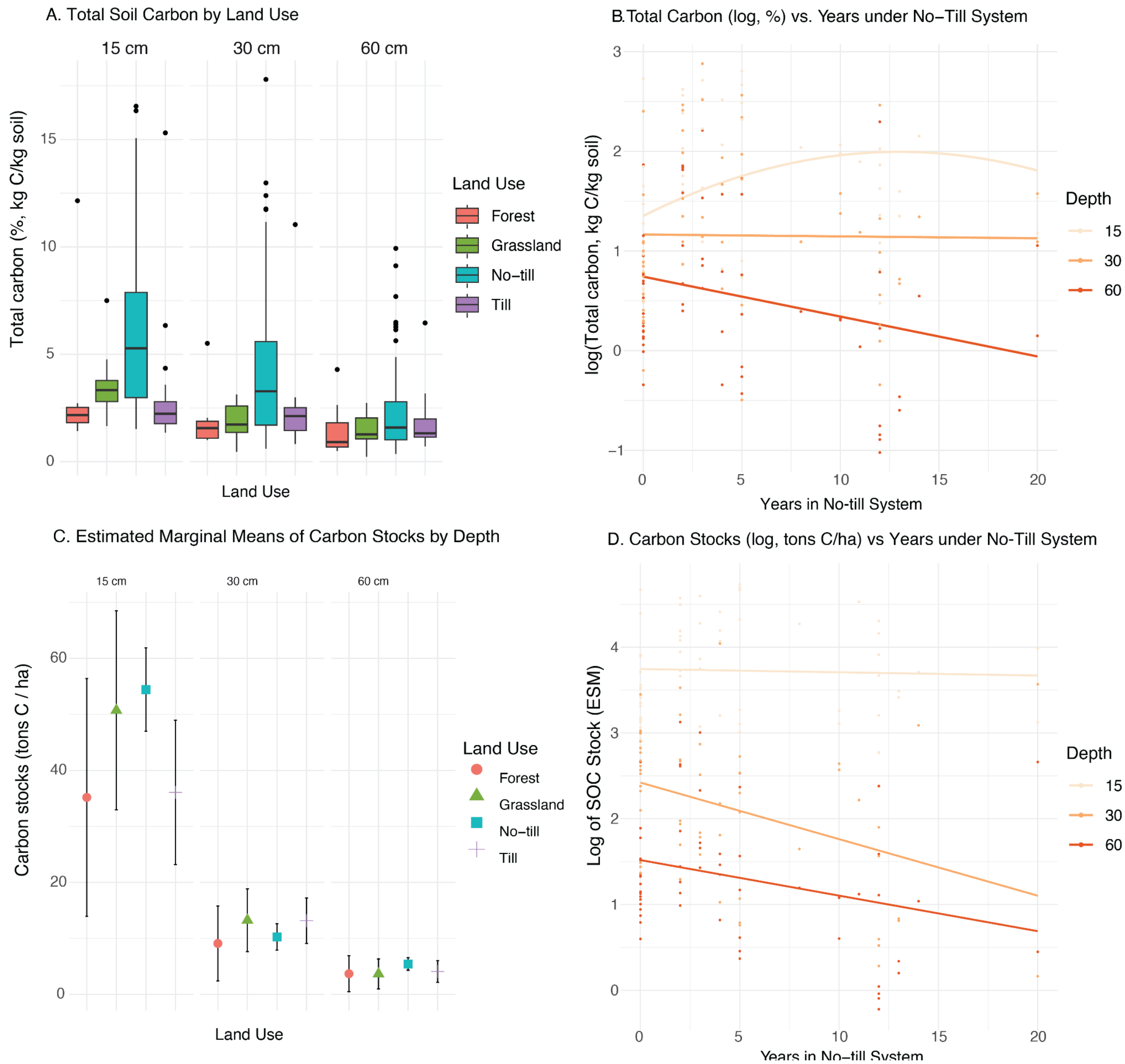


Figure 4. (A) Total carbon concentrations in the soil, according to land use type. The hand-scale no-till system had significantly higher levels of carbon at surface depths when compared to surrounding tilled agricultural systems and land use types. (B) This figure only plots sampling locations under agricultural cultivation, demonstrating changes in soil carbon with years since last tillage event. The x-axis ranges from plots under tillage systems or just tilled that year (far left) to plots that had been under hand-scale no-till management for 20 years. At the surface (0 - 15 cm), total carbon concentrations tended to accumulate for the first 10-12 years, then decline slightly. Intermediate soil depths had no significant trend with years under no-till management. At depth (30 - 60 cm), total carbon concentrations *declined* with years, indicating possible redistribution of carbon from deeper in the soil profile.

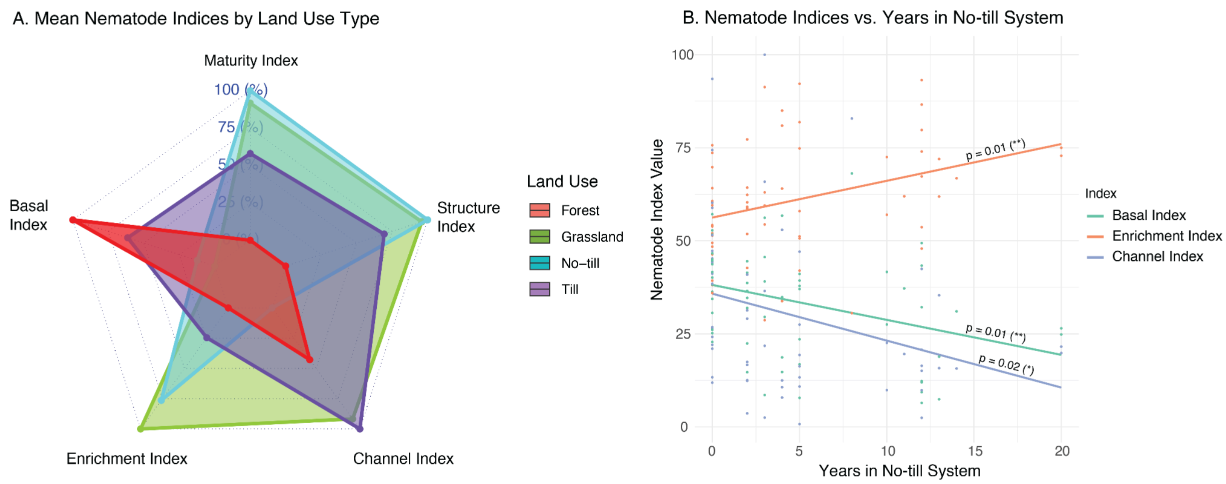


Figure 5. (A) A spider diagram demonstrating the different assemblages of the soil food web according to land use type on and surrounding the farm sites. From this analysis, hand-scale no-till exhibited the highest Maturity Index and Structure Index, indicating the presence of more omnivores and predators, and more connectivity between the trophic levels in the food web. Grasslands shared this characteristic, with only slightly lower levels of these indices. Hand-scale no-till and grasslands also exhibited high Enrichment index, suggesting a nutrient-rich environment with high populations of bacterial-feeders. Hand-scale no-till, however, had dramatically reduced Channel Index, suggesting greater abundance of bacterial-feeders, as well as higher Enrichment Indices compared to till. Overall, this figure demonstrates how the hand-scale no-till system, when compared with tillage systems, increased food web structure and increased nutrient cycling. (B) Nematode indices including Basal Index, Enrichment Index, and Channel Index plotted against the number of years under hand-scale no-till management. All three of these indices were significant even after accounting for soil texture. These data suggest that hand-scale no-till increases nutrient turnover and nutrient enrichment of the food web (Enrichment Index) over time, while decreasing populations of nematodes that thrive in disturbed and damaged soil ecosystems (Basal Index). Meanwhile, decreasing Channel Index with years of implementation suggests that hand-scale no-till slowly downregulates fungal decomposition pathways in favor of bacterial ones.

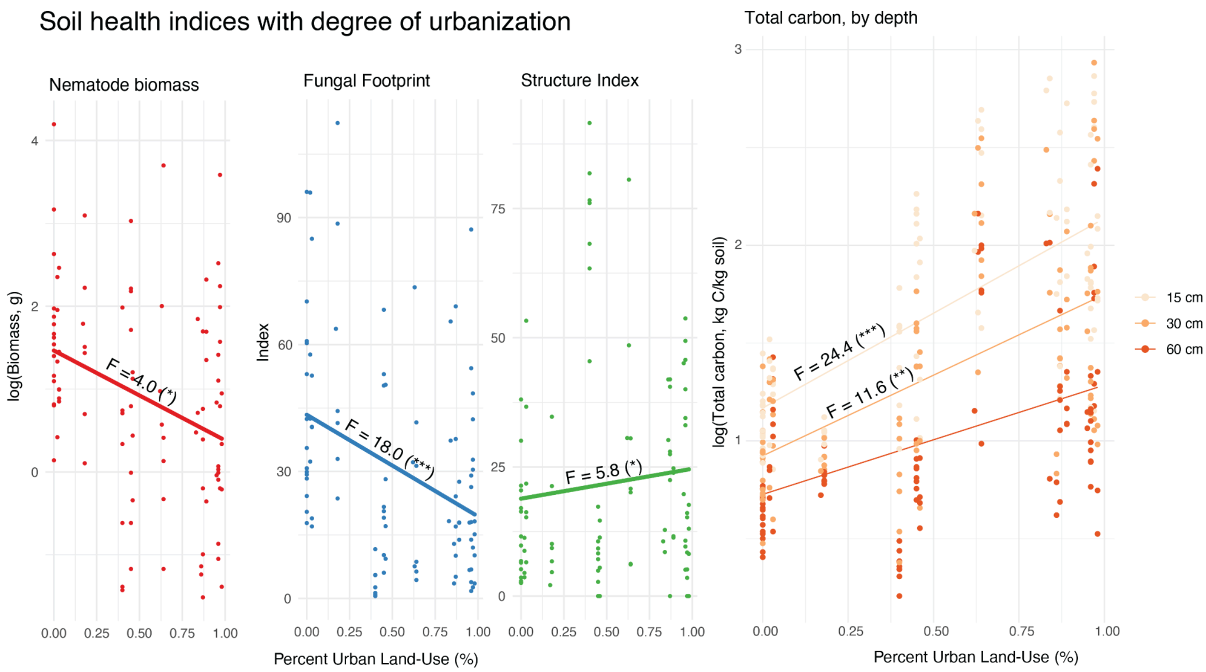
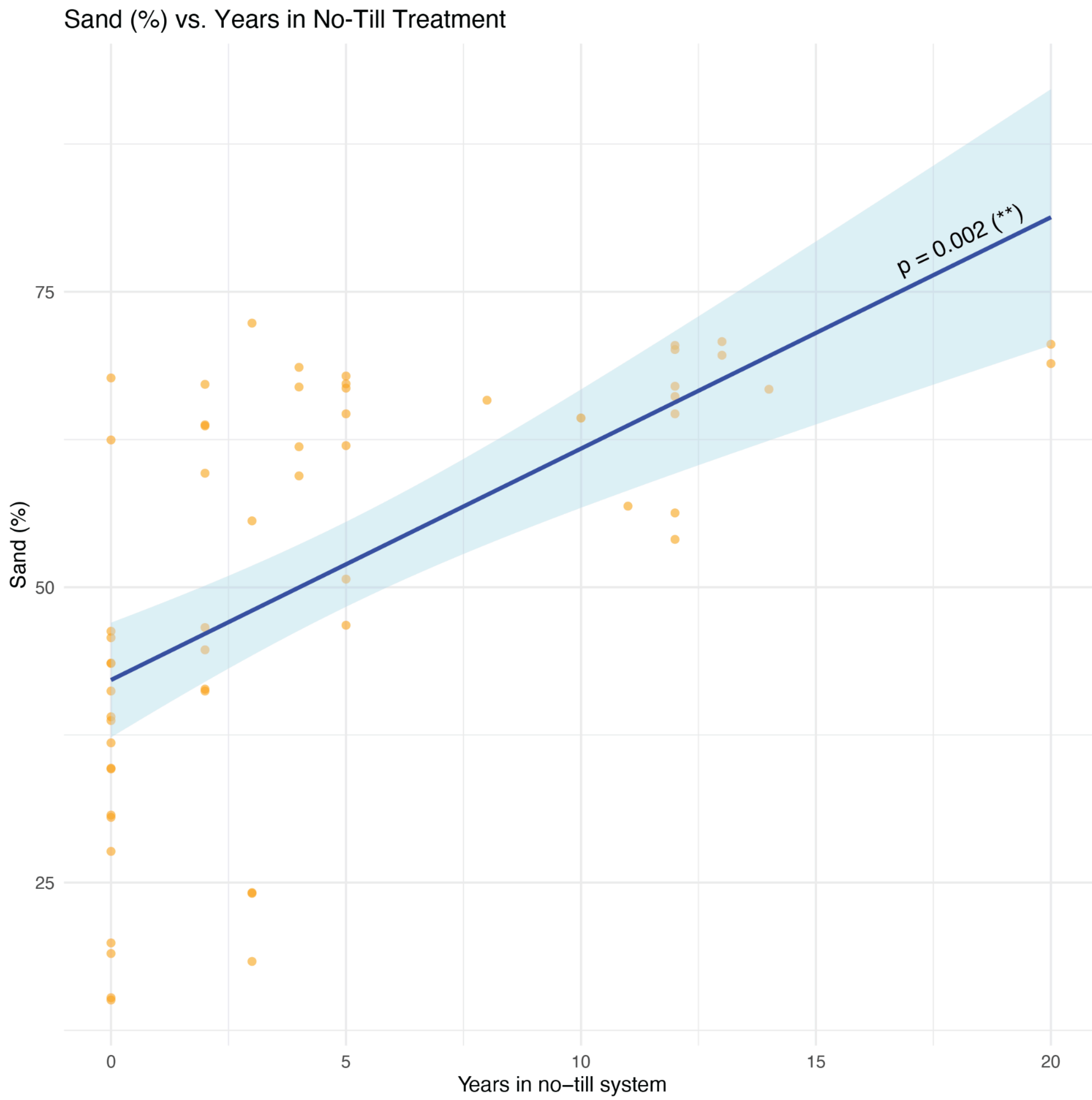


Figure 6. (Left) Nematode indices including biomass (mg), fungal footprints (µg C (l soil)−1), and structure index plotted against percent urban land-use coverage as classified by Dynamic World. Nematode biomass and fungal footprint (total carbon flux through fungal decomposition pathways) decreased with urbanization. Soil food web structure, meanwhile, increased with urbanization. F-statistics resulted from linear mixed-effecets models and ANOVA tests. (Right) Total carbon concentrations plotted against percent urban land-use. Carbon concentrations increased by an average of 1.5% along a rural-urban gradient of the 16 participating farm sites. Similarly, F-statistics are reported from linear mixed-effects models and ANOVA.



Supplementary Figure 1. Volume percent of sand-sized particles with years since implementation of hand-scale no-till, with a linear regression fit by *lmer* function in . Percent sand was highly correlated with the age of hand-scale no-till plots. Texture, however, is understood as a relatively inflexible soil property that does not change significantly with management. Thus, we must conclude that texture has a strong influence on a farmer's decision to adopt, or maintain, hand-scale no-till. Hand-scale no-till may help address challenges that farmers face when working with sandier soils by reducing erosion, minimizing leaching, improving water retention, and increasing soil organic matter.