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Agroecology and soil stewardship: values and techniques of smallholder farmers in Bernalillo County

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To my daughters, who have been a source of joy and comfort throughout all my endeavors. Together, in times of perpetual homework and global crisis, we continue to thrive in our love and care for each other.

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ABSTRACT

Agrarian movements around the world use agroecology to build sovereignty and steward dynamic ecosystems. Research has shown that agroecological farmers steward more resilient crops, more resilient soil biomes, and greater biodiversity than conventional agriculture. GIS and remote sensing offer many tools to detect the impacts of these farmers on the environment, but it is less clear how such technologies fit into agroecological goals. This study asks: what values, experiences and knowledge do smallholder producers in Bernalillo County embody in their soil stewardship practices? Also, what experience or knowledge do smallholder producers in Bernalillo County have about remote sensing, and would they use remotely sensed data to understand the impact of their soil stewardship practices? To answer these questions, I look to political ecology and feminist theory for understanding the embodied knowledge and practices that are fundamental to agroecology. I find that the practice of farmers in this study embody the same values and methods of agroecology farmers worldwide. Additionally, the remote sensing process could be useful to detect the impacts of farmer practices on soil dynamics in Bernalillo County.

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CHAPTER 1: Introduction

Healthy soil is everything to a farmer! Without healthy soil,
you have nothing.
-Producer 30

Smallholder food growers around the globe have played an important role in social, economic, and environmental systems for millennia. Each individual region is home to Indigenous communities with centuries of collective knowledge about a unique ecosystem. New Mexico is home to dozens of Puebloan communities including the Tiwa, Tewa, and Towa peoples. The Albuquerque area (Tiwa) is the longest-inhabited metropolitan region in North America (M. G. Brown et al. 1986; Shaul 2015). This means that for over 10,000 years the inhabitants of this land have been learning about the soils, water, plants, and fauna of one of the most diverse ecoregions in the United States (Environmental Protection Agency 2023; National Park Service 2022). Around 2,000 BCE corn arrived (M. G. Brown et al. 1986), and so began the journey of agricultural and soil stewardship for this region's earliest inhabitants.

This embodied knowledge that informs how to grow food as a part of a unique ecosystem can be referred to as agroecology. In this thesis agroecology is an intentional method for growing food in harmony with local ecosystems and communities to provide sustenance and sovereignty. This definition aligns with global agrarian reform movements like La Via Campesina and Movimento dos Trabalhadores Rurais Sem Terra (MST) (Why Hunger n.d.). Markers of success for agroecology include vitality in cultural, economic, and environmental projects around the globe. (Altieri and Toledo 2011; Fixing Food 2018; Rosset and Martínez-Torres 2012). These contemporary agrarian movements and others around the globe use agroecology to build sovereignty and create dynamic ecosystems with resilient soil biomes

(Ericksen 2008; Fixing Food 2018; Union of Concerned Scientists 2015). Additionally, the agroecological stewardship practices of smallholder growers is creating agriculture plots more resilient to climate catastrophes than conventional agri-business models (Altieri et al. 2015; Ewing et al. 2023). Discussions about agriculture and soil go hand in hand, and this thesis draws attention to soil stewardship within agroecology that supports sovereignty and communities of care.

Food is the center of culture, and many agricultural projects in or near BernCo are important sources of community celebration and collective care. Especially amidst increasing times of crisis, local producers play a key role in providing sustenance for communities. The COVID-19 global shutdown in 2020 displayed the resilience of New Mexico's regional food system by providing nutritious, ethical foods to the people. The land and soil stewardship of local growers over the years has contributed to communities and economies of care that so many depended on in light of the most recent global crisis. The proliferation of Mutual Aid and CSA (community-supported agriculture) programs at the advent of the shutdown is just one way resilience manifested and communities of care were activated (ABQ Mutual Aid 2023; The Paper Staff 2020; Walker 2020). At the foundation of resilient and responsive agricultural systems is soil (Altieri et al. 2015; Altieri and Toledo 2011), and my research explores one aspect of the local food movement by unpacking values, knowledge, and technologies smallholder producers utilize in soil management in Bernalillo County. Second, this thesis explores the utility of remote sensing data to supplement agroecological methods among smallholder producers in Bernalillo County.

Inspired by political ecology and feminist theory, this thesis asks:

(I) *What values, experiences and knowledge do smallholder producers in Bernalillo County embody in their soil stewardship practices?*

(II) *What experience or knowledge do smallholder producers in Bernalillo County have about remote sensing, and would they use remotely sensed data to understand the impact of their soil stewardship practices?*

Researchers in social, ecological, and Geographic Information Sciences (GIS) are documenting the impacts of agroecology around the globe (Altieri et al. 2015; Clinton et al. 2018; Stratton, Kuhl, and Blesh 2020). Stakeholders have significant interest in understanding the geospatial relationships of soil to vegetation and surrounding environments in general (Snapp 2022; Symochko, Hoxha, and Bayoumi Hamuda 2021; Wulf et al. 2014). The remote sensing process is the systematic procedure of identifying a question, collecting in-situ and remote sensing (RS) data, and then converting that data into presentable information (Jensen 2016). Remote sensing technologies, which includes "proximal" instruments used in the field, have been used widely to understand soil indicators in agricultural and environmental systems (Breure et al. 2022; Hamada et al. 2014; Maynard and Levi 2017; Wulf et al. 2014), and could be helpful to smallholder producers in Bernalillo County (BernCo). This thesis explores the potential of using the remote sensing process for smallholder farmers to analyze their soil health, within the context of agroecological stewardship.

Qualitative methods were used to gather data on producer values, knowledge, and soil management methods. These data help gauge participant use of different soil testing methods for understanding soil health on agroecological farms. This is important because producers face complex institutional, political, environmental challenges to grow a bountiful local food system. I argue that the producers who participated in this study have a deep sense of responsibility to develop communities of care and build towards food sovereignty through their agricultural work. I find that their embodied experiences and knowledge about soil in their agricultural plots is technical, holistic, and invaluable to growing highly nutritious foods and building resilient ecosystems. Secondarily, I argue that there are significant opportunities to utilize remote sensing technology for analyzing the impacts of smallholder stewardship practices on soil health.

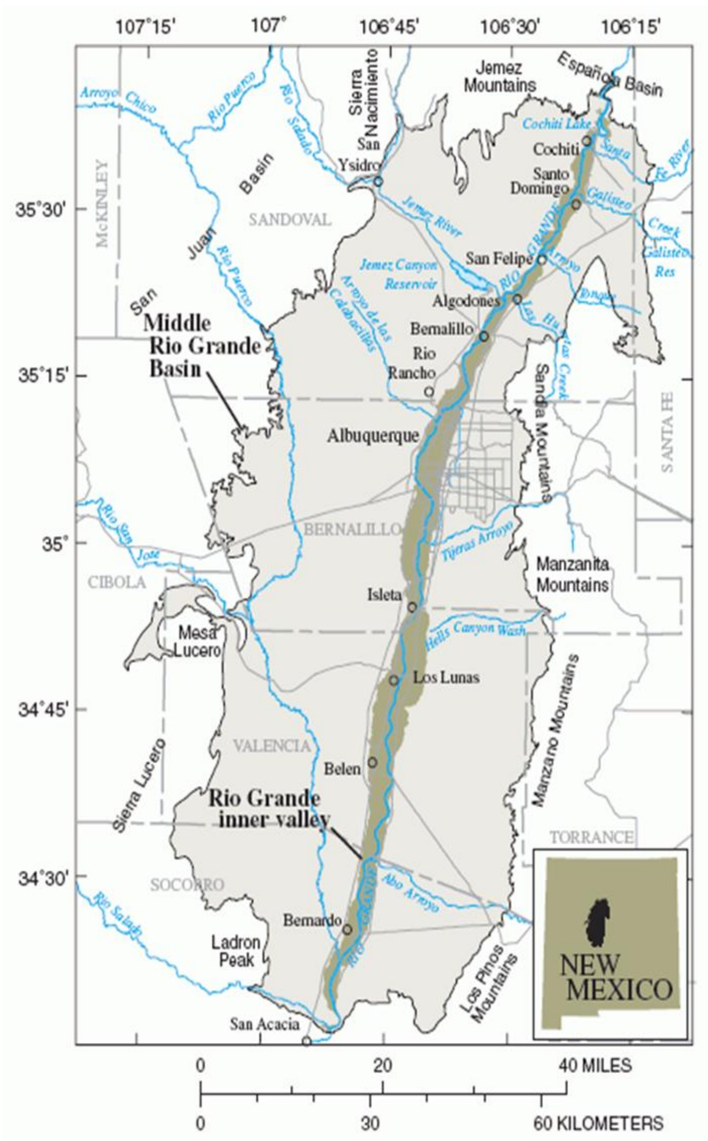

Figure 1.1. A map of the Rio Grande Basin, spanning across Sandoval, Bernalillo, Valencia, and Socorro counties from North to South (U.S. Geological Survey 2024).

1.1 Background

This research focuses on the soil management practices of smallholder farmers in Bernalillo County which spans 1,161 square miles, with elevation ranging from 1,500 meters (4,950 ft.) in the valley to over 2,100 meters (6,700 ft.) at the base of the mountains. The county encompasses part of the Middle Rio Grande Basin, with the Rio Grande River passing from North to South through the center of the county (figure 1.1). According to 2022 Census Data, the total population is 672,508 people, with approximately 50% female and 50% male individuals. Approximately 51% of the population is reported as Hispanic or Latino, 36% as White, 7% as American Indian and Alaska Native, and 4% as Black or African American. Slightly higher than the state average, in Bernalillo County 62% of the population is 18 to 64 years old, and 18% are 65 and older (U.S. Census Bureau 2022).

According to the 2022 Census of Agriculture, Bernalillo County has a reported 964 farms, with 1,730 total producers. In the Census, “producers” includes farmers who grow livestock, livestock feed, food for human consumption, Christmas trees, and more. Nearly 56% of those producers are male, and 44% are female. The average age of producers is 58.7 years, with the largest age group represented being 65 to 74 at 28%, and second largest age group being 55 to 64 at 23%. Non-White Hispanics were not distinguished from Hispanic, but the largest represented group is 1,537 White producers, and the second largest group is 692 Hispanic producers. Additionally, there are a reported 149 American Indian or Alaska Native producers, 11 Asian producers, 10 Black or African American producers, and 23 producers who reported more than one race (U.S. Census Bureau 2022).

This Census also captures plot dynamics relevant to this study. The median size of farms is 4 acres in Bernalillo County, 698 farms are 1-9 acres, and 136 farms are 10-49 acres. In this study, the average size of farms in this study is 3 acres, with the largest farm reported at 16 acres. According to the Census, a reported 119 farms harvested vegetables for sale comprising of over 50 reported cultivars (i.e., various muskmelons, berries, beans, etc.). Additionally, there are data about machinery and other agricultural inputs such as fertilizer, rototiller or “no-till” usage.

1.2 Road map

The following chapter describes how agroecology is both a movement and a practice. Political ecology and feminist theory help outline how agroecological projects around the globe are stewarded by smallholder farmers who embody complex and technical stewardship practices. I review the political economic roots of Critical Agrarian Studies (CAS) and Science and Technology Studies (STS) which informs a historical lineage and discussion about power dynamics and the situated experiences of smallholder farmers, and agrarian technologies.

These theoretical frameworks also guide the placement of this research within a body of literature that contemplates the politics of human-nature binaries and scale in GIS research. By challenging human-nature binaries, this thesis unpacks how agroecological farmers in this study align with feminist goals to value more-than-human beings and build communities of care. This discussion is important because CAS and STS call for researchers in Geographic Information Sciences (GIS) to value the situated knowledge of smallholder, peasant, and indigenous farmers. The theoretical frameworks, and research in CAS and STS, then inform my review of studies that examine soil and vegetation dynamics relevant to examining smallholder agricultural plots.

Chapter 3 of this thesis describe how CAS and STS inform my approach to gathering qualitative data. A systematic review of current soil health resources informed the development process of the questionnaire. Participant responses and field notes serve to ground-truth what I might see in remotely sensed imagery of a smallholder plot. The rest of the methods chapter describes the process for developing and deploying the questionnaire. A retroductive approach to coding questionnaire responses which me to highlight political ecological, feminist, and agroecological themes in participant responses. Throughout the coding process, information that could support the remote sensing process is discussed in the results chapter.

Chapter 4 incorporates discussion throughout the reporting the results. This is because the vast amount of data captured by the questionnaire is best conveyed by connecting paticipant responses to specific themes related to theory and applied practice. The first set of results discusses participant values related to agriculture and soil. They also describe their embodied technical knowledge about soil, while building communities and economies of care through stewardship. The second set of results reports on participant's familiarity with and openness to using the remote sensing process to understand their soil health. Lastly, this chapter describes how situated knowledge about plot design should be considered by a researcher when examining remotely sensed imagery.

The final chapter concludes my thesis, and reasserts my findings and arguments. I find that the producers in this study are driven by a deep sense of responsibility to care for their communities and the ecosystem through their stewardship. Producer values and beliefs inform how they manage their plots, and they embody a unique agroecological methodology. They are open to using the remote sensing process to understand their soil health, and the indicators they care most about can likely be detected in remotely sensed imagery. There is great potential for researchers to understand the impacts of smallholder methods on soil health using the remote sensing process.

CHAPTER 2: Theoretical framework and literature review

This chapter contributes to a foundation for understanding how smallholder food producers in New Mexico build communities of care and food sovereignty from the ground up. This thesis acknowledges the value of farmer knowledge and techniques as an equally important data source in a remote sensing study. I draw on political ecology, feminist theory, and critical agrarian studies to examine dynamics of power, knowledge, and the value of Geographic Information Sciences (GIS) and remote sensing (RS) technologies in agricultural research. These frameworks helped prioritize the lived experiences, embodied knowledge, and more-than-human actors of the agrarian community in this study.

The social movement and practice (or praxis) of agroecology is an umbrella, which I argue embraces the same goals of critical agrarian studies (CAS), feminism, and political ecology. Political ecological concepts are useful to explore the dynamics of power in remote sensing research, and (separately) agriculture and soil management in Bernalillo County (BernCo). The acknowledgment and valuing of other living things in an agroecological system is complemented by more-than-human concepts in feminist theory. Lastly, I argue that the politics and science of agroecology uplift a vibrant movement of smallholder food producers in New Mexico who embody essential knowledge, techniques, and communities of care. Their embodied knowledge about soil and stewardship practices is central to managing unique agroecological systems. The physical impact of these values and practices on soil health and climate resiliency is potentially measurable using remote sensing technology.

2.1 Political economy and technology

Critical agrarian studies (CAS) and Science and Technology Studies (STS) provide valuable tools for discussing agroecology as both a social movement and practice. Following a political economic lineage of Karl Marx (1887) and Karl Polanyi (1944), my research takes place in the context of a region the traditional communities of New Mexico were subject to land enclosure, privatization, and agrarian displacement. This lineage manifests as a part of the global modernity-coloniality (MC) project for the imagined "Latin" region of today's Southwest United States (Escobar 2007; Gómez 2018; Mignolo 2005; Van Sant, Milligan, and Mollett 2021). Mignolo (2005) is critical of European colonial powers because "the achievements of modernity go hand in hand with the violence of coloniality," (5). This means that colonial efforts to "Modernize" communities around the world are inherently violent. Most obviously the violence is seen through war, but these tactics include systematic displacement of peoples from their lands and cultures.

The theoretical lineage in this thesis transitions from *political economy* to *political ecology* in agricultural research. Colonial societies in South America and elsewhere sought to devalue the land and its inhabitants which resulted in the undermining and co-optation of agrarian livelihood (Graddy-Lovelace 2018; Nehring 2021). For example, the Green Revolution (GR) is an MC project, and a vehicle for neoliberal market incentives (Moseley 2017). The GR as a project looks to artificial and highly-mechanized technologies as the best hope to feed the world's hungry, without valuing the tools and technologies of traditional agrarian communities (Hall 2013; Moseley 2017; Moseley and Ouedraogo 2022; Navdanya 2020). In part, the GR is characterized by World War II warfare chemicals which were refurbished as chemical inputs for agricultural management. These artificial herbicides, pesticides, and fertilizers are detrimental to soil ecosystems, and the health of people who work with them (Gunstone et al. 2021; Shahid and Khan 2022). On the other hand, traditional agricultural techniques like companion planting, cover-cropping, and crop-livestock rotation are just a few technologies shown to improve soil health, soil and crop resiliency, and higher resistance to climate disasters (Altieri et al. 2015; Altieri and Toledo 2011).

With Marxist and anti-colonial roots, CAS disrupts traditional understandings of how science and technology have been used to establish and maintain exploitative and extractive colonial systems over land-based communities (Nehring 2021). Frameworks using CAS facilitate a transition from a Eurocentric Science and Technology Studies, to a post-colonial one. This transition centers the "lived experiences" of agrarian communities and questions the legitimization of external knowledge or authority about agrarianism (Nehring 2021). This context allows the agrarian knowledge and techniques to hold utility and value equal to "Modern" technologies. For this thesis, the theoretical frameworks above unpack the entangled histories of traditional agrarian communities in the face of colonization. This admission is important because agroecology explicitly values the knowledge and technologies embedded in agrarian practices in the field.

2.2 Political ecology, Geographic Information Sciences, and remote sensing

This thesis considers how remote sensing technologies can support agroecological goals. Therefore, it is important to consider the socio-political history of remote sensing technologies. A foundational review of literature by McCusker and Weiner (2003) describes how political ecological questions are essential to GIS and RS research. They argue that "GIS has its roots in land information systems and produces representations of nature that shape how environmental resources are perceived, controlled, and exploited," (201). They examine the linkages between GIS and political ecology by reviewing how spatial resolution and politics cause differing and contradictory interpretations. Additionally, participatory field work can help merge political ecology and GIS by increasing awareness of the socio-political circumstances impacting the visible outcomes in a particular community (McCusker and Weiner 2003). In this thesis, a political ecology framework helps me understand spatial and scale-dependent dynamics impacting smallholder access to land and technology in my study area.

Figure 2.1 A pilot and photographer from the U.S. Navy mounted on an airplane in 1914. "This photograph illustrates difficulties encountered in early efforts to match the camera with the airplane-- neither is well-suited for use with the other." (Campbell and Wynne 2011).

The political ecological lineage of remote sensing is explored in this thesis by building from Michel Foucault's *Discipline and Punishment: The Birth of the Prison* (1975). I question the widespread dissemination of remote sensing technologies as a tool for surveillance and violence. Remote sensing involves capturing an image and interpreting the visible characteristics, which has its roots in early photography. The use of remote sensing is traced back to 1858, when early photography equipment was attached to balloons, and the field was further developed in 1909 by equipping airplanes with cameras to capture imagery as shown in figure 2.1 (Campbell and Wynn 2011). The proliferation of RS imagery, and technological development of aerial photography can be credited to World War I (1914-1918), when "The value of aerial photography for military reconnaissance and surveillance became increasingly clear… and its applications became increasingly sophisticated" (Campbell and Wynne 2011, 8).

An important milestone of RS for civilian use in agriculture was the use of color infrared film for crop detection. The imagery technique, developed for use in WW2 as "camouflage detection film," was applied by Robert Colwell to detect diseases in crops in the 1950s (Campbell and Wynne 2011). I've centered the historical development of RS technologies in this research to examine its legacy and impacts within New Mexico, a place long characterized by its history of violent U.S. military and settler occupation (Gómez 2018; Lane n.d.).

In GIS and RS, researchers might succumb to the "god-trick", overlooking situated knowledge of humans and other actors on the ground (Haraway 1988). To avoid such erasure, a researcher must be critical of conventional data production and analysis in human-ecological and environmental research which often overlooks local human actors in their study areas (Turner 2003; Turner and Taylor 2003; Pritchard et al. 2022). These fields of research are relevant because agricultural plots are sites where humans interact with their surrounding environments, especially within agroecological systems. In-situ data from local knowledge holders and land stewards can contribute to rigor by verifying big data covering vast scopes, typically with a low spatial resolution (Kelley 2020). In the methods and results I will continue to unpack how the values, embodied knowledge, and soil management techniques of the participants in my study are valuable for inclusion in a mixed-methods RS project.

2.3 Towards an agroecological lineage in New Mexico

A significant body of literature establishes global grassroots agroecology as a movement by agrarian communities for land, water, and food sovereignty. Simultaneously, it values agrarian technologies as sustainable, resilient, and productive agricultural management methods. I align historical and contemporary agrarian projects in New Mexico to global agroecological movements because "Rural organizations and peasantries around the world share the same global problems even though they confront different local and national realities," (Martínez-Torres and Rosset 2010, 150). This section briefly reviews how agrarian communities in the region have been subjected to modernity colonial projects since statehood, in the context of historical conversation and agricultural initiatives. Despite the legacy of modernity coloniality projects on land and water that still resonate with smallholder producers today, they continue to work towards restoring soil, resilience, and rebuilding sovereignty. This lineage is important to questions of technology in my thesis because remote sensing has been widely used for land-use development and in conservation research. Additionally, the field of research has not yet deciphered the impacts of smallholder food-growers in an accessible and comprehensive manner.

Alex Loftus (2017) asks, "Where is Political Ecology?," and seeks to understand how researchers might decenter Eurocentric political ecology to challenge the reproduction of colonial research. Inspired by agroecological praxis, this research takes a de-colonial approach through acknowledging the agroecological knowledge and technologies of smallholder producers in this study. Within political ecology and Science and Technology Studies, "Actor-Network-Theory" (ANT) facilitates discourse about human-environment interactions, and the impact that humans have had on their surrounding ecosystems. Although ANT is used widely in academic theory, it lacks robust, critical application for valuing agroecological goals and technologies. Critics of ANT argue that the theory centers humans, contributes to Enlightenment-era binaries that humans are separate from their surrounding environment, and frequently serves neoliberal conservation policies (Benson 2019; Lave

2015). New materialist, feminist, and more-than-human theories are better aligned with political ecological commitments (Lave 2015), and therefore agroecology is a fitting framework for this study.

Lave (2020) looks towards theoretical frameworks such as new materialism and feminism to embrace a more holistic definition of human-nature interactions. New materialism is described as the "more complex and relational perspective" of one's lived experiences, and extends agency beyond human actors (Benson 2019). Social-ecological systems (SES) is used to describe the "environmental challenges, and the concept of system resilience is now often referred to when identifying environment and natural resource management goals," (Benson 2019, 261). Social-ecological systems is a fitting phrase that can be used to describe agroecological systems as spaces where humans interact, adapt to, and support soil environments to grow food for sustenance or otherwise. A more critical political ecology is useful because it speaks truth to the power of agrarian communities and the natural ecosystems they are embedded within. Tracing the history of agroecology projects in New Mexico, can facilitate a de-colonial understanding of land relations. Donna Haraway's concepts of situated knowledge, natureculture, and more-than-human beings (1988; 2003) helps articulate the land and soil stewardship practices fostered by smallholder farmers. The embodied agroecological knowledge of farmers holds power because they steward a system that provides sustenance to human and wild communities alike. In this thesis, agroecology inextricably connects the communities of care and more-than-human valuing to technical questions about soil management and analysis.

2.4 Agrarianism in New Mexico and agroecology

The term "agroecology" was coined and popularized in response to the advent of modern industrial agriculture after World War II from the "margins of Western ecological science," (Figueroa-Helland, Thomas, and Aguilera 2018, 181). Agroecology has been reclaimed by peasant farmers and agrarian communities world-wide because it describes a way of life that has been practiced for thousands of years (Martínez-Torres and Rosset 2010). Agroecology is now recognized internationally as a promising path towards ecological restoration, sovereignty (Figueroa-Helland, Thomas, and Aguilera 2018; Fixing Food 2018), and soil restoration (Altieri and Toledo 2011). A significant body of literature has been published on the traditional agricultural practices and values of communities in New Mexico, especially in relation to "querencia" (a deep sense of place and love for one's land) (Fisher 2008; Fonseca-Chávez, Romero, and Herrera 2020), acequia governance, and sovereignty (Arellano 1997; Jaramillo 2020; Lamadrid and Rivera 2023; Rodríguez 2006; Romero 2021). The historical and contemporary embeddedness of sovereignty and collectivism in New Mexico is essential because they demonstrate what agroecology scholars consider as important values to agroecological movements (Altieri and Toledo 2011; Figueroa-Helland, Thomas, and Aguilera 2018).

The specific term "agroecology" has scarcely been used in published research about this region. Gregory Cajete and Devon G. Peña are foundational authors researching and publishing on indigenous and chicane ecologies, traditional ecological knowledge (TEK), and agricultural practices. Gregory Cajete's "A People's Ecology: Explorations in Sustainable Living," (1999) is a collection of essays about traditional ecological knowledge (TEK) and ecological politics from indigenous pueblo perspectives in the New Mexico region. This collection explores themes relevant to agroecology such as TEK, the impacts of food ways on health, environment and culture, and the impact of colonization on human relationships with the land (Cajete 1999). Devon G. Peña's "Chicano Culture, Ecology and Politics: Subversive Kin " (1998) is another collection of essays commenting on land development, conservation and agriculture, and contains one of the earliest uses of the term *agroecology* in literature about New Mexico. In his own essay, Peña describes a political ecological lineage in the context of agrarian resilience throughout waves of modernization and development. His analysis on bioregionalism (how human and their unique surrounding environment impact one another) bridges the gap between ecological and cultural studies in the Río Arriba watershed regions of Northern New Mexico. These frameworks "legitimize the regenerative capacities inherent in the traditional ethnic folkways," (Peña 1999, p.41). These authors align with grassroots and academic discourse about agroecology values and technologies worldwide.

Sundberg et al (2020) examines four points of origin of the nature-culture dichotomy- patriarchy, colonialism, Modern epistemologies, and colonial-capitalist economies. She describes how *encounters* and *institutions* implement and perpetuate the dichotomy, referred to as "technologies of power," (Sundberg, Dempsey, and Marchini 2020). Benson (2019) writes that "This belief— that humans are separate from and doing things to nature—is an ontological stance that is embedded within the environmental and natural resource laws of the United States," (252). These methods and technologies are also referred to by Haraway (2003), as means to train, control, and dominate other non-European, non-white people, and all other living beings (Haraway 2003). Concluding the Mexican-American War in 1848, the Treaty of Guadalupe-Hidalgo marked the end of communally held land and the beginning of a 64-year territorial period. During this time the United States strategically displaced traditional and indigenous communities until they had enough land and white settlers to allow New Mexico to become a state in 1912 (Gómez 2018). This journey into statehood marks more rigorous interventions in land, water, and agricultural management (Benson 2019; Lane n.d.) to "tame" the landscape, its peoples, and advance the separation of nature from culture.

Figure 2.2 A photo of farmworkers on a large harvest tractor. The author notes wrote, "trainees [are] performing separate functions of seed bed preparation. Assigned trainees compute the amount of fertilizer, seed rate and essentials for operation... each trainee operates each phase from cost to market." (Aberle n.d.)

United States environmental management enforced the separation of nature from human, and collective societies. Maria Lane (n.d.) details the process by which "Progressive" politics shaped resource conservation initiatives in the U.S., based on principles of "rational, expert control" (7). This becomes evident in agricultural extension programs, which provided valuable resources to rural communities, yet worked to transition farmers away from growing sustenance crops to market-driven commodities such as feed for livestock, pecans, chile peppers, and cotton (Aberle n.d.). Sophie D. Aberle's archival collection demonstrates these initiatives in Navajo Nation, Zuni, and other pueblos, showing how conservation and extension offices provided training programs for farmers to introduce them to new technologies for managing their crops. These technologies included agrichemicals, machinery, and other capital. Feminist political ecology examines “the relationship between forms of oppression and domination of nature,” (Sundberg 2017), which is demonstrated in historical initiatives for agricultural and environmental management in New Mexico. In addition to general political efforts to displace traditional and indigenous communities from the land, these agricultural “Modernization” initiatives contributed to the disempowerment of agrarian communities throughout the region. This context is important to keep in mind as I propose yet another “modern” technology in the form of remote sensing, to examine the practices of smallholder food-producers growing for sovereignty and a sustainable environment.

2.5 Embodied knowledge, stewardship and more-than human relationships

I return to feminist frameworks that contribute to uplifting and valuing the embodied

Figure 2.3 Photos show the preparation (left) and irrigation of land (middle), and end results (right). The author notes wrote, "Trainees performing separate functions of seed bed preparation. Assigned trainees compute the amount of fertilizer, seed rate and essentials for operation... each trainee operates each phase from cost to market." (Aberle n.d.)

knowledge of smallholder producers in this thesis. In “Situated Knowledges” (1988), Haraway says that objectivity is impossible to achieve, and that every type of knowledge, everywhere, is situated. Haraway uses feminism to challenge the “abstract masculinity” of theories such as Modernity and Marxism because they dichotomize and create false objectivity. Blind trust in western science’s objectivity enables the “god-trick” (582) and encourages transcendence and superiority of the researcher using a "theory of innocent power to represent the world" (580). She argues that knowledge is embodied because the world is experienced through a combination of our senses so we will always be partial. Haraway presents a new kind of objectivity- "Feminist objectivity means quite simply situated knowledges" (581). This kind of objectivity challenges the historical and contemporary "conquering gaze" of Western science which divides, subjugates, and fetishizes. This analysis insists that I value the embodied knowledge of human and non-human subjects in my study as actors, and not just passive agents.

I argue that agroecological projects are a form of research and decolonial action (Smith 1999). This research recognizes how smallholder agroecological farmers work to build communities of care through agroecology- below and above ground. Producers are simultaneously facilitating the growth of more-than-human actors within the soil, plants and fauna within the agro-ecosystem, and humans within their community (Dombroski, Healy, and McKinnon 2018; Graddy-Lovelace 2018). In examining the care work involved in breeding and cultivating crops, Graddy-Lovelace (2018, 238) emphasizes the importance of acknowledging care that may be hidden in technological discussions:

> *Tracing the carescapes at work in pre-breeding entails recognising the carework comprising in-field agricultural biodiversity and its intellectual dimensions. From the agronomic perspective, growers have cultivated agrobiodiversity through careful attention to well-being and lack thereof. At the heart of this, attending to plants is tending to them. Driving careful observation is care itself.*

This excerpt eloquently describes the importance of valuing the embodied knowledge and stewardship practices in a research study. In this thesis, agroecological engagement with a more-than-human soil is key to a technically-framed remote sensing question. The stewardship of smallholder farmers builds a resilient foundation of soil for growing nutritious crops in a community of care.

2.6 Detecting the impacts of smallholder methods on soil

Both remote (far) and proximal (near) instruments are used for sensing spectral data at different wavelengths of the electromagnetic spectrum (EMS). “Remote” sensing is conducted typically by aircraft or satellite, or another instrument that is far away from the object under examination. “Proximal” sensing data can be captured using drone instruments, handheld spectrometers, or laboratory spectral instruments (a glossary of terms is included in table 2.1 in the appendix of this thesis). Different types of surfaces on the Earth are detectable because they have a unique spectral reflectance- with water, soil, and vegetation being some of the most significant to agriculture (figure 2.4). In the scope of agricultural

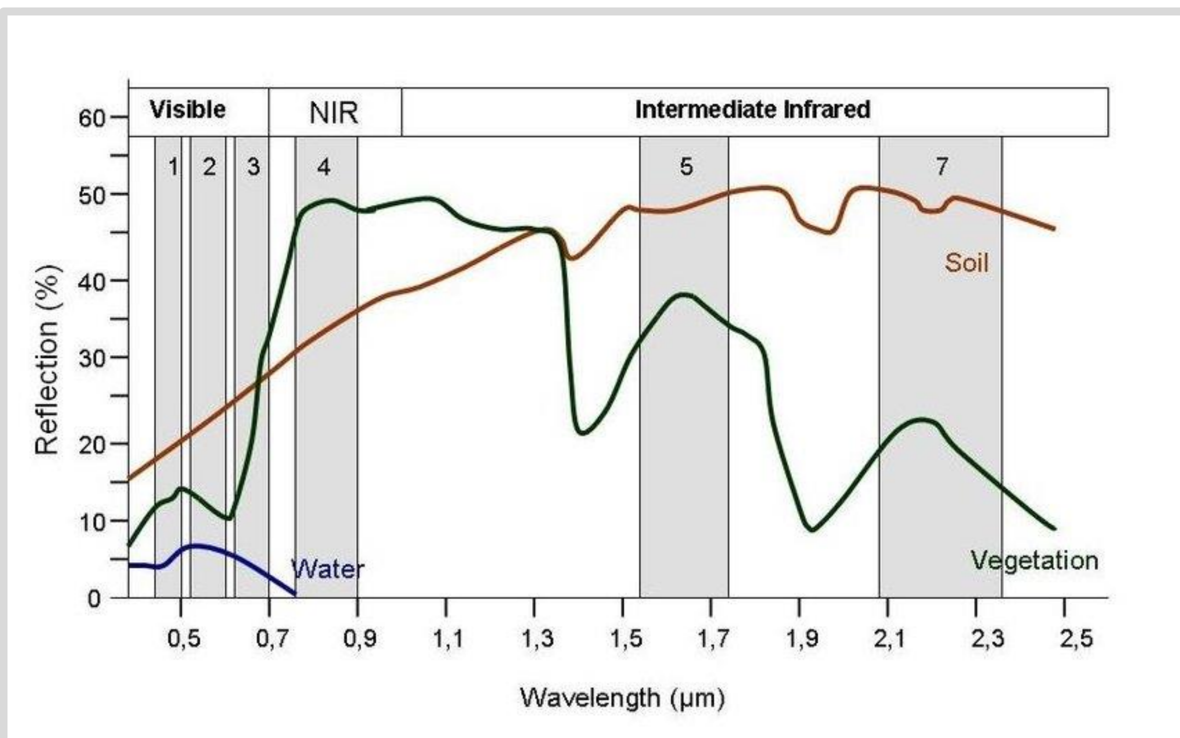

Figure 2.4 The typical reflectance spectra of water, soil, and vegetation with highlights indicating the band availability from Landsat 7 (Siegmund and Menz 2005).

research, both remote and proximal instruments have been used at all scales to detect crop and soil properties (Wulf et al. 2014). Proximal sensing instruments, laboratory analysis of soil (Bhattacharyya et al. 2014; Gogé et al. 2014; Ji et al. 2016; Maynard and Levi 2017), as well as qualitative data from human actors on-site (Kelley 2020), can serve to ground-truth data from remotely-sensed imagery. Mixed-methods which incorporate qualitative data in the form of farmer knowledge, is essential in agroecological research and for understanding the impact of farmer practices and ground-truthing remotely sensed imagery.

Previous research in Geographic Information Sciences (GIS) and remote sensing (RS) has examined rural and urban agriculture in relation to land development (Clinton et al. 2018; Eckert 2011; Kelley 2020; Mueller-Warrant et al. 2015), a variety of soil health indicators, soil-plant interactions in natural environments (Angelopoulou et al. 2019; Breure et al. 2022; Hamada et al. 2014; Rozenstein and Adamowski 2017; Maynard and Levi 2017), and to distinguish agricultural activity in and around urbanized areas (M. E. Brown and McCarty 2017; Browning and Steele 2013; Forster, Buehler, and Kellenberger 2009; Saha and Eckelman 2017). Relevant models and statistical analyses are found in studies related to human-environmental and ecosystem research (Turner and Taylor 2003), or that examine agriculture at regional scales (Jordan and Barroll 2013; Verma et al. 2014). Researchers have also examined vegetation cover productivity relative to grazing techniques on agricultural pasture lands (Turner 2003). In publications on urban agriculture, researchers focus on detecting vegetation cover for agricultural land change and land use (LCLU) (Eckert 2011; Mueller-Warrant et al. 2015; Turner 2003). Many of the urban agriculture studies may be useful for this thesis because they test classification models for complex landscapes, although they do not examine soil health.

Digital soil mapping (DSM), as described by Wulf et al. (2014), is the breadth of research on "the creation and population of spatial soil information [using] field and laboratory observational methods, coupled with spatial and non-spatial soil inference systems." (10). Remote sensing data on crop and soil dynamics can supplement DSMs using vegetative proxies and specific spectral signatures of soil based on color (related to moisture and SOM), mineral content, texture, and more as shown in figure 2.5 (Wulf et al. 2014). Other studies compare methods that use laboratory testing of soil samples to ground-truth remote or proximal spectral data (Dehaan and Taylor 2002; Gogé et al. 2014), verify the impact of specific nutrients to spatial variability of soil (Foroughifar et al. 2013), and links vegetation conditions to soil functioning (Hamada et al. 2014; Maynard and Levi 2017; Schaaf et al. 2011). These types of studies are all relevant to developing a research design that supports producer interest in holistic indicators of physical, chemical, and biological measures of their soil using the remote sensing process.

In New Mexico, remote sensing studies have been limited to the analysis of vegetation dynamics in arid landscapes (Ritchie et al. 2001), or the analyses urban sprawl development feasibility (Bajracharya, Lippitt, and Sultana 2020). One unpublished study used mixed-methods to examine the heating effect of agricultural land loss due to urbanization from 1990 through 2010 in a South Valley Community (Griggs et al. n.d.). To the best of my knowledge, there are no studies examining the impact of soil stewardship practices by smallholder farmers in the state utilizing GIS and RS tools. Researchers utilizing RS instruments must always consider tradeoffs in resolution and cost. No research designs are simultaneously high spatial, temporal, and spectral resolutions and utilizing low-cost or free imagery. Literature on RS for vegetation and soil monitoring shows that there are many useful methods applicable to a study examining soil conditions of smallholder farms.

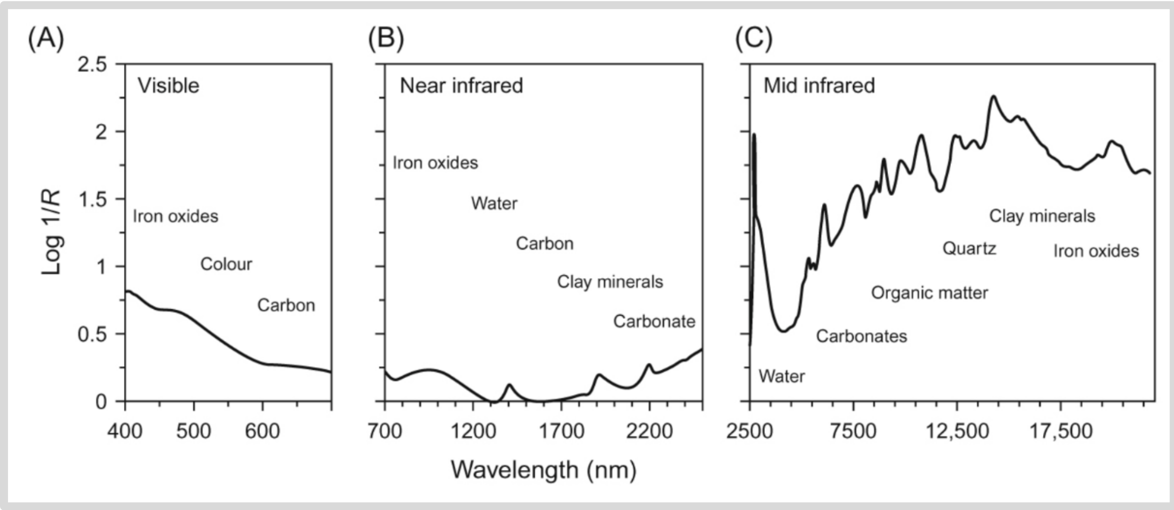

Figure 2.5 The signatures of particular soil indicators along the electromagnetic spectrum (EMS) from the (A) visible (vis), (B) near-infrared (NIR), and (C) mid-infrared (mid-IR) [Viscarra Rossel et al., 2011] (Wulf et al. 2014)

CHAPTER 3: Methods

This thesis deploys a questionnaire to smallholder food producers in Bernalillo County to collect data on their agricultural and soil values, management techniques, experiences with soil testing, and familiarity with GIS and RS. The term “producers” targets individuals who are growing crops or livestock for the purpose of selling at a market. *Producer* also captures the variety of smallholders selling sustenance products like dairy, meat, fruits, vegetables and medicines. Each section of the questionnaire has open and closed-ended questions that allow respondents to elaborate on certain topics and verify their responses. In developing the questionnaire I avoided jargon and defined terms (McGuirk and O’Neill 2021) like food insecurity, companion planting, and precision agriculture. First, a systematic review of soil health resources in Bernalillo County was carried out via internet searches, email correspondences, social media, phone calls, and video calls. Major service providers were contacted, including New Mexico State University (NMSU) and Bernalillo County’s local extension agent, Ciudad Soil and Water Conservation District, Middle Rio Grande Conservancy District, and the New Mexico Soil Health Working Group. This background information was helpful to understand the dynamics that farmers are faced with when seeking out resources to manage their soil. The results of this systematic investigation are detailed further in appendix B.

3.1 Questionnaire design

Part one of the questionnaire is dedicated to respondent demographics and general information. These questions help describe who the participants are within the farming community, and what they grow. I ask what values and motivations drive them to participate in agriculture, and what mainstream practices they identify with. Part two focuses on the embodied soil values, knowledge, and stewardship of producers. Questions prompt the participants ecological, chemical, and biological knowledge about soil. They draw out the technical knowledge and techniques the participants use in their practice. Participants are prompted to describe the physical senses they use to engage with the soil. Part three aims to understand what resources are useful and important to participants. Participants were asked to share their experiences with collecting soil samples and sending them to laboratories, or about their experiences with soil testing kits. Respondents could select "other" as a way to elaborate on additional creative analytical techniques they use. This section also serves to investigate the accessibility and utility of soil testing resources, and familiarity with remote sensing technologies.

In the questionnaire, inquiries about soil health priorities and techniques were separate from questions about remote sensing. This design choice was to avoid limiting participant responses based on their own assumptions of what they know about RS (or not). For example, if I were to ask, "how likely would you be to utilize remote sensing to analyze the soil texture of your plot?" they may have been hesitant to respond a certain way because they did not know what is possible. Woven throughout each section are opportunities to capture the creative and technical ways respondents are engaging with their agricultural and soil systems, and simultaneously informing what we might expect to see on producer plots in high-resolution imagery. Agricultural design, crop choice, and farm infrastructure influence the physical, biological, and chemical conditions of soil. For example, if a respondent uses permaculture and low-till methods, I might expect to find crop spectral reflectance of annual and perennial crop types (within the same pixel), and few instances of freshly-exposed soils.

3.2 Questionnaire deployment and field work

I drafted the questionnaire and recruitment materials, which included a flier, a written script to be used in person and via email. The UNM Institutional Review Board approved the proposal for a minimal-risk project involving human subjects. The questionnaire was open for seven months starting in February 2023 and closed the following September. I limited my recruitment efforts to Bernalillo County to minimize the distance for potential travel, and to analyze my data in the context of agriculture in this region. Since I have broad inclusion criteria, to screen participants via e-messaging or in person I asked, "Is your production farm in Bernalillo County?" If their answer was yes, I asked them, “Are you willing to complete a questionnaire about farmers in Bernalillo County, and your experiences with soil management and testing?” If they fit into my criteria, I proceeded with the informed consent process and options for physically completing the questionnaire. Informed consent was also included as the first section in the questionnaire.

To recruit potential participants I made contact through community events, telephone, and electronic messaging platforms. The first attempt to recruit farmers was using emails from online vendor lists (i.e., farmersmarketsnm.org). I contacted colleagues with well-established listservs of farmers, for example my questionnaire was shared by Bernalillo County’s local agricultural resource specialist, and the Rio Grande Community Farm network of growers. Next, I attended several local farmers markets, sometimes more than once. These were the Cedar Crest Farmers Market, Downtown Growers Market, Rail Yards Market, and La Familia Growers Market. I approached farmers at community events, such as a garden opening event at Project Feed the Hood Community Garden, and an Acequia Talk and Walk event by the Center for Social Sustainable Systems. At these moments, I invited producers to participate and gave them the Google Forms link or a physical copy of the questionnaire. I limited my recruitment attempts to two follow-up invitations if people did not respond with interest in the study. Respondents consented to participate in my research by continuing the questionnaire, and they were offered a $15 Visa gift card upon completion. With permission from the respondent, I mailed them the gift card or met them in person at an agreed upon location. The questionnaire was available via Google Form online or as a paper copy. Only one respondent requested a paper copy.

Field work occurred in the form of conversations with farmers during recruitment and when meeting someone to deliver a gift card. After the visits I wrote field notes about our conversations (Emerson, Fretz, and Shaw 2011). I wrote about individuals who voluntarily (often enthusiastically) shared their work to restore soil, or experiences with soil testing. If I met a participant at a farm, I took notes on their farm design like when I saw hoop houses, cloth row covers, mulched pathways and rows, cover crops, or companion planting. I recruited a total of 32 individuals through farmers markets, the market websites, attending community events, and snowball sampling.

3.3 Questionnaire analysis

This questionnaire was analyzed through systematic coding. Coding can help explore data, organize information, and pinpoint key themes in participant responses (Cope 2021). I used a *retroductive* approach to analyzing questionnaire responses through coding. This means that I had a preconceived theoretical framework (deductive), but the responses also shape my approach (inductive) to how I ultimately relate my codes to theory (Emerson, Fretz, and Shaw 2011). I used descriptive and analytical codes to analyze participant responses. Descriptive codes are one way for identifying the actions, experiences, or emotions of the participants in this study (Waitt 2021). For example, I use descriptive codes to notate when producers are using their physical senses (sight, taste, touch, etc.) to observe their soil. The descriptive codes in this analysis serve to build my argument about the embodied knowledge and experiences of study participants. When using analytical codes, I notate an abstraction of what a participant is saying in the response (Emerson, Fretz, and Shaw 2011). An example of an analytical code is notating “more-than-human” when a participant relates their self to plants or soil. These specifics of the coding process are important because it ensures rigor in the analysis of qualitative data (Cope 2021).

Data was compiled via automatic download on Google Forms into an excel document. I coded each question individually by hand for both descriptive and analytical information (Cope 2021; Waitt 2021). The codes used in this study are listed in table 3.1 in the appendix. There is significant thematic overlap between individual codes, so although “more-than-human” is placed under “feminist and political ecological values,” it is still an important value to “agroecological commitments,” and aligns with a respondent’s comments on their technical methods for analyzing certain soil indicators.

For the most part, “feminist and political ecological values” highlights instances when respondents describe acts of care, acknowledge the agency of soil and other actants within the agro-ecosystem, or criticize social dynamics of power (such as class) or sovereignty. As discussed in the literature review, agroecology aligns significantly with the aforementioned theoretical frameworks. Using “agroecological commitments” as a larger theme, I code for instances that respondents reflect similar commitments to global agroecology movements. For example, some are against industrial chemical use, and others are concerned for environmental issues or sovereignty. Codes under “technical knowledge” identify when respondents describe their technical expertise and methods for plot and soil management. Soil analysis through personal observation was considered as both embodied knowledge and a technical skill. The last set of codes under “general values” in table 3.1 represent emergent themes when respondents expressed a deep sense of responsibility to the land and society. Writing about their impacts on community or on future generations revealed concerns about society at large.

Several of the participants in this study (N=32) are new farmers with an overall average of 7 years of experience, and one person with 20 years of experience. The average age of participants in this study is 39, with the youngest participant being 18, and the eldest 67. The majority of the participants self-identified as male (~66%), with six female, three nonbinary people, and two who preferred not to answer. Almost half of the participants (~47%) identified as a part of a Hispanic or Latine ethnic group with self-identified descriptions such as Chicane, Latine, Native American, Mexican Indigenous, and American Latino. Participants also identified as White, Caucasian, or European-American heritage (38%), and a few identifying as East Indian, African American, or mixed. The largest groups represented in this data are White and Hispanic. Every single participant reported growing vegetables, with others reporting on fruit, herbs, dairy such as eggs or milk, and three who also produce meat products. Exactly half of the participants farm for at least three seasons out of the year, and nearly the entire other half (~44%) farm year-round for Winter, Spring, Summer and Fall.

These methods used a questionnaire for gathering qualitative data on smallholder farmer values and soil stewardship methods, and gauged farmer perceptions about the utility of remote sensing to support those values and soil health goals. Recruitment efforts targeted primarily at local farmers markets and community-based events introduces a bias in the types of responses collected because these outlets are inherently a gathering space for community-oriented individuals growing food on smaller scales. Farmers growing food or livestock feed may not be involved in these outlets, and thus this research may exclude responses from these types of producers in the County. The study participants do reflect Bernalillo County producers in some ways; for instance, the racial/ethnic and gender make-up of the study participants generally reflect the population of producers in Bernalillo County. However, the farmers included in the study are much younger, on average, than the farmers in Bernalillo County more broadly. This means that this data in this study are more likely to reflect the values and practices of younger, more community-engaged, food producers than the average producer in Bernalillo County. Thus, the results are not strictly representative of all farmers in Bernalillo County and the data must be interpreted in light of this bias.

Nonetheless, the questionnaire captures important data about the stewardship methods of participants in this study and the nature of smallholder plot dynamics. Critical reflexivity, writing memos were also important instruments for documenting interactions with producers and further detailing unique situated knowledges about their plot and soil stewardship. By highlighting producer voices, I acknowledge their experiences, knowledge, and stewardship techniques.

CHAPTER 4: Results

The farmers in this study articulate a dynamic and holistic embodied knowledge of their soils. Using low-tech resources, they are building a holistic understanding of the soils they steward. The data collected from the questionnaire contributes to an empirical foundation for valuing the embodied knowledge and skills of producers in Bernalillo County (BernCo). The results convey agricultural and soil values, techniques for determining soil health, and experiences with testing resources.

In the following section of this chapter, I describe what drives respondents to participate in agriculture and the role of soil in their work. Following, I describe the practices and knowledge respondents use to manage their plots, and how they physically engage with soil. Throughout each section, I incorporate discussion on how participant responses reflect political ecological, feminist, and agroecological concepts. I also draw on the results to understand how incorporating respondent knowledge from this community provides invaluable socio-political context and ground-truthing in an analysis of remotely sensed (RS) imagery.

The producers in this study engage with their soil in holistic and resourceful ways. They work to grow diverse, living soils that support agricultural productivity *and* their communities. Lastly, producers express an understanding of issues related to social and environmental justice issues, and sovereignty. In some instances, I use to the term *methodology*, which helps describe how the beliefs and embodied knowledges influence how producers steward their soil. Producers that comprise this food system are making substantial investments on soil health, local ecosystems, and local communities.

4.1 Why participants engage in agriculture

In this section I report results from questionnaire responses that asked about motivations for engaging in farming. The results show a strong desire to build communities and economies of care, a deep sense of responsibility to a more-than-human ecosystem, and a commitment to justice and sovereignty. I also asked questions about their roles to understand who they are as stakeholders in our local food system. I first present them with a list of popular agricultural movements to identify with.

Respondents identified with an average of four different agricultural practices, and one person identified with all nine practices. Organic management practices were reported by 90%, sustainable by 78%, regenerative by 59%, and permaculture by 47%. Some respondents also selected traditional, agroecology, and food forest. Few report using conventional and agribusiness practices. However, by nature of scale, diversity, and values, these practices are not the same as those employed by corporate agriculture criticized in previous chapters. Most of the named practices refer to significant, popular movements with specific methods related

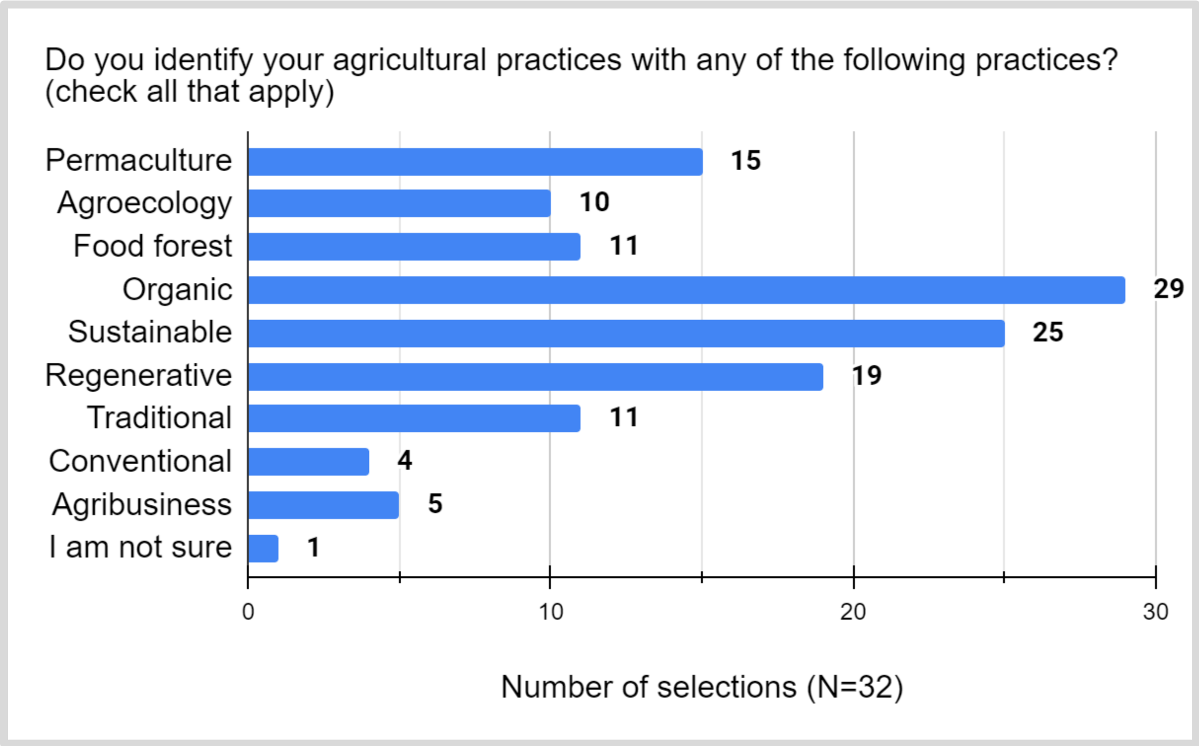

Figure 4.1 A closed-ended question that asked participants to "check all that apply" to their personal identification with various agricultural movements.

to crop and soil management (Figueroa-Helland, Thomas, and Aguilera 2018). The implications of these methods in GIS and RS studies are relayed further in the following sections, but they also suggest that producers farm for a purpose and have goals connected to larger social movements or methodologies.

The following closed and open-ended questions ask about more personal and community-level motivations. Results from both inquiries show that producers in this study are motivated by their values connected to communities of care. An overwhelming 93% reported they participate in agriculture to support food sovereignty, 93% said to support local agriculture, and 84% for food security for others. Roughly 62% of the respondents participate in agriculture for food security for themselves and 41% for economic security for themselves. These statistics are bolstered by open-ended responses to the question, "What values are important to your agricultural work, and why?" Producer 7 wrote about "building a stronger community," and others feel "responsible" to a collective society. Producers also describe this sense of responsibility to the land, planet Earth, "Earth Mother," and the "Creator." Producer 14 wrote that "...community building, relationship building and healing," are values important to their work. Consistent with literature on communities of care (Dombroski, Healy, and McKinnon 2018; Haraway 1988) and agrarian care in particular (Graddy-Lovelace 2018), the majority of respondents in this study want to be a part of a community that takes care of each other and is thriving.

The high number of responses to 'support local agriculture' builds on communities of care, but also elaborates on an economy of care (Dombroski, Healy, and McKinnon 2018). Respondents wrote about participation and sales in local markets, increases in production, creation of jobs, and the state economy. Some respondents reference opportunities for communal production, communal bounty, and equity for workers and consumers. For example, Producer 28 enthusiastically wrote, "Ethics are value! Work delegation and distribution is a value!... Collaboration and cooperation is a value!". Producer 8 describes an economy of care that values life-supporting cycles and systems by "...building our business with reverence for the seasons and balance for our family life." Respondents want to participate in an economic system that values them, their families, and community. Producer 9 wrote they feel obligated to care for the land and society by "...becoming a better, responsible human being who cares for the planet." This sense of ethical responsibility and stewardship of the land is repeated in other responses. For instance, Producer 11 notes that it is essential to, "Save seeds for future generations and healing," and Producer 20 describes agriculture as a resource for "food security, [and] education." As described by Producer 29 in the following quote, agriculture and seeds are sources of sustenance for the respondents and future generations, and each is necessary to building economies and communities of care in Bernalillo County.

> *...to continue our Agricultural Legacy and Culture in New Mexico and pass on those cultural teachings, land, water, and community ways of being to future generations… [I] also [grow] to use our Acequias, fight for water rights for the farmers in New Mexico and teach these cultural ways to our youth and community. [I want] to educate others on how to grow food at their home. To create edible landscapes, training programs, internships, and positions in Bernalillo County that support Agriculture.*
> *-Producer 29*

A recurring theme throughout this section is a sense of responsibility to the more-than-human actants in their agroecosystems, with references to plant and soil actants as companion species. Producer 7 wrote, "When we forget that we're part of the Earth, and think of ourselves as her (and others') masters— we've lost our way. Gardening and farming can be a quick reminder that we are as much a part of the cycles and development of the earth as any earthworm, microbe or other fellow being." The use of words like "harmony" and "communing" by others, emphasizes the reciprocity that respondents seek out at all scales of their agricultural work. Producer 28 wrote, "I value reciprocal and symbiotic relationships! Soil health is a value! Nutritional food is a value! Biodiversity is a value!" The web of actants that respondents reference include nature, the land, plants, animals, and insects, soil, and Earth at large.

An emergent theme was the systems approach respondents take to understand their personal work on an agricultural plot as a single part of a larger system, "Helping the soil and ecosystem I work on, and growing good quality food," wrote Producer 23. References to sustainability are both about longevity, and agricultural efficiency. For Producer 12, "generational health and healing, learning, traditional local culture," are values that drive them. Producer 8 is "...building resilient landscapes, [and] raising my son to understand our deep-rooted agricultural traditions." Another important aspect of systematic approaches is understanding the amount of input required to support that system. Agricultural inputs could include labor, time, synthetic and natural fertilizers, herbicides and pesticides. Several respondents are concerned about the inputs their agricultural system may require, and aim to produce using low-input, low-disturbance, reciprocal practices that are sustainable into future generations. Producer 26 aims, "To produce food on a small-scale using no chemicals and minimum fertilizers with as little fossil fuel footprint and water use as possible…" These are examples of how respondents believe their agricultural practices are a part of a bigger system and society. We begin to see how respondent agricultural values are complex and intertwined with many aspects of their lives.

Another emergent theme included how the producers viewed their agricultural work as foundational to quality nutrition, plot productivity, the ecosystem, and to society itself. Producer 26 wants "to feed nutrient dense high-quality veggies, with equality throughout our community. Fight hunger and nutrient deficiencies, while building immune systems from the ground up." This response is metaphorically and literally referencing just food systems growing from the ground, as the building blocks for growing ethical and nutrient-dense foods. Producer 14 believes their work is important to the soil and an ecosystem that serves society at large by "building soil, giving back to the land more than extraction, [using] low till methods, [supporting] pollinators, community building, relationship building and healing." Lastly, producer 21 feels that a person's ability to relate plant growth and life cycles, "is important for all aspects of life." This theme is important because food is literally foundational to health, and embedded in society and cultures worldwide. The quote from Producer 32 below describes why agriculture is important to their work, community, and future generations.

> *The Land Based Healing and Learning Department at our school pushes to more deeply Indigenize, Decolonize and Localize. Growing our own foods and medicines on campus and having our children involved [in] this process is deeply important in the effort of cultural resurgence and restoring our relationship to the land and ourselves. We also grow medicines on campus because it provides children the opportunity to develop a deeper relationship with the plant medicines. They are working with in class to make teas, salves, compresses, and more…*
> *- Producer 32*

Respondents see their work as connected to issues of social justice and sovereignty. Some respondents reference issues with a critical perspective on power relations, and a concern for social justice. Producer 28 noted that sovereignty is the only resolution to "help food insecurity in less invested areas." Other responses mention food and environmental justice, "fighting" against climate change or corporations, and concerns about racism and classism. Aligning with other critics of capitalism and Modernity (Marx 1887; Latour 1993; Mignolo 2005), the responses above reflect political ecological concerns of power dynamics, and ask the question of who benefits and who bears the burdens of systematic exploitation. This is important because the producers in this study are not only navigating resources and barriers to manage their own agricultural projects, but the food they produce is also distributed through complex systems impacted by class and race dynamics in a market-driven system.

4.2 Knowledge and values about soil

> *Soil is alive and crucial for the work that we do. Soil is the foundation, and the medium to get healthy nutritious healthy crops for our people. Many times, at schools or community gardens our soils have been depleted, sprayed on, flat lining (dirt, barely soil) and we work hard to rebuild it and to strengthen our connection to creating healthy soils and fertile ground we can grow in.*
> *-Producer 29*

In this section I report on where respondents learn about soil, and why soil is important to their work. The producers in this study see soil as one of their most important resources. Here I convey again their deep sense of responsibility to steward soil, and how they see it as a more than human actant in their agroecosystems. Soil is foundational not only for them as producers, but to society at surrounding ecosystems. Most frequently, 89% of the respondents learn about soil from personal experience, and 75% from personal research. Many have also learned about soil from a training or workshop, or an elder, mentor, or a professional colleague. Other sources of knowledge include formal education, and one farmer emphasizes how they developed their own expertise over many years (as an arborist). Respondents show they are most familiar with self-analysis of soil health by manually engaging with, smelling, and looking at soil characteristics visible to the naked eye. The responses below emphasize that soil care is the foundation for crop productivity and agroecosystems in general. Additionally, soil is sometimes seen as more-than-human, and has an important role in helping producers build economies and communities of care.

Producers are repeatedly prompted to describe what they value about soil. Most of the respondents highlight the foundational importance of their soil to farm and crop productivity. Producer 22 believes simply that soil is their “number one resource,” and Producer 29 wrote that “A healthy living soil is resilient and provides the best medium to support good plant health." Respondents also refer to soil as foundational to growing quality and nutrient-dense food, to the ecosystem and to society at large. For example, Producer 28 wrote that "... to genuinely feed people, nutritious food is crucial. That comes from the soil." Furthermore, others describe soil as a complex ecosystem, and an important part of the environment at large. Respondents show that they are thinking beyond food as just something to eat, and that soil is not simply a composition of certain chemicals. By building their soil, producers can grow nutritionally-dense foods for a healthier overall society.

Some respondents emphasize the vital role of soil microbiomes, describing various signs of life as the most important qualities of healthy soil. Simultaneously they express a sense of responsibility and stewardship to the soil. "Soil is a living being. Soil is us. Protecting soils from development and healing from contamination," wrote Producer 11. This expression is one example of how farmers do not view soil as an inanimate substance. They are making references to soil as more-than-human, and constitutive of companion species (Haraway 1988; 2003). The specific mention of contamination, also reiterates how producers are concerned with social justice and sovereignty.

4.3 Embodied techniques and analysis

This section is to understand how the participants in this study learn about soil, and how they approach soil health analysis. Participants in this study embody a holistic and creative understanding of their soil. They engage with soil using their physical senses, and describe technical knowledge and creative tools for analyzing soil health. Open-ended prompts capture the embodied knowledge of respondents with regards to their soil and what physical senses they utilize to analyze and interpret soil health. Producers most frequently describe how they use touch, and manually examine the texture and structure of soil. Aspects of tilth are described in 36 different instances. Tilth is the structure, texture, and consistency of soils. Producer 14 emphasizes several details important to healthy soil such as, “nutrient content, microorganisms in the soil, earthworms, weeds growing, organic matter.” Respondents frequently mention reliance on smell and the colors of wet or dry soil, and other visible indicators. Producer 4 even writes about tasting the soil to examine it, “I smell it, taste it, put it in water to see how it dissolves, see the color, look at what grows and how it's growing.” These combined techniques, especially with some sort of basic chemical analysis, can allow a grower to make many assumptions about the biological, chemical, and physical conditions of soil. In the following quote, Producer 15 describes their processes for observing soil using technical descriptions and their physical senses.

> *…[I] look for soft, almost fluffy soil that is not hydrophobic. dark, almost black in color. it smells inviting, a bit like after it rains.*
> *-Producer 15*

Farmers are using the same professional and technical skills that a trained soil scientist or agronomist might use in a field consultation described above (see systematic review of soil testing resources in appendix B). Baseline chemical measures such as pH and N-P-K (the golden trio for plant growth) are important, but respondents tend to frame chemical nutrients as just one aspect of a complex system. They understand that crop productivity is also dependent on physical and biological components of their soil and agro-ecosystems. Producer 2 describes their experience with manually examining their soil, similar to the professional consultation described in the first section, “[I] dig down to look at the profile, fill with water to check drainage. Then check for smells and texture of moist soil.” Producer 27 considers the “texture, color, depth, structure, porosity, and pH levels- to find the ‘sweet spot' in the makeup of the soil… A good ratio of sand, silt, clay [and] soil biology." Thematic coding of the responses reveals that producers most commonly used descriptors of physical qualities for the soil. These responses continue to describe the embodied techniques and knowledge of participants, while simultaneously conveying a technical understanding of certain scientific processes.

Many respondents describe complex ecological processes dependent on their soil. Compared to other measures, hydrological aspects of soil functioning are mentioned second-most frequently in this section. For example, they mention hydrological functions such as moisture retention, or erosion from water or wind. Producer 15 understands that "...healthy soil can breathe well and isn't too sandy or too compact…it has the ability to hold water so that it is not lost to evaporation." Microbial, chemical, soil organic matter (SOM), and plant productivity are also considered important qualities of healthy soil. Producer 8 describes healthy soil as "rich in organic material, balanced in pH, good loamy texture to grow in." Producer 4 writes "organic matter, biological activity, enough nutrients, nutrient cycling, water retention" as important characteristics. These again point to the holistic lens of some respondents, showing that they understand how one factor affects another within a larger, complex system. Producer 1 uses a simple and creative phrase that still conveys the complexity that producers look for when examining their soil.

> *Chocolate cake.*
> *-Producer 1*

This quote and the following data show the creative and technical methods utilized by producers. Specifically, chocolate cake is moist, has a firm yet porous structure, and is visually dark– all aspects of “loamy” soil. Producer 26 references a technique using common household supplies, “I use vinegar or baking soda to determine pH levels…” Additionally, this respondent uses phenotypic observation of crops as soil indicators, “I plant a variety of crops to find the best locations for certain ones. This helps to "bumper" my results by keeping multiple crops in a row. If it is a low nitrogen row, the legumes do well. If it is a high nitrogen row, the tomatoes, corn or other heavy feeders do well.” This is just one example of how respondents may monitor crop systems, which depended directly on soil function. Producer 8 describes hydrological aspects such as water retention and runoff, “Feeling it in our hand, watching plant response to different areas of fields, watching water pooling or draining in different areas.” Lastly, Producer 20 describes features related to soil organic matter, and other aspects, “You can smell the organic compounds in soil, also dark soil indicates soil health, porosity.” These data show that respondents have many hands-on resources for determining baseline physical, chemical, and biological quality of their soil.

These data convey the complex knowledge, techniques, and values that respondents embody in their agricultural work and soil stewardship. Producers express a breadth of knowledge and experiences with different soil testing techniques, but rely heavily on personal observation and examination. The producers in this study care deeply about building communities and economies of care by participating in the local food system. They hope their agricultural work furthers our community towards sovereignty, just food systems, and robust health. In their practice, they steward the many actants in their agro-ecosystem while growing nutritious foods, and work towards more reciprocal relationships with their soil and community.

4.4 Participant perceptions on remote sensing

The questionnaire helps gauge respondent familiarity and interest in remote sensing (RS) research and extract smallholder plot details relevant to examining remotely sensed imagery. Roughly one in three respondents have heard of the term “remote sensing” before this questionnaire, while two in every three said they have not heard of the term. A closed-ended question revealed that 45% of the respondents have heard of GIS-related fields such as digital soil mapping, and 35% of them have heard of precision agriculture and a field spectrometer. Despite relatively low familiarity with GIS and RS technologies, 80% of respondents said they were at least somewhat likely to learn and use free remote sensing software to analyze their soil, and 20% said they were not likely at all. Additionally, 85% said they were at least somewhat likely to use pre-processed RS data about their soil, while 15% said they were not likely at all. These results indicate that a RS study that honors their values and priorities may be well-received amongst smallholder producers, consistent with other studies on the acceptance of RS by smallholder producers (Diana and Farida 2023). With increased availability of high-resolution RS imagery, researchers and producers may be able to bypass intensive and costly in-situ data collection methods such as handheld spectrometer readings or soil probe sampling for laboratory testing. Appropriate imagery, in combination with field testing methods, and their own observations, farmers could efficiently analyze their management techniques.

4.5 Extracting data relevant to a remote sensing analysis

Figure 4.2. Aerial views of the same local farm from NAIP aerial imagery at 1 meter (top) versus Landsat satellite imagery at 30-meter resolution (bottom). Note the clarity of the images, with plot design distinguishable in the NAIP image (U.S. Geological Survey 2022).

In this study, smallholder plots were an average of 3 acres (similar to an average of 4 acres reported in the county), with only one "large" farm at 16 acres. Based on site visits, there is high variation in plot design and soil coverage (including by vegetation) as frequently as every 2-3 feet. Therefore, in a RS study I recommend a spatial resolution of 1-square meter or less. Measurable changes in soil conditions are best captured at fine spatial resolutions and frequent temporal resolutions over long periods of time. A number of proximal sensing instruments could meet temporal, spatial and spectral requirements. Access to instruments such as field spectroradiometers or drones is limited, and currently there is no free satellite and aerial imagery that meets all resolution needs. Imagery from the National Agricultural Imagery Program (NAIP) is free, has a high spatial resolution (1 meter), and band availability in visible, and near-infrared spectra captures many relevant indicators. The images are acquired every 4 years, so the temporal resolution is low with only 6 dates for New Mexico over 11 years (table 4.1).

NAIP Specifications	Year	Acquisition months for NM
Aerial imagery acquired via commissioned aircraft mounted with digital cameras (Intergraph and Leica); Spatial Resolution- 1 meter; EMS Range: RGB, NIR (Band 1) (Band 2) (Band 3) (Band 4)	2011	May, June
	2014	May, June, July, August
	2016	May, June, July
	2018	May 2018 - March 2019
	2020	May, June July
	2022	May, June, July, August

Table 4.1 The specifications of imagery from the National Agriculture Imagery Project. The table details years and acquisition months, were acquired from a search of "NM" and "New Mexico" on USDA's data hub for NAIP imagery (Unites States Department of Agriculture 2023). NAIP specifications were acquired from USDA imagery specifications sheet from the Farm Service Agency (United States Department of Agriculture 2017).

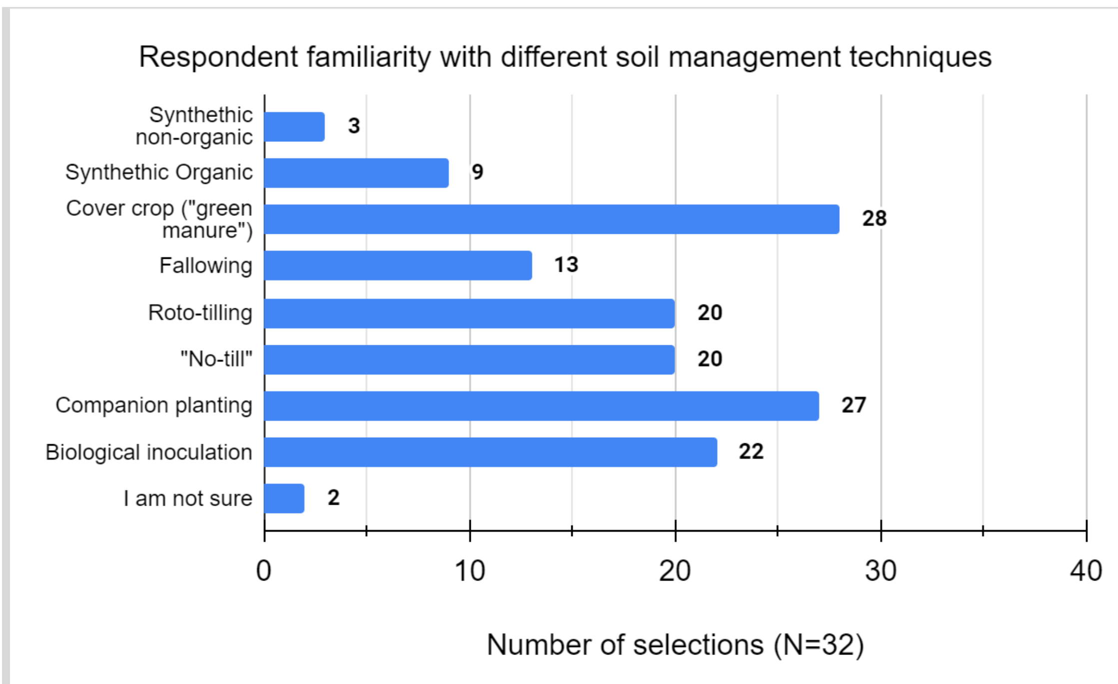

Figure 4.3 The list of soil management practices reported by respondents in this study. Each of these practices has impacts on above and below ground conditions.

The questionnaire results also provide information relevant for ground-truthing remotely sensed data from smallholder plots, detailing management techniques that can affect both ground-cover and below-ground soil conditions. For example, respondents report on synthetic fertilizer use, the use of plants to input nutrients back into soil (cover cropping), using inoculants like nematodes and fungi (biological inoculation), and more. Respondents have experience with an average four types of management techniques. The most common techniques used by respondents are cover cropping and companion planting reported by roughly 85% of participants. Next, just over 50% of the participants chose biological inoculation, roto-tilling, and “no-till”. Respondents also mentioned the use of plant-based fertilizer (alfalfa and soy), inoculation of seeds, mulching, tarps (used to kill off unwanted vegetation in the summer, or keep soil warm in the winter), double-digging, and using low-disturbance tools like a broad fork. Lastly, one farmer references a “soil sponge” method, which refers to a technique of layering different materials to create a “sponge” with high organic matter and water-holding capacity. Nearly 70% of respondents said that they leave old vegetation in between crops. Slightly fewer said that they remove old vegetation to plant cover crops. Only two indicated that they clear out the vegetation immediately (without specifying the use of mulch or cover crops in between periods). This data describes ground cover conditions, which vary greatly because several techniques can be implemented simultaneously and in various combinations. This situated information is important because a researcher can ground-truth their aerial imagery by identifying known plot dynamics identified from situated in-field perspectives.

Based on plot management details from respondents, agroecological plots may have less visibly exposed soil over time. This is an important soil health principle and practice for sustainable smallholder agriculture (NM Healthy n.d.) but it poses a problem for attempting to directly detect soil reflectance using RS instruments (hence the value of vegetation proxies for soil conditions). Given access to high temporal and spatial resolution imagery, indicators related to components of soil organic matter (SOM), soil organic carbon (SOC) (Angelopoulou et al. 2019), and detecting soil productivity by incorporating soil-vegetation dynamics (Hamada et al. 2014; Maynard and Levi 2017; Wulf et al. 2014) could prove useful to researchers and producers alike. Producers who participated in this study are implementing one or more of the soil health principals with methods like cover cropping and low-disturbance tilling. They are likely impacting factors such as water retention and biological conditions of soil related to SOM and SOC. The remote sensing process could be used to compare above and below ground dynamics using many regions of the electromagnetic spectrum (EMS). High resolution (spatial and

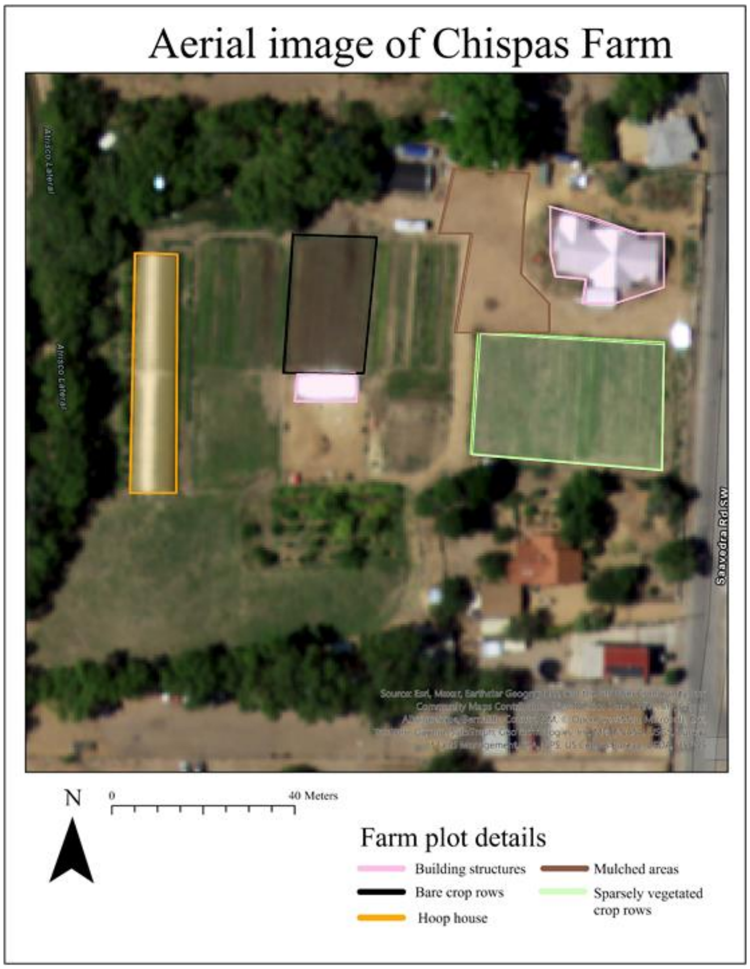

Figure 4.4 An aerial NAIP image of Chispas Farm conveying the complexity of some production farm designs (U.S. Geological Survey 2022).

temporal) imagery would be required to predict soil properties at a finer spatial resolution (Forster, Buehler, and Kellenberger 2009; Hamada et al. 2014; Wulf et al. 2014). Statistical modeling like kriging, various regression models, and object-based classification methods are common for smoothing raster data at a local scale (Angelopoulou et al. 2019; Breure et al. 2022; Forster, Buehler, and Kellenberger 2009; Ji et al. 2016). Table 4.2 in the appendix summarizes some studies that may have useful methods for research examining smallholder farms in Bernalillo County.

CHAPTER 5: Thesis conclusion

Smallholder agroecological farmers around the globe are gaining more attention from researchers concerned with land use, human-environmental relations, climate resiliency, and more (Altieri et al. 2015; Hatfield et al. 2020; Turner 2003; Weiss, Jacob, and Duveiller 2020; Rhodes 2014). The local food movement in and around Bernalillo County is bountiful, and there are many opportunities to capture the impacts farmers are having on culture, the economy, and ecology. Not everyone in this study is familiar with the term *agroecology,* but my research shows strong evidence for a local agroecological movement that mirrors global movements in both ideology and practice. Discussions about agriculture go hand in hand with discussions about soil, and this thesis draws attention to soil stewardship within agroecology.

Agroecology is useful for tracing a political ecological lineage of power, land, and technology for agrarian communities (Polanyi 2001; Rosset and Martínez-Torres 2012; Van Sant, Milligan, and Mollett 2021). Certain aspects of feminist theory like the valuing of more-than-human actants and communities of care (Dombroski, Healy, and McKinnon 2018; Haraway 1988; 2003) are also embodied in agroecology (Graddy-Lovelace 2018). Combined, these frameworks are useful for upholding that agroecology is a praxis for building sovereignty, communities of care, and resilient soils.

A part of this thesis explores how the remote sensing process can be used to support the goals of smallholder producers in Bernalillo County (BernCo). I have investigated this issue concerned with relations of power, access to technology, and how to uplift the embodied knowledge and principles of smallholder farmers as stewards to soil. I find that the producers in this study are open to learning about the remote sensing process and using remote sensing technologies. This is important because the methodologies of smallholder agroecological farmers around the globe are gaining more attention from researchers concerned with land use, human-environmental relations, climate resiliency, and more (Altieri et al. 2015; Hatfield et al. 2020; Turner 2003; Weiss, Jacob, and Duveiller 2020; Rhodes 2014). The impacts of the soil stewardship methods used by smallholder producers in Bernalillo County are measurable using remote sensing data and analysis while honoring their situated experiences and values.

Participant descriptions of their soil management techniques could serve as ground-based data in remote sensing data analysis. Respondents in this study have holistic priorities for their soil health beyond conventional N-P-K measures (Nitrogen, Phosphorus, and Potassium are baseline nutritional requirements for growing crops). This aligns with new resources and information on soil biology developed by major agricultural service providers such as New Mexico State University's Agricultural Extension services (New Mexico State University 2023). A more holistic picture of soil health is important because it provides a wider range of opportunities to produce research relevant to smallholder producers in BernCo, and researchers seeking to understand soil ecosystem functioning.

There are substantial challenges to analyzing crop and soil dynamics on agroecology farms using remotely-sensed imagery. Access to imagery with a fine enough spatial and temporal (many images captured throughout the year, or over many years) resolution is required. In a study, a relevant indicator for chemical, physical, or biological productivity would need to be selected that captured information relevant to farmers and the community. In the results chapter I discussed how smallholder producers in this study examine crop indicators to understand their soil health conditions using in-field techniques, and which indicators they prioritize. They are concerned with physical texture, ecosystem or microbial processes, components of soil organic matter (SOM), and the opportunity to use vegetative proxies as indicators of their soil conditions. As higher resolution imagery becomes more available, there is great potential for RS research to capture the impact smallholder producers are making to soil health via their stewardship. The values that drive producer management choices (their methodology) should be forefront of agricultural research utilizing remote sensing technologies.

5.2 Summary

It is important to document the values and practices of smallholder producers because each person has their own perspectives on why and how they farm. This study asks– what values, experiences and knowledge do smallholder producers in Bernalillo County embody in their soil stewardship practices? Social, ecological, and GIS fields of research are beginning to interpret the impacts of agroecological practices on soil and crop resiliency (Altieri et al. 2015; Stratton, Kuhl, and Blesh 2020; Clinton et al. 2018). Therefore, this study also explores how the remote sensing process can support agroecological and soil health goals of smallholder producers. There are substantial opportunities to capture this data and unveil the impacts of agroecological farmers in Bernalillo County using remote sensing technologies.

Critical Agrarian Studies and Science and Technology Studies share feminist commitments to value the embodied knowledge of actors on the ground in research that has a tendency to hide or erase their situated experiences (Nehring 2021). Mixed-methods studies incorporating the experiences and knowledge of on-the-ground actors give valuable socio-political and situated context in GIS and RS studies (McCusker and Weiner 2003; Turner 2003; Turner and Taylor 2003). Therefore, if a study is carried out in BernCo, a mixed-methods approach should be utilized that works with growers to measure the impacts of their methods verified by spectral, chemical, or biological analysis (Breure et al. 2022; Dehaan and Taylor 2002; Gogé et al. 2014; Hamada et al. 2014; Maynard and Levi 2017; Rozenstein and Adamowski 2017).

A questionnaire was effective for capturing data about both participant values and practices. Using both open and closed-ended questions allowed me to prompt my participants for specific information and verify their responses. Recruitment efforts for the questionnaire were taxing because it was deployed during the growing season. My recruitment tactics and choice of locations also introduced bias into this study, which may have influenced the types of data collected in my final sample. Therefore, my assumptions about participant values, motivations, and stewardship methods are not generalizable to the general population of producers in the county. I found that I was more likely to recruit participants if I visited them in person at markets and other local agriculture events. Nonetheless, even if I had some entré with an individual it did not guarantee their participation. This is important because future researchers will have to be intentional and persistent to recruit participants for their study.

A retroductive approach was effective while coding responses for both descriptive and analytic information (Cope 2021; Emerson, Fretz, and Shaw 2011; Waitt 2021), which means that I approached my data analysis with presumptions informed by political ecology and feminist theory, but also allowed the data to shape my theoretical framework. I looked for instances when respondents describe their sense of responsibility to nature or society, their valuing of more-than-human actors, building communities of care, and concerns for sovereignty or environmental justice issues. I also coded for embodied knowledge and experiences of respondents by identifying instances when they referred to technical soil analysis using personal observation or other tools. I related these responses to political ecology, feminist theory, and agroecology. These methods were effective because respondents relayed that they are committed to growing soil that sustains a local food system, their community and the environment. These commitments dictate why and how they steward their soil for growing ethical and nutritious foods. Additionally, the care about global movements related to sustainable agriculture like permaculture, regenerative agriculture, and more. The farmers in this study see their work on both a local and global scale.

The questionnaire also helped me capture how the producers in this study employ methods that alter above and below ground plot conditions in visible, physical, chemical and biological measures. The average farm size in this study is 3 acres, and soil functioning can differ both within a single growing season, or over the span of several years. I found that study participants have experience with a variety of resources for soil health analysis. Additionally, they are open to applying the remote sensing process to analyze their plot conditions. Therefore, a spectral analysis of soil and crop conditions in Bernalillo County should utilize remotely-sensed imagery that has high spatial and temporal resolution.

Agroecological projects around the globe are stewarded by smallholder farmers who embody complex and technical stewardship practices. Participants in this study demonstrate agroecological practices proven to be effective around the globe, and not one field of research has attempted to capture this data in Bernalillo County. Producers here are faced with complex institutional, political, environmental challenges to grow a bountiful local food system and a rigorous study could support moving their work forward. Agroecological producers in Bernalillo County are performing a vital service to the community, soil ecosystems, and the economy as they continue to grow food using dynamic and sustainable methods.

> *If our soil isn't healthy, our foods and medicines are not healthy, therefore neither will we be.*
> *-Producer 32*

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Appendix A: Tables

Table 2.1 A glossary of terms related to remote sensing.

Glossary	
Electromagnetic spectrum (EMS)	The spectrum of the energy that ranges from radio waves, to infrared, visible light, and gamma rays. The different regions of the EMS are quantified by the frequency of wavelengths.
Ground-truthing	Verifying large scale or remote sensing data with field samples or observations.
In-situ	A sample of data collected on-site or in the field.
Methodology	Particular philosophies and values that drive methods.
Proximal sensing (PS)	The collection of spectral data using an instrument close to the object(s) of interest.
Proxy	One indicator (such as vegetation) that is informative of another indicator (such as soil).
Remote sensing (RS)	A field of research examining land surface dynamics using the electromagnetic spectrum; An instrument that collects spectral data from a far distance.
Spatial resolution	The physical area that a single pixel encompasses in an image. This can range from centimeters to kilometers. High resolution imagery has more, smaller pixels.
Spectral resolution	The region of the EMS that is being used to detect an object of interest such as visible (VIS), near-infrared (NIR), infrared (IR).
Temporal resolution	The frequency that the spectral imagery was obtained.

Table 2.2 Studies that examined indices relevant to this research, also detailing some classification and analysis techniques that would be useful to examine complex smallholder plots.

Remote sensing studies with measures and analysis useful to this thesis				
Authorship	Title	Relevant indicator or analysis	Spectral resolution	RS Source
Angelopoulou et al. (2019)	Remote Sensing Techniques for Soil Organic Carbon Estimation: A Review	Soil Organic Carbon (SOC); kriging, support vector machine (SVM), partial least squares regression (PLSR), random forest (RF)	VNIR (400 nm) – SWIR (2500 nm)	Spaceborne, airborne, unmanned aerial systems (UAV), in-situ
Breure et al. (2022)	Comparing the Effect of Different Sample Conditions and Spectral Libraries on the Prediction Accuracy of Soil Properties from Near- and Mis-infrared Spectra at the Field-scale	Soil Organic Carbon (SOC), pH, Clay; Partial least squares regression (kernel)	VNIR (400 nm)-MIR (2500 nm)	Laboratory spectral analysis, handheld spectrometer
Brown and McCarty (2017)	Is remote sensing useful for finding and monitoring urban farms?	Normalized difference vegetation index (NDVI), normalized difference water index (NDWI), enhanced vegetation index (EVI); Data mining, visual classification by user	VIS (400 nm– 700 nm)	Spaceborne (Landsat 8, MODIS), Google Earth Pro
Forster et al. (2009)	Mapping urban and peri-urban agriculture using high spatial resolution satellite data	Object-based classification	VIS (400 nm)-NIR (2500 nm)	Quickbird (0.5 m- 4 m)
Hamada et al. (20114)	Toward Linking Aboveground Vegetation Properties and Soil Microbial Communities Using Remote Sensing	Soil Microbial Communities (SMCs) via leaf mass per area (LMA), photosynthetically active radiation (PAR), photochemical reflectance index (PRI), enhanced vegetation index (EVI), soil-adjusted vegetation index (SAVI), nitrogen (N), phosphorous (P), plant community composition and diversity	VIS (400 nm)-NIR (2500 nm), SWIR (900 nm- 1700 nm)	Satellite, laboratory spectral/ chemical/ biological analysis
Ji et al. (2016)	Prediction of soil attributes using the Chinese soil spectral library and standardized spectra recorded at field conditions	pH, Soil Organic Matter (SOM), Total N (TN); Direct standardization (DS), locally weighted regression (LWR)	VIS (400 nm)-NIR (2500 nm)	Laboratory spectral analysis/ chemical/ biological analysis

Remote sensing studies with measures and analysis useful to this thesis (continued…)				
Authorship	Title	Relevant indicator or analysis	Spectral resolution	RS Source
Maynard and Levi (2017)	Hyper-temporal remote sensing for digital soil mapping: Characterizing soil-vegetation response to climatic variability	Support vector machine (SVM); NDVI, Modified soil adjusted vegetation index (MSAVI)	VIS (400 nm)-NIR (2500 nm)	Landsat Thematic Mapper (TM)
Rozenstein and Adamowski (2017)	A review of progress in identifying and characterizing biocrusts using proximal and remote sensing	Biocrusts via minerology, water content, SOM, texture, chlorophyll, cellulose, lignan	VIS (400 nm)-NIR (2500 nm), Thermal infrared (TIR)/ Long-wave infrared (LWIR) (700 nm- 1400 nm)	In-situ spectroscopy, airborne
Shaaf et al. (2011)	Mapping Plant Functional Types at Multiple Spatial Resolutions Using Imaging Spectrometer Data	Plant functional types (PFTs); Spectral mixture analysis (SMA), object-based classification (MESMA)	VNIR (300 nm) – NIR (2500 nm)	NAIP (1 m); Airborne Visible InfraRed Imaging Spectrometer (AVIRIS) (20 m)
Wulf et al. (2014)	Remote Sensing of Soils: Technical Report [and Review]	Soil texture, vegetative proxies, soil water index (SWI), soil organic matter (SOM), calcium carbonate (CaCO3), soil organic carbon (SOC), cellulose, starch and lignin, plant functional types (PFTs); Interpolation, extrapolation, kriging, multiple linear regression (MLR), partial least square regression (PSLR)	VNIR (400 nm)-SWIR (2500 nm), TIR (1400 nm)	Spaceborne, airborne, in-situ spectroscopy

Table 3.1 Descriptive and analytical codes used for questionnaire analysis related to larger themes of political ecology, feminist theory, agroecology, technical knowledge and general values of study particpants.

Themes communicating embodied values and practices of respondents			
Feminist and political ecological values	Agroecological commitments	Technical knowledge	General values
Communities of care	Against industrial chemicals	Soil organic matter	Foundational to nutrition
Companion species	Food justice or social justice	Soil or microbial ecosystems	Foundational to society
Critical perspectives on power	Economies of care	Foundational to productivity	Heritage
Microbial ecosystems	Systems thinking	Foundational to ecosystem productivity	Sense of responsibility
More-than-human	Stewardship	Hydrology	
	Sustainability	Soil-plant systems	
	Sustenance	Physical	
	Resilience	Smell, sight, taste and touch	

Table 4.1 The specifications of imagery from the National Agriculture Imagery Project. The table details years and acquisition months, were acquired from a search of "NM" and "New Mexico" on USDA's data hub for NAIP imagery (Unites States Department of Agriculture 2023). NAIP specifications were acquired from USDA imagery specifications sheet from the Farm Service Agency (United States Department of Agriculture 2017).

NAIP Specifications	Year	Acquisition months for NM
Aerial imagery acquired via commissioned aircraft mounted with digital cameras (Intergraph and Leica); Spatial Resolution- 1 meter; EMS Range: RGB, NIR (Band 1) (Band 2) (Band 3) (Band 4)	2011	May, June
	2014	May, June, July, August
	2016	May, June, July
	2018	May 2018 - March 2019
	2020	May, June July
	2022	May, June, July, August

Appendix B: Systematic Review of soil health resources

This review is important because it gives context to how producers have to navigate their access to soil analysis. New Mexico State University (NMSU) used to provide soil testing for faculty, state agencies, and the public since 1973. Due to the increased availability of laboratories specializing in soil testing for crop growth, the NMSU lab closed in 2012 (KRWG Public Media 2012). Still, NMSU provides other online resources for producers to understand their soil health. For example, they have free online guides on how to manually examine soil in the field (Flynn 2012). They detail protocols on how to properly collect soil samples which can then be mailed to different laboratories for testing biological, physical, and chemical properties (Flynn 2012; NMSU n.d.). There is also the New Mexico Healthy Soil Working group, whose collective work helped pass the 2019 NM Healthy Soil Act. The act allocates state funding to provide grants to groups and individuals for implementing any one of the 5 soil health principals at their site (Garcia and Goetz 2023). For example, one activity for the grantee site visits includes digging several feet into the ground to examine soil layers, texture, and other physical characteristics (figure 1). This event shows that even academic and other scientific institutions emphasize the importance of physically engaging with soil, which can be a reliable method for analyzing soil health.

Figure 1. A series of photos garden managers learned about examining physical properties of the soil. Pictured is a consultant inside of a pit to give a demonstration on how to 1) sift particles of soil, 2) work water into the soil and 3) to examine the proportions of clay and silt in the soil (Photo credits: Stefany Olivas).

Another institutional-based resource was the community soil health laboratory sponsored by the Middle Rio Grande Conservancy District (MRGCD) and based out of the Larry P. Abraham Agri-Nature Center in the village of Los Ranchos (Coughlin 2022). This lab opened and shut down within the time of this thesis due to lack of funding and capacity. The Soil and Water Conservation District (SWCD) and NMSU Agricultural Extension agents offer on-site consultations to assist farmers in manual observation of their soil (such as the activity described above) and review laboratory soil tests results (Acosta 2023; Goetz 2023). These individuals are a valuable resource, but access to their time is in high demand since they provide broad agricultural services, and are assigned to large regions (e.g., one agent manages resources for one county).

There are many community-oriented soil evaluation resources in BernCo. Dozens of workshops are hosted every year by non-profit and community-based organizations (figure 2; figure 4). These workshops deliver hands-on educational experiences on soil type, compost building, soil bed preparation, and more. The material is often geared towards teaching attendees how to evaluate soil health using practical methods. Even with the resources just described, analyzing soil health and complex laboratory results can be challenging for producers. Recently a new approach to community-based resources for soil analysis was founded at the Catena Commons (figure 3). This cooperative-style space is located in Albuquerque, NM and dubbed as a place for "People and Dirt to Connect," (Catena 2023). The commons are a place to assist with soil sample preparation for laboratory analysis, and on-site chemical and physical testing. They also host community events related to local arts, music, and more. The creation of the Catena Commons and abundance of locally hosted workshops, contribute to communities and economies of care that also benefit more-than-human beings in the soil itself. From community-based groups to local soil experts and growers, people in Bernalillo County collectively invest in resources to create robust soils for sustainable, ethical, and nutritious foods.

Figure 2. A flier that invited the community to a work day focused on the site's Johnson-Su Bioreactor compost structures at a local community garden managed by Project Feed the Hood (Project Feed the Hood, 2024).

Figure 3. A flier describing the ongoing soil testing resources located at a Catena Commons, a cooperative soil health work space in Albuquerque, New Mexico (Catena Commons, 2024).

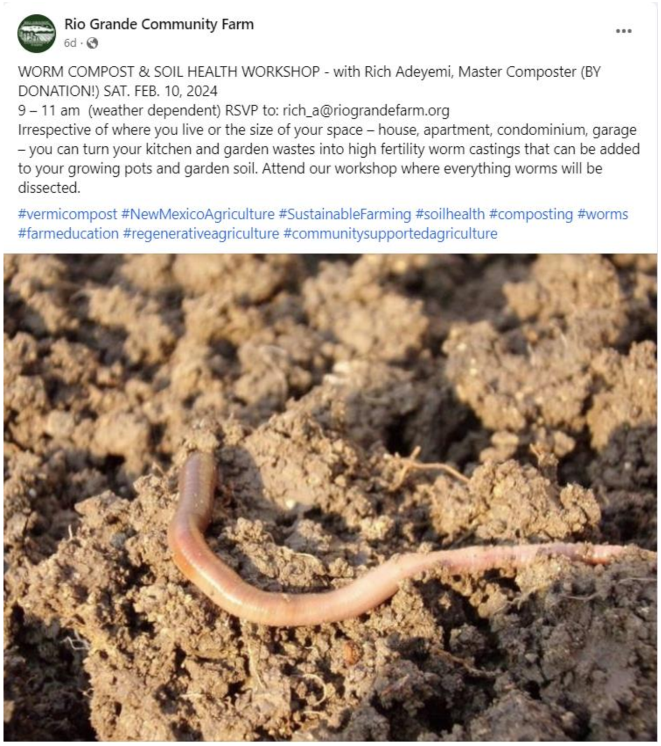

Figure 4. A screenshot of a social media post detailing a workshop focused on vermicomposting (compost made from worm castings) hosted at Rio Grande Community Farm with an expert from the Master Composters program (Rio Grande Community Farm, 2024).

With the context of available resources described above, the questionnaire captures participants' experiences as an important demographic in need of soil health management resources. Half of the respondents in this study have submitted soil samples for laboratory analysis, which typically includes nutritional (chemical) details, and sometimes including physical or microbial analysis. Producers express mixed feelings about the usefulness of laboratory analysis in this study, some stating that they had difficulty in interpreting the results. This was reflected in my conversations with farmers throughout the research process. Soil labs often provide interpretation guides, but they can still be difficult to navigate. Institutions such as NMSU and SWCD try to reconcile this issue by providing consultations described in the preceding review, but as previously mentioned– their time and capacity are limited.

Appendix C: Questionnaire

Questionnaire on farmer experience

Stephanie Olivas, from the Department of Geography and Environmental Studies is conducting a research project. The purpose of the research is to understand farmer soil practices and their experiences with soil testing. **You are being asked to participate in this questionnaire because you are a smallholder farmer in Bernalillo County, NM who grows food.** ***Even if you do not own a farm, we would like to capture your perspectives!*** If you are not a farmer in Bernalillo County please do not complete this questionnaire. You will be asked about your farming practices, values, and soil testing experiences. It should take about 30 minutes to complete.

Your involvement in the research is voluntary, and you may choose not to participate. There are no known risks in this research, but some individuals may experience inconvenience in time. Data will be stored on a password protected computer and may be used for future research without your additional informed consent.

The findings from this project will provide information on the local soil health movement and contribute to a foundation of support for local producers. In return for your time, the first 40 participants will receive a Visa gift card valued at $15 (please be sure to include contact info at the end to receive your gift card).

If you have any questions, concerns, or complaints about the research, please feel free to call Stephanie Olivas at (505) 688-8066 or Solivas2@unm.edu. You may also contact the Principal Investigator Marygold Walsh-Dilley at 505-277-5041 or marygoldwd@unm.edu. If you have questions regarding your rights as a research participant, or about what you should do in case of any harm to you, or if you want to obtain information or offer input, please contact the UNM Office of the IRB (OIRB) at (505) 277-2644 or irb.unm.edu.

By continuing the questionnaire, you will be agreeing that you are a farmer in Bernalillo County willing to participate in the above-described research, and this is your first time completing the questionnaire.

Part 1

Questionnaire instructions: This questionnaire should take about 30 minutes or less. Please fill out this questionnaire to the best of your ability. There are three parts to this survey. Response options range from short answer, to multiple choice, and choosing from a scale rating. If you have any questions, please do not hesitate to contact me (Stephanie Olivas) by call or text at 505-688-8066, or email at solivas2@unm.edu. Thank you for your time in contributing to this research.

1. 1) Age

2. 2) Ethnicity or race? (you may write 'prefer not to answer')

3. 3) Preferred gender (you may write 'prefer not to answer')

4. 4) How many acres do you farm on? (estimate)

5. 5) How many different local farms have you worked for? (estimate)

6. 6) What seasons do you grow in? (check all that apply)

Check all that apply.

- [ ] Winter
- [ ] Spring
- [ ] Summer
- [ ] Fall

7. 7) Is farming your primary source of income?

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] During at least one season of the year

8. 8) Are the site(s) you work on considered "production" farms? Productions can mean growing for the purpose of any outlet of distribution like a CSA, a growers or farmers market, food boxes, etc.

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Some

9. 9) What types of food do you grow? (fruits, vegetables, herbs, meat, etc.)

____

10. 10) How long have you been a farmer?

____

11. 11) Please list some reasons that describe why you participate in agriculture? Food insecurity can mean to face financial or physical barriers to accessing food to eat. Sovereignty can mean having decision-making power over food, land, water, or bodies (check all that apply)

Check all that apply.

- [ ] Economic security
- [ ] Food security for me
- [ ] Food security for others
- [ ] Support local agriculture
- [ ] Support food sovereignty
- [ ] Other
- [ ] I am not sure

12. 12) If you selected "other" above, please describe.

13. 13) Do you identify your agricultural practices with any of the following types of farming practices? (check all that apply)

Check all that apply.

- [ ] permaculture
- [ ] agroecology
- [ ] food forest
- [ ] organic (not necessarily organic certified)
- [ ] sustainable
- [ ] regenerative
- [ ] traditional
- [ ] conventional
- [ ] agribusiness
- [ ] I am not sure

14. 14) What values are important to your agricultural work, and why?

Part 2

General definition of "Composition" for questions #13-15: the parts that make up the whole, such as root materials, other organic materials, clay, silt, loam, etc.

15. 1) Why is soil important to your agricultural work?

16. 2) Where or who have you learned about soil from? (check all that apply)

Check all that apply.

- [ ] Personal research
- [ ] Personal experience
- [ ] Taught to you be an elder or mentor
- [ ] Through a training or workshop
- [ ] Through school
- [ ] Other
- [ ] I am not sure

17. 3) If you selected other above, please describe.

18. 4) What soil management techniques have you used or do you have experience with? (check all that apply)

Check all that apply.

- [ ] Apply non-organic synthetic fertilizer
- [ ] Apply organic synthetic fertilizer
- [ ] Apply cover crop ("green manure")
- [ ] Fallowing
- [ ] Rototilling
- [ ] "No-till"
- [ ] Companion planting (planting two or more crops together to benefit each other)
- [ ] Biological inoculation (microbial, fungal, humic, nematodes, etc.)
- [ ] Other
- [ ] I am not sure

19. 5) If you selected other above, please describe.

20. 6) What type of testing have you used or do you have experience with to determine soil health and crop production? (check all that apply)

Check all that apply.

- [ ] Manual analysis by touch
- [ ] Manual analysis by smell
- [ ] Manual analysis by color
- [ ] Other types of manual analysis
- [ ] At home chemical tests (N, P, K, pH)
- [ ] Laboratory service for chemical analysis (N, P, K, pH, minerals etc.)
- [ ] Laboratory service for physical analysis (Texture, Bulk Density, Sand or Clay content, etc.)
- [ ] Laboratory service for microbial analysis(Soil Organic Matter, Soil Respiration)
- [ ] Other (Soil Organic Carbon, etc.)

21. 7) If you selected "other" above, please describe.

22. 8) If you provided an answer to #6 above, what was the most helpful? What was the least helpful? Please describe.

23. 9) Is there any information you wish was included in the results from the soil health examination? Please describe.

____

____

____

____

____

24. 10) What types of barriers do you face in getting laboratory analysis? (check all that apply)

Check all that apply.

- [ ] Financial barriers
- [ ] Time Constraints
- [ ] Physical Capacity
- [ ] Lack of supplies
- [ ] Lack of resources for information
- [ ] Lack of understanding of the results
- [ ] I am not sure

25. 11) What types of barriers do you face in performing self-analysis? (check all that apply)

Check all that apply.

- [ ] Financial barriers
- [ ] Time Constraints
- [ ] Physical Capacity
- [ ] Lack of supplies
- [ ] Lack of resources for information
- [ ] Lack of understanding of the results
- [ ] I am not sure

26. 12) What do you think are the most important qualities of healthy soil? Please describe.

27. 13) Thinking about composition, texture, smell, color, etc. of soil- how do you analyze your soil health yourself? Please describe.

28. 14) Thinking about composition, texture, smell, color, etc. of soil- how would you describe healthy soil? Please describe.

29. 15) Thinking about composition, texture, smell, color, etc. of soil- how would you describe poor quality soil? Please describe.

Part 3

If you do not have your own farm, please imagine how likely it is you would use the resources IF you did have a farm.

30. 1) Have you heard of the term "remote sensing" before this questionnaire?

Mark only one oval.

- Yes
- No

31. 2) Remote sensing (RS) is an area of expertise that uses imagery collected from sensors at different light wavelengths (visual, infrared, etc.). Have you heard of any of the terms below related to using remote sensing technology on farms? (check all that apply)

Check all that apply.

- [ ] Precision agriculture (using remote sensing technology such as scanners and drones in the field)
- [ ] Field spectrometer (or spectroradiometer)
- [ ] Digital Soil Mapping (organizing soil health information spatially)
- [ ] Other
- [ ] None

32. 3) If you selected other above, please describe.

33. 4) If the following types of data were easily available on your soil and crop health, how likely would you be to use them (1 not likely at all, 2 somewhat likely, 3 very likely)

Check all that apply.

	1	2	3
Laboratory tests where you collect a sample and send it in.	☐	☐	☐
self testing kits for pH, N, P, K.	☐	☐	☐
Remote sensing imagery	☐	☐	☐

34. 5) To gain data from a remote sensing image, you would manipulate the imagery using a computer to calculate health indicators. What is the likelihood you would use free tutorials and images of your farm to assess soil health? (1 not likely at all, 2 somewhat likely, 3 very likely)

Mark only one oval.

- 1 (not likely at all)
- 2 (somewhat likely)
- 3 (very likely)

35. 6) What is the likelihood you would use the results from analyzed image data of your farm farm to assess soil health? (1 not likely at all, 2 somewhat likely, 3 very likely)

Mark only one oval.

- 1 (not likely at all)
- 2 (somewhat likely)
- 3 (very likely)

36. 7) What barriers prevent you from using remote sensing data for understanding the health of your soil health? (check all that apply)

Check all that apply.

- Financial barriers
- Time Constraints
- Physical Capacity
- Lack of supplies
- Lack of resources for information
- Other
- I am not sure

37. 8) If you selected other above, please describe.

____

____

____

____

____

38. 9) Have you heard of the Agri-Nature Center self-testing soil laboratory before this questionnaire (Click on link to learn more)?

Mark only one oval.

- ⬭ Yes
- ⬭ No

39. 10) How likely is it that you would take soil samples to utilize the Agri-Nature Center laboratory? (1 not likely at all, 2 somewhat likely, 3 very likely)

Mark only one oval.

- ⬭ 1 (not likely at all)
- ⬭ 2 (somewhat likely)
- ⬭ 3 (very likely)

40. 11) Is there more information or resources you would like in order to access for understanding your soil health? If yes, please describe.

____

____

____

____

____

Part 4

41. 1) In between crops, how do you manage the plots? (check all that apply)

Check all that apply.

- [ ] Clear out old vegetation immediately
- [ ] Leave old vegetation until I am going to plant the next crop
- [ ] Clear out old vegetation and plant cover crops
- [ ] Other

42. 2) If you answered "other" above, please describe.

43. 3) If you can think of any additional details about the design of your farm, for example mulched pathways or major open areas, please describe.

44. 4) I would like to thank you for spending time on this questionnaire. Your responses will provide vital information on soil testing experiences and resources in Bernalillo County. Lastly, please check all that apply.
(link to map)

Check all that apply.

- [ ] I am willing to be contacted about my $15 Visa gift card (please be sure to include your contact below to receive the card).
- [ ] I am willing to be contacted with follow up questions about this questionnaire.
- [ ] I would like to learn more about the information and resources mentioned in this questionnaire.
- [ ] I would like my farm to be added to a public map with other gardens and farms (link in this question description).

45. 5) If you selected an option above, please provide your email and/ or phone number.

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