UNDERSTANDING THE SOIL HEALTH KNOWLEDGE OF FARMERS IN THE YAKIMA VALLEY

by

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A Thesis
Submitted in partial fulfillment
of the requirements for the degree
Master of Environmental Studies
The Evergreen State College
December 2018

This Thesis for the Master of Environmental Studies Degree

by

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ABSTRACT

Understanding the Soil Health Knowledge of Farmers in the Yakima Valley

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Soil scientists and agronomists have established a number of parameters defining soil health; however, it is unclear how effectively this information reaches farmers and land managers. This study asks: what is the soil health knowledge (SHK) of farmers in the Yakima Valley, and where does this information originate? Through semi-structured interviews, 15 participants were asked questions addressing seven main points: demographic background, history, education, community involvement, farming philosophy, management practices and risk aversion. Soil cores were then collected to measure bulk density, carbon and nitrogen contents of two fields that each farmer determined to be of high fertility or low fertility.

The interview results show that although the participants have different demographic characteristics, education, and agricultural backgrounds, all 15 participants understand the importance of organic matter to overall soil health. Through the implementation of at least one of these management practices (cover crops, manure or compost application, minimum tillage or no-till, and/or perennial crop cultivation), the participants in this study understand the benefits of adding organic matter to their soils.

A number of factors inform farmers' SHK, which includes: education; developing connections with neighbors, experts and chemical distributors; and to a lesser degree, governmental and university recommendations. The most significant contribution to the farmers' SHK, though, is trial-and-error and practical experience. In addition, some farmers described intuition as a major influence on their management decision-making.

In order to analyze soil samples, paired t-tests showed no significant difference between high fertility and low fertility sites of all 15 farms sampled; however, variation can be found when considering farmers and their land on an individual basis. A multiple linear regression found significant correlations between all three variables (bulk density, % carbon and % nitrogen) and crop type; blueberry farmers had the lowest bulk density and highest % carbon and % nitrogen of all crop types sampled. Other significant findings concern different types of certification (farming philosophy), dream farm description (risk aversion) and work with crop consultants (community involvement). However, with such a small sample size, it is difficult to suggest any concrete findings from this study.

More research into the management practices, farming philosophy, community involvement, and risk aversion may provide insight into a farm's soil health and a producer's SHK. During a time of population increase, climate change and rapid soil degradation, it is necessary for us to understand what contributes to SHK and what management practices can be used to improve overall soil health.

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Acknowledgements

There were so many individuals contributed their support and skills to this project. I'd first like to thank Kaile and the Science Support Center for their help accessing the lab, retrieving necessary materials, and being available for any issue that arose.

Thank you to the baristas at Olympia Coffee Roasters, my regular study spot. I *really* would have struggled throughout this process without your smiles and your free-flowing caffeine, so thank you so much!

I sincerely appreciate the support of my "adjunct" advisors: Erin Martin, Kathleen Saul, and Mike Ruth. Erin, thank you for teaching me how to use (and troubleshoot) the CHN analyzer, answering questions and giving ample advice on analyzing my soil sample. Kathleen, I sincerely appreciate your help analyzing and synthesizing my data. And Mike, many thanks for teaching me how to use the random sample generator, in addition to helping me maintain order in my data.

Thank you to my friends and family for your guidance throughout this process. A special thank you goes to my roommate, Sarah Morrison, for providing an ear or a shoulder to cry on through the thick of it. This project would have been so much more over my head without you all.

Kevin Francis: I'm so grateful for the time we spent together on this project over the course of TWO YEARS. You've seen this through from its inception. You've been available when I needed you, gave me validation when the going felt nearly too tough to handle, and gave me space to grow and learn throughout this process. Thank you for everything!

Finally, I'd like to thank the farmers who participated or contributed to this study. Thank you for inviting me into your homes, offices, trucks, cafes and communities, and showed me what you know about your land and shared such amazing stories about your relationship with farming and your land. You all made this thesis happen, and I'm so honored that you've allowed me to share your soil health knowledge with the world.

Chapter 1: Introduction

As humans move into the 21st century, we are beginning to realize that the extent of our terrestrial frontier has been reached; at this point, we have relatively few places to continue inhabiting, farming and extracting natural resources. As such, it is necessary for us to restore our exhausted and overworked lands on a global scale (Doran, 2002; Biel, 2016). While this may seem like a straightforward task, the ideology and epistemology of the two most influential players responsible for land management, farmers and scientists, have misunderstood each other for over a century. In order to truly conserve our natural resources and protect our land from degradation, these two groups must learn to speak each other's languages, respect each other's point of view, and work collaboratively.

Farmers, the doers, users and interactors, have developed their management practices from an extensive historical framework dating back thousands of years; these individuals learn through experience and share information generationally and communally (Jensen et al., 2007). While this group has developed a nearly pre-historic tradition of land management, many of their practices have been found to lead to environmental destruction and have been attributed to the demise of entire civilizations (Montgomery, 2007). While these individuals possess a breadth of knowledge and have gained an intuitive understanding of their land through generations, many of them do not have the resources to effectively monitor the impacts of their management decisions on their local environment. They lack the depth of understanding concerning complex biological, physical and chemical processes taking place above and belowground.

Soil and Agricultural Scientists are oriented towards science, technology and innovation; they've developed their understanding since early Antebellum America and have formalized their inquiries into established scientific fields (Jensen et al., 2007; Cohen, 2010). These individuals are able to observe and monitor natural phenomena in the lab and in the field, from a microscopic to global scale. Their contributions towards our understanding of the land and soil are immense, specifically developing established physical, chemical and biological indicators of soil health (Doran & Parkin, 1994). They acquire a depth of understanding on a given subject; however, traditional scientific inquiry has favored a reductionist approach in which a complex biological system is deconstructed and understood as a sum of its parts (Kloppenburg, 1991; Biel, 2016).

The popularization of the German university model during the 19th century has resulted in the over-emphasis of basic scientific inquiry in academia (O'Boyle, 1983; Oosterlinck et al., 2002). In addition, soil and agricultural scientists have struggled to establish themselves as a respectable scientific field, suggesting that they receive less funding for research. This has resulted in their preference towards basic scientific inquiry, the pursuit of knowledge for the sake of knowledge, in favor of applied science, which seeks to understand how it is best diffused for use by a wider audience (Fox et al., 1987; Oosterlinck et al., 2002). Soil and agricultural scientists have immensely increased our understanding of the natural world; however, if their insights are not effectively communicated to the end users, their efforts towards land and soil conservation may not be fully realized.

While these two groups largely differ in their epistemological, social and cultural ideologies, their collaboration is absolutely essential to conserve natural resources and prevent land degradation on a global scale. In order to do so in the most effective way possible, farmers and scientists must work cooperatively to improve our understanding of how management practices impact our local environments (Hoffman et al., 2007). By utilizing established indicators of soil health upheld by scientists in conjunction with site-specific and experience-based knowledge practiced by farmers, the two groups can work together to improve overall understanding of soil health across the globe (Doran, 2002). Unfortunately, the heavy reliance on basic science in the last century has created a coincidental hegemonic dominance of western science over other modes of learning, particularly local and traditional ecological knowledge (O'Boyle, 1983; Fox et al., 1987; Oosterlinck et al., 2002; Bouma, 2018). This has forced farmers to doubt their experience-based understanding of their land, and the expert to non-expert relay of information has become the norm. The lack of communication and understanding between these two groups has allowed for the pattern of human-induced soil degradation to continue, even though our understanding of these systems has increased immensely.

I therefore argue that increasing our understanding of how these two groups diverge in epistemologies and ways of knowing, identifying commonalities between these two groups, and providing examples of successful applied scientific inquiry, will help pave the way towards truly sustainable land management. To further this inquiry, I ask a three-fold research question: what is the soil health knowledge (SHK) of farmers in the Yakima Valley? Where does this knowledge originate? And how familiar are these individuals with established indicators of soil health upheld by the agricultural and soil science communities?

In order to address these questions, I interviewed 15 farmers inhabiting the Yakima Valley, one of the most agriculturally productive regions in the United States (USDA Census, 2012). These individuals grow a wide variety of crops and come from a diverse array of backgrounds; their demographic information, history, education, work with internal and external groups, farmer identity, farming philosophy, and risk aversion were all points considered to potentially influence their SHK. I then asked farmers to identify one field of high fertility and one field of low fertility, and measured bulk density percent carbon and percent nitrogen, all established indicators of soil health and organic matter[1] content, to see what factors contributed to soil deemed healthy by academia.

Based on the literature, I suggest that older farmers (at least 50 years of age) born into farming families (with at least three generations of farming history), who grew up in the Yakima Valley, and are well connected to local agricultural communities will have better SHK and subsequently better soil health than other farmers. In addition, I hypothesize that my chosen indicators of soil health, bulk density, percent carbon and percent nitrogen, can accurately identify organic matter levels in the soil, which can then be used as a means to communicate soil health. This analysis will observe whether or not organic matter, the living component of the soil, can serve as a point of connection between both farmers and scientists. Both groups recognize the vital role living and dead organisms play in soil health, although as previously discussed, their ways of interpreting and communicating their understanding are different (Lobry de Bruyn & Abbey, 2002; D'Hose et al., 2014; de Souza Mello Bicalho & dos Guimaraes Peixoto, 2016).

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[1] For soil organic matter, the abbreviations OM and SOM will be used interchangeably.

Roadmap of thesis

This thesis begins with an extensive literature review of the history of land management, and how soil and agricultural sciences were born out this historic practice. I will then analyze how farmers and scientists differ in their modes of learning and will identify how these divergent epistemologies may have contributed to land degradation on a global scale. The methods section explains how I collected, analyzed and compared my interview and soil data. I then follow with the results and discussion, beginning with a comprehensive explanation of interview data, soil sampling results, followed by a thorough synthesis of these two sets of data. As a truly inter-disciplinary project, I hope to create a more comprehensive understanding of how farmers and scientists differ, how these discrepancies have contributed to global soil degradation, and how we can move forward collaboratively to ensure natural resource and land conservation indefinitely.

Chapter 2: Literature Review

This literature Review begins with an abridged examination of the history of agriculture and human land management, and how soil and agricultural science was born out of an early Agrarian America. I show that since soil and agricultural science has struggled to be recognized as valid scientific fields, the widespread application of new and noteworthy research has received little credence. I then examine how the neglect of scientific application has deepened the divide between farmers and scientists, encouraging farmers to rely solely on universities for support and information, and contributing to the Productivist era and the Green Revolution. Nevertheless, it is then essential to bring to light the vast contributions made by the soil and agricultural sciences, specifically creating physical, chemical and biological indicators of soil health; an explanation of how specific management practices impact the soil is also worthwhile, since this information can largely inform how farmers can better manage their land.

At this point, I delve deeper into the divergent epistemologies upheld by farmers, the doers, users and interactors (DUI) and the scientists, technologists and innovators (STI). I show how both groups have much to contribute to our understanding of the complex processes taking place above and belowground, but the fact that they exist in different cultures has historically prevented collaboration. I then cite specific ways in which farmers and scientists can learn to work together to increase mutual understanding and encourage the dissemination of practices of land conservation, offering successful case study examples.

Next, I delve into the tacit knowledge upheld by farmers. This group gathers information through trial-and-error, trusted internal and external groups, and is frequently passed down from generation to generation. Farmers develop knowledge through experience, and typically possess extensive knowledge of a specific site or region. Regardless of the knowledge they possess, I have also chosen to analyze whether or not other factors, like social capital, market demands, or risk management, impact their management decisions. This explains why I have selected seven indicators of soil health knowledge: demographic information, personal history, education, community involvement, farmer identity, farming philosophy and risk aversion.

As discussed throughout the literature review, much of farmers' knowledge is context and site specific; because of this, I have offered an abbreviated examination of the geological and social history of the area. Understanding the volcanic activity, glaciation, periods of flooding helps to inform the soil forming processes taking place, and exploring the social history, from the population of the area by the semi-nomadic Yakima tribe to the impacts of Euro-American settlement, we can see how the area became the agricultural epicenter it is today.

History of soil science

Agriculture – Then and now

In terms of terrestrial ecosystems on planet Earth, soils are the basis of existence for all life on land. We are born from soil, we are supported by the soil throughout our lives, and when we die, we become the soil again. All terrestrial organisms have learned to work with the natural processes occurring above and belowground, reaping benefits from the land during fertile years and cutting back in times of drought or famine. As carbon-based life forms, we grow from, benefit from and become the organic matter of the soil, and we work, grow and change within our constantly evolving planet.

While the health of any ecosystem depends on the maintenance of natural processes taking place on the soil surface and within the soil column itself, the well-being of humans depends on the health and wellness of the land in which they inhabit (Barrios, 2007; Buneman et al., 2018). Humans began establishing settlements in favor of nomadic living roughly 11,000 years ago and began cultivating particular plants for their consumption (Bellwood, 2017). As this occurred, humans' relationship with the soil inevitably changed.

According to Montgomery (2007) as humans became stationary and nutrient cycling changed on agricultural lands, humans began to quickly recognize the impacts on the soil due to the extraction of nutrients in the form of consumable crops. The author argues that "soil loss contributed to the demise of societies from the first agricultural civilizations to the ancient Greeks and Romans, and later helped spur the rise of European colonialism and the American push westward across North America". Soil degradation can be defined as a continuous human-induced process that typically limits agricultural pursuits, and deteriorates the chemical, physical and biological properties of a given soil; through interactions with both topography and climate, the undisturbed ecosystemic processes of an area are altered, and the sustainability and subsequent agricultural productivity of the land diminishes, threatening human and animal food security (Baumhardt et al., 2015).

This led to a number of inquiries into maintaining soil health and fertility at the dawn of the agricultural era, explaining how a number of the first written documents concerned the maintenance of soil fertility (McNeill & Winiwater, 2004). In what would become the United States, some Native American tribes classified soils, and prescribed different management techniques for different soils (Brevik et al., 2016). While it is true that major civilizations fell due to rapid expansion and exhaustion of resources, humans have continued to grow and develop, essentially changing the face of our planet. Even today, much land on the Eurasian and African continents have been farmed since the dawn of agriculture; in order to survive, humans had to learn how to adapt to the natural cycling of nutrients above and belowground, and learned to not only exist, but thrive in the ecosystems in which they inhabited (Bellwood, 2017).

In the United States, human expansion westward was in pursuit of new land, new opportunity and new development. Since the Renaissance, the Western world has been in perpetual pursuit of the new Frontier; utilizing and exhausting resources in one area and taking land from other individuals to perpetuate this process (Montgomery, 2007). With the help of modern science and historical inquiry, humans have begun to see the patterns of previous civilizations and are beginning to recognize that we've reached the limit of our pursuits (Doran & Zeiss, 2000).

Dating back 4,000 years in ancient Egypt and Sumar, plows were initially branches used to scratch the soil's surface; however, the first plows to actually rip through the soil column were f utilized during the 17th century (Pryor, 1985). With the invention of the cast iron moldboard plow by John Deere in the 19th century, a new form of land conversion was underway; this allowed for the conversion of fertile but densely-packed soils of the Great Plains, perpetuate the continuation of Manifest Destiny to the west (Montgomery, 2007). The fertile soils of the Great Plains were rich with organic matter from plant and animal biomass accumulation, and their conversion to farmland permitted became viewed as a seemingly inexhaustible natural resource for crop production. As described by the U.S. Geological Survey in 1902, though, "The High Plains, in short, are held by their sod"; this shows that early 20th century scientists recognized that the conversion of grassland to agricultural land would result in the rapid decomposition of organic matter, leading to deterioration of the soil (Montgomery, 2007). The most well-known instance of soil degradation in American History is the wind-induced erosion of the Great Plains in the 1930s, later referred to as the Dust Bowl; however, other events including the destructive water erosion of the Badlands in Mississippi in 1910 can also be described as events where human management was unsustainable, and the demand for food outweighed the supply of the land, resulting in fertile topsoil loss (Baumhardt et al., 2015). More recently, the post-World War II conversion from an animal and crop residue nutrient base to a synthetic chemical nutrient base has led to the excess application of synthetic fertilizers, particularly nitrogen, phosphorus and potassium (Kvaløy, 2004; San Martin, 2017).

As tractors became more popular and new tillage implements were invented, intensive tillage contributed to increased water and wind erosion (Montgomery, 2007). This erosion contributes to the loss of excess nutrients into major above and belowground water systems, resulting in eutrophication, the over-growth of algal blooms that create hypoxic environments where life cannot exist (San Martin, 2017). The greatest example in the United States is the massive dead zone in the Gulf of Mexico. Due to the leaching of excess nutrients into the Mississippi River, approximately 8,776 square miles of the Gulf of Mexico are uninhabitable by aquatic wildlife, disrupting not only the fishing industry in the area, but the natural ecosystem processes (van Grinsven et al., 2014; Gallegos, 2017).

These examples represent a continuation of the problem described by Montgomery (2007); humans encounter a new frontier, utilize and exhaust the resources of the newly discovered land, and the civilization either falls apart or the population moves towards a new area to continue the cycle. A similar pattern can be discerned with science and technology. As was the case with the invention of the moldboard plow, the tractor and synthetic chemical fertilizers, the rapid adoption of these new discoveries and technologies before their impacts on the land were fully understood resulted in large scale soil and land degradation (Sears, 1935; Walker & Brown, 1936; Biel, 2016).

As previously discussed, farmers have inhabited the Eurasian and African continents for thousands of years; they've learned how to adapt to the systems where they live, for the most part, in order to survive. Many of these individuals did not do so in isolation, though; particularly in the past 300 years, new technologies have assisted in the maximization of their land for increased production and their continued survival on the land (Hoffman et al., 2007; San Martin, 2017).

An Antebellum introduction and Land-Grant/extension formation

The true development of soil science as an academic field dates back to the post-Revolutionary War America, where the inquiry into soils shifted to a more formal and scholastic pursuit. Cohen (2010) argues that the early Republic or Antebellum Era of the United States (1790s-1850s) are the origins of early soil science and geology as established scientific fields. The author examined the contemporary rural press of the time, records of regional agricultural societies, and state scientific surveys. For example, to become a member of James Madison's Agricultural Society of Albemarle, participants were expected to conduct experiments on their own land, write a short report, and share their findings with the group. These inquiries included: animal care, crop rotation strategies, fertilizer use recommendations and other important agricultural pursuits (Cohen, 2010). Through this analysis, the author identifies that the new 'era of systematic agriculture' at this time was so pervasive, that the requirements of this new agrarian lifestyle shaped the young nation's political economy and policy (Cohen, 2010). The early establishment of soil science as a field is deeply rooted in the relationship between humans and the soil, and how to improve the health of the soil for human use.

Simultaneously, the German university model, which ‘exemplified the ideal of pure learning, the disinterested pursuit of truth, knowledge for its own sake’ began to take hold in the United States during the second half of the 19th century (O’Boyle, 1983, p. 3). The ‘scientification’ of soil and agricultural sciences from the Antebellum movements paired with this interest in higher learning resulted in the formation of land grant universities in the second half of the 19th century. With the Morrill Act of 1862, “…each state, which may take and claim the benefit of this act, to the endowment, support, and maintenance of at least one college where the leading object shall be, without excluding other scientific and classical studies, including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts…” (Morrill Act, 1862).

Soil scientists, taught at the newly developed Land-Grant Universities, relied heavily on farmer and land manager participation; soil surveyors and fertility experts had direct and intensive contact with stakeholders, utilizing empirical interpretations for suitable land usage based on practical experience (Bouma, 2018). As more information was required to answer modern land use questions, quantitative inquiry and modeling replaced farmer inquiry, and the dichotomy between the farmer and soil scientist began to take shape.

McDowell (2003) argues that the allotment of 17,430,000 acres of land for agricultural and mechanical arts-based universities signaled a shift in academia by allowing the working classes to finally pursue higher education outside of aristocratic intellectual pursuits; in addition, this signals an expansion in the scope of scholastic inquiry to practically-applicable fields relevant to more end users. Through this engagement, Land Grant universities provided a means to connect the creation of knowledge and art with practical application in fields like agriculture that were not previously viewed to be worthy of academic pursuit. While this was the anticipated result of the formation of Land Grant universities, many students pursued higher knowledge but did not return to the farm, and the goal of transmitting knowledge to farmers and end users who did not attend university was not achieved. To reach end users, the Cooperative Extension through the Smith-Lever Act of 1914 followed suit, which provided federal government funding to disseminate knowledge created in the universities to farmers and land managers (McDowell, 2003).

Some have argued that maintaining a purely practical-based emphasis unfounded or disconnected from theoretical knowledge prevents a scientific field from creating revolutionary change. While the Cooperative mandate facilitates the dissemination of knowledge to end users, pressure rests on the shoulders of the agricultural sciences to not only teach new students and farmers, but to also develop new agricultural knowledge through basic research. According to McDowell (2003), the extension obligation imposed by the agenda of the U.S. Department of Agriculture occupies between one-third and one-half of faculty and research objectives. As explained by Fox et al. (1987), this struggle for recognition and funding between applied and basic agricultural research in some cases encouraged competition for recognition between the two fields, and discouraged cooperation and collaboration. Other authors explain that the two fields should not be mutually exclusive, but the pursuit of developing ‘knowledge for the sake of knowledge’ within the basic sciences in tandem with the distribution of new science to farmers and land managers through applied science deserve equal recognition and funding (Fox et al., 1987; Oosterlinck et al., 2002). Nevertheless, since the formation of

Land Grant Universities in the mid-19th century, soil science has grappled to define itself outside of the applied science realm.

Tension rises at the turn of the 20th century

The struggle between applied and basic science within the agricultural sector continued well into the 20th century. Two authors express this dichotomous clash of objectives: Dr. P.E. Brown, a professor of soil science at Iowa State University argues for the enhancement of soil and agricultural sciences as a reputable basic science, and Paul B. Sears, a botany professor at the University of Oklahoma, justifies the need for continued applied research and work with land users and by providing the Dust Bowl Era as an example. As an agricultural science professor at a Land Grant university, P.E. Brown's article published in *Science* entitled: *The New Soil Science* (1929) argues for the need to look beyond practical application for soil science as a means to create true change within the field itself. On the opposite scale, Paul B. Sears, one of the first ecologists on the academic scene, explains in his book *Deserts on the March* (1935) that the problem of soil erosion during the Dust Bowl was a result of careless land management with the westward expansion of the United States. While the struggle for applied and basic research persisted into the 20th century, it is unclear why the agricultural sciences do not recognize that applied and basic research are not mutually exclusive, and the development of one is reliant on the success of the other (Fox et al., 1987).

As explained by Brown, soil science originated out of applicable necessity, as with most sciences, because of the “struggle by man toward the utilization of nature” (1929, p. 619). But in his manifesto, Brown asserts that “there is an even more powerful source than use in bringing about the evolution of sciences. It is the unconscious struggle of our natures for the acquisition of abstract knowledge or for the discovery of the laws of phenomena” (Brown, 1929, p. 619). The author then asserts that complex classification systems must be formulated in order to differentiate one soil from another, and to manage each soil based on its specific characteristics. Soils, he argues, are no longer purely a medium for plant cultivation and crop production but are studied as an individual entity within themselves. Through soil classification, analyses of vegetationk, environmental conditions, geological formation, and transport (among other formative processes), the ‘new soil science’ has the objective to answer specific questions for each soil type; in so doing, the soils may then be managed properly to meet the needs of the soil and the plants they grow (Brown, 1929).

This shift in the investigation of soils suggests that soil scientists wanted to establish the field as a reputable basic science. By ‘adding to the sum total of human knowledge’ and contributing to the ‘establishment of the principles and laws of soil science’, soil science could be recognized as possessing a theoretical basis and could then be recognized as a real science (Brown, 1929, p. 621). As mentioned earlier, this was of significant value, for each soil could be treated and managed to its particular specifications. This separation of the ‘new soil science’, away from soil examination purely for human application, would widen the divide between farmers and soil scientists (Ingram et al., 2010). Within scientific inquiry, more questions are raised than answered;

although valuable new information is frequently found and recorded, the disconnect still exists with the application of these revolutionary ideas (Fox et al., 1987). Dr. P.E. Brown envisioned that the 'new soil science' would be "definitely and indisputably agriculturally practical" (1929, p. 620); however, as will be discussed in detail later, the deductive model scientific inquiry does not align with how farmers acquire and disseminate knowledge.

Around the same time as P.E. Brown's call for a new soil science, Paul Sears, an ecologist and botanist at the University of Oklahoma, was calling attention to the rapid degradation of land and soil throughout the American landscape. The author describes the development of agricultural civilizations throughout history, explaining that most follow a similar trajectory: first, humans inhabit and farm in valleys with fertile, rich soil. As nutrients are extracted without being returned, the soils become depleted of nutrients, and are rendered useless. Humans then move to the uplands where forests are cleared; this results lumber for further development, fresh soil, and more fertile mud moves downstream to re-fertilize the valley soils.

The author explains that this model is not sustainable, and cites the fall of a number of civilizations, including the Mayans and Romans due to the disregard to the laws of nature.

> "The laws which govern the development of soil and vegetation are as inescapable as the laws of conservation of energy and of matter upon which they are based. No matter how complex or seemingly mysterious the operations of the organic world, they are still based upon cause and effect. It is as impossible to get something for nothing as it is to make water run uphill. If man destroys the balance and equilibrium demanded by nature, he must take the consequences. There is no magic which will undo the mischief he has wrought" (Sears, 1935, p. 67)

The author considers the Dust Bowl, and how intensive mechanical agriculture has disrupted this natural cycle of inputs and outputs. The result being millions of acres of soil degradation to wind and water erosion, and the further encroachment of humans onto the most sensitive lands.

The author states that, 'the picture we have seen is not one of utilization and adjustment, but of exploitation and waste' (Sears, 1935, p. 142). While many would argue that decreasing ownership towards a commons model would encourage soil conservation, the author asserts that, '…it is human nature for a man to take better care of his property than of another's, provided that he has been trained to do so' (Sears, 1935, p. 150). To move from this model, the author suggests increasing education and information dispersal to all vested groups, with an emphasis on young adults; he argues that county and extension workers have worked to stave off total destruction of our lands but believes that 'there is too much emphasis on detail, and not enough on policy' (Sears, 1935, p. 151). He also proposes that taxation and incentivization are surefire methods to increase soil and land conservation.

Sears then considers the role of scientific development in soil conservation, arguing that scientific development can be both useful and dangerous.

> "Sometimes, but by no means always, the man of science can control the thing he is examining, and thus learn its behavior under special circumstances. This he calls an experiment. Often, he is obliged to take apart whatever it is he is learning about. This he calls analysis. If the thing is very simple, he can put it back together, as a child might do with a block puzzle… What is true of the simplest plant or animal is infinitely more true for man and of society. The delicate interplay of motives, the clash of desires, and the seemingly spontaneous growth of culture patterns, so like the irresistible, rhythmic process of birth—all of these involve matters which defy the relatively simple language of science, even when science affixes names to them!"
> (Sears, 1935, pgs. 157-158).

Here, it is clear that Sears warns against the over-simplification of reducing biological systems to a sum of their parts. In addition, he calls on scientists to seek out more social involvement and effective means of publication to successfully diffuse their findings throughout society.

Interestingly, changing social and climatic conditions during the Dust Bowl Era shifted P.E. Brown's focus somewhat towards application, aligning more closely with Sear's call for applied scientific inquiry. In 1936, P.E. Brown and R.H. Walker published their findings from a soil erosion survey throughout Iowa conducted in 1934. The authors found that only 87% of the land was affected by soil erosion, and that at least 40% of the land surveyed was over 50% degraded due to erosion. According to the authors contributing factors to soil erosion included: rainfall distribution and intensity; land topography; soil texture, type and characteristics; and management (Walker & Brown, 1936). During this time, the authors recommend that farmers grow 'non-tilled and pasture crops at regular and frequent intervals, to reforest steep and broken areas, and build up the organic matter content of the soil' among other recommendations (Walker & Brown, 1936). While the need to alter management practices to prevent soil degradation and conserve natural resources is highlighted, the steps necessary for both agricultural scientists and farmers in order to facilitate this shift is not described.

Both Brown and Sears are aware of the need to change management practices to prevent soil erosion, and both believe that a shift of focus towards either basic (Brown, 1929) or applied (Sears 1935) science will lead to the improvement of the opposing scientific inquiry. Brown's declaration of *A New Soil Science* (1929) represents a shift away from creating change through practical application; in so doing, he argues that the knowledge will naturally be transferred to land managers since the extension system is already in place. Sears, on the other hand, not only stresses the need to change management practices in the future but prescribes a means to do so: educate the masses, enact relevant and useful policy, and encourage scientists to play a role in the communication of their intellectual findings. While both scientists take a different approach, the two agree that either applied or basic science are not mutually exclusive; while they argue in favor of one form or the other, other authors have found that the success of one is dependent upon the success of the other, and that investment and funding in both basic and applied science is necessary for the development of any scientific field. (Oosterlinck et al., 2002).

The Green Revolution and Productivism

As previously described, farmers and agricultural scientists were beginning to realize the limitations of intensive tillage in agriculture as was observed during the Dust Bowl. The recurrent export of nutrients as crops with no nutrient replenishment was not a model that could feed the world's growing population; this resulted in the degradation of large amounts of originally fertile land throughout the country (Sears, 1935; Walker & Brown, 1936). In the realm of soil science, the synthesis of atmospheric nitrogen (N_2) gas into a usable form for plant uptake (either ammonia (NH_3), or a combination of ammonia-nitrate (NH_4NO_3) was first pioneered by a chemist by the name of Fritz Haber, winning him the Nobel Prize in 1918 (Science History Institute, 2017.).

The mass production of synthetically derived fertilizers was perceived by many to be the answer to meet the food demands of the growing global human population (Biel, 2016). After World War II, interest in global agricultural production increased, but not under the guise of providing aid to impoverished farmers in the global South. At this time, the World Health Organization (WHO) and many developed countries recognized Malthusian fears of increased population with a subsequent increased demand for food and believed that current agricultural production was unable to meet these demands (Kvaløy, 2004). The Green Revolution was not only motivated by an 'altruistic' need to meet the demands of an increasing population in the global south, but also as a political strategy to prevent the rise of Communism in these areas (Kvaløy ,2004). According to San Martin (2017), agricultural development and the use of synthetic fertilizers were viewed as a tool to combat the rise of Communism. "Cold War politics understood agricultural production, technologies, and agrarian reforms as central to the development of better social and economic conditions in the countryside… the *Feeding the World* argument [as defined by the Rockefeller Center's Mexican Agricultural Program in 1951] is in part the product of the ideological framework which understood food access and agricultural production as a critical dimension of international relations during the Cold War" (San Martin, 2017, p. 782).

As a result, global spending on agricultural and soil research sky-rocketed in the 1960s and 1970s, and the Green Revolution was upon the world. Regardless of what factor contributed to the rise of the Green Revolution, soil and agricultural sciences experienced a golden era of funding and research in light of this emphasis on agricultural development (McDowell, 2003). Through international institutions like the Consultative Group in International Agricultura Research (CGIAR), funding for research on the three main cereal crops (wheat, maize and rice) during the first part of the Green Revolution was around $13 billion (Pingali, 2012). In addition, synthetic Nitrogen fertilizer increased by 366% from 1961 to 1988, and a 759% increase from 2013 to 1961. The mass-production and widespread use of genetically modified seeds as well as synthetic fertilizers have tripled the amounts of cereal crops produced annually with only a 30% increase in land use change in the past 50 years. Without the new technological advancements of the latter half of the 20th century, the food supply could only support half of the population today (San Martin, 2017).

This emphasis on agricultural production by increased mechanization, decreased labor, and increased synthetic inputs has also been referred to as Productivist agriculture. What was once a natural system of nutrient loops and flows then became a means to feed a growing population, transforming natural complex biological systems into simplified machines with the purpose of increasing production (Biel, 2016). Wilson provides a formal definition, stating that Productivist agriculture is "…a commitment to an intensive, industrially-driven expansionist agriculture with state support based primarily on output and increased productivity" (2001, 78). Within agricultural production, the industrialization, commercialization, specialization and increase in corporate involvement are all typical of the Productivist model. It is interesting to note that within Productivism, agriculture ideologically upholds a central hegemonic position in rural society. In addition, "Food regimes during the Productivist era are… characterized by mass consumption of agricultural commodities, the expansion of world food trade in a rapidly growing capitalist market, and the adoption of Fordist regimes of agricultural production' (Wilson, 2001, p. 79).

Whether as a means to combat Communism or a truly altruistic mission to end world hunger, the technological advancements of the 20th century provided food and fiber for an exponentially increasing population. But at what cost? According to San Martin (2017), the overuse of synthetic N fertilizers results in losses of up to 60% of applied N, creating pollution in above and belowground bodies of water, coastal ecosystems and watersheds through eutrophication. In addition, the energy-intensive production of synthetic fertilizers has increased greenhouse gas emissions by an average of 3.9% between the years 1961 and 2010. Interestingly, during the first wave of the Green Revolution (1960s-1980s), large amounts of funding were provided for agricultural development; however, much of that investment has waned in the last 20 years (Pingali, 2012).

Although many of these schools still offer ‘colleges of agriculture’, the original emphasis, to primarily teach agriculture and mechanical arts, has nearly fallen to the wayside. As more U.S. citizens began attending college, and as the economy grew and changed, Land Grant universities shifted their focus to higher sciences and unfortunately some have little agricultural identity today (McDowell, 2003). And as the emphasis in many of these Land Grant universities has shifted away from agricultural and soil science in favor of other academic pursuits, the funding and research in support of those fields has descreased significantly. One can discern a similar pattern at the turn of the 20th century, where education and outreach for agricultural sciences in Land Grant universities stagnated, and interest in the past twenty years in the field either through applied or basic scientific means waned. A call for a *New Soil Science*, as identified by both Brown (1929) and Sears (1935) is upon us yet again.

At a time when human-induced soil degradation has reduced the ‘productive capacity’ of soils by 40% due to erosion, pollution, soil cultivation, over-grazing, land clearing, salinization and desertification, funding and interest in research and academic institutions specifically oriented toward soil science and sustainable agriculture was at an all-time low at the turn of the 21st century (Doran, 2002). Hartemink & McBratney (2008) compared the funding, total number of scientists and research publications in the major scientific journals (*Science* and *Nature*) that were devoted to soils with all other scientific pursuits from 1993 to 2007. Interestingly, the authors found that 0.5% of all publications in *Nature* and *Science* were devoted to soils; that less than 1% of total global research and development funding was granted to soil science projects (€3.2 billion toward soil science and €3.2 trillion total); and finally, that 0.5% of all scientific researchers are soil scientists (16,000 compared to 4 million). Even so, Hartemink & McBratney (2008) argue that a soil science renaissance is upon us, and that renewed interest in the field can be discerned by an increased trend in research publications and other academic endeavors.

At the turn of the 21st century, the call for the development of both applied and basic scientific inquiry within agricultural sciences resurfaced. J.W. Doran (2002), a famous soil scientist from the University of Nebraska who played a major role in defining soil quality, called for a shift away from the increased crop yield and production model of the Green Revolution; instead, the author suggests scientists orient towards a focus on sustainable management where yields are maintained with minimal impacts on the environment. The author argues that it is the responsibility of soil and agricultural scientists to create strategies for sustainable management that enable producers to maintain soil health and improve the overall ecosystem; however, purely defining indicators and identifying management practices is not enough. Scientists and farmers exist in separate realms, they acquire and communicate knowledge differently, and sometimes, they have different objectives. It is the responsibility of both groups to understand these differences, forge relationships, and align their goals in order to prevent further degradation and improve soil health on a global scale.

Researchers in agricultural and soil sciences

As previously described, soil and agricultural scientists have revolutionized agriculture in a number of ways. In addition to the substantial strides made in the 20th century discussed previously, over a century of scientific analysis has allowed soil and agricultural scientists to classify soil characteristics, understand soil-forming processes, define indicators of soil quality and health, and understand how they can benefit ecosystems and humanity. Not only have they helped farmers to increase food and fiber production globally, but they have greatly informed our understanding of the chemical, physical and biological parameters that make up the soil[2]. This section describes ways in which soil and agricultural scientists have improved our understanding of soil-plant relationships, suggests areas of future development within these realms, and explains what the STI mode of learning looks like in practice. While the contributions to agricultural development will be highlighted, it is also essential to explore how the scientific model has nearly silenced other modes of learning, and that the reduction of biological systems to the sum of their parts has been shown to lead to environmental and ecosystem degradation.

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[2] For a detailed description of these parameters, see: The Soil Itself, p. 57

Evaluating the quality, health, functions and services of soils

Pedology, or the study of soils in their natural form, involves a number of sub-disciplines to explain their origin and formation. Pedogenesis and soil morphology define the formative and transformative characteristics of soils, while soil surveys are conducted to describe the landscape of soils along with creating a classification system. These pedological collections are then used to interpret a soil's properties for the optimal management and use of the land (Singer, 2015). According to Hartemink (2015), it is essential to classify soils for two reasons: 1) because without it, the knowledge would be 'factual chaos' without a codified system, and 2) it enables soil scientists to understand the interactions among and between soils within specific locations, thereby allowing soil scientists to predict behaviors of soils with similar characteristics.

The classification of soils is a necessary first step in fully understanding their basic characteristics; however, according to Bouma et al. (2015), taxonomies lack functional analysis of soils. Therefore, establishing indicators of soil quality allows soil scientists and other stakeholders to evaluate a soil for specific uses; these indicators include a whole host of variables, but can be grouped into three main categories: physical, chemical and biological. In addition, assessing soils based on abiotic, biotic and functional parameters may add further insight into the quality of a given soil (Vincent et. al., 2018). The overarching definition of soil quality, as established by Doran and Parkin (1994): "the capacity of a soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health". This broadens the emphasis of soil and agricultural sciences beyond the simplified goal to increase production commonly upheld during the

Green Revolution (also referred to as Productivist agriculture); although plant production is a facet of soil function, it should also be managed in such a way to minimize air and water pollution, and to promote plant, animal (and consequently human) health.

Recent decades have indicated a shift towards valuing soil quality as a facet of ecosystem functions and services. As defined by Costanza et al. (1997), "ecosystem services consist of flows of materials, energy, and information from natural capital stocks which combine with manufactured and human capital services to produce human welfare (whether directly or indirectly)" (pg. 254). Scientists utilize soil quality as a means to evaluate how healthy soils function in an ecosystem, since they are a fundamental component of most terrestrial ecosystems. For example, Bouma et al. (2015) identified the eight 8 ecosystem services provided by soil; examples include: biomass production, storing, filtering and transforming nutrients, as well as a physical and cultural environment for humans and their activities.

In addition, Buneman et al. (2018) categorizes these services into three groups: soil threats, functions, and services, and then diagrammatically represents how these three sectors are inter-connected. A threat like erosion relates to the soil functions habitat provision, element cycling, soil structure maintenance, and water cycling; these are then related to such ecosystem services as biomass production, biodiversity conservation and consequently, erosion control (Buneman et al., 2018)[3]. By defining these functions and connecting them to relevant threats and ecosystem services, soil scientists are then able to situate their research in a relevant framework for continued research.

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[3] See Table 6, Appendix, p. 344

As approaches to soil and land evaluation evolve, it is the responsibility of the soil science community to create systems for soil quality analysis that maintain an ecosystem's ability to function, minimize soil threats, and appeal to the stakeholders and end users responsible for carrying out practices that maintain soil quality. Buneman et al. (2018) examined 62 published articles with 65 minimum data sets for soil quality analysis. The areas of emphasis for most studies included the ease of sampling and the indicators' sensitivity to management changes. The most frequently utilized indicators analyzed chemical components of the soil; total organic matter, carbon and pH were the most frequently cited indicators, but others of note included: available phosphorus and potassium, total nitrogen, electrical conductivity, cation exchange capacity, and mineral nitrogen (Buneman et al., 2018). Although cited occasionally, biological and biochemical indicators were less frequently measured when compared to physical and chemical indicators.

The author calls for a shift in the focus of soil science towards: 1) conceiving of soil quality as part of a complex matrix of quality assessment and adaptation systems; 2) recognizing novel tools in soil quality assessment that support ecological agriculture; 3) re-orienting towards a 'fundamental system re-design' through regenerative agriculture; and 4) working towards achieving societal goals like the UN's SDGs to 'stress the importance of [improving] soil quality' for the betterment of society (Buneman et al., 2018, pg. 107). Although the authors call for a realignment of goals in the field towards societal objectives, their conclusions do not suggest methods to increase outreach or education of new or optimal soil quality indicators to land managers, or the public in general. Nevertheless, considering what scientists what the other soil and agricultural scientists believe the future of soil science should be will provide insight into the objectives of the field in general.

Future of soil science inquiry

Buneman et al. (2018) prescribed novel soil quality indicators that require continued research. According to the study, biological indicators are the most responsive to immediate management changes, and as 'canaries in the coal mine', would accurately represent the effectiveness of management changes on a shorter timeline (Buneman et al., 2018). In addition, the authors discussed other novel indicators that should be further developed, like the more active/labile pools of organic matter that are also sensitive to change, as well as the technological advancement of soil sensing through in-the-field or laboratory analysis by means of near-infrared spectroscopy, electrical conductivity monitors, and x-ray tomography that give three-dimensional images of the soil structure (Buneman et al., 2018). The following section explores where the soil science literature in general hopes to focus its research efforts in the near future; interestingly, the same tension between applied and basic science discussed previously can be observed.

Soil biology

When comparing natural ecosystems with managed agricultural systems, the internal regulation of above and belowground nutrient and carbon flows are drastically different. Natural controls present in undisturbed ecosystems are significantly compromised on cultivated land, and the manipulation of ecosystemic processes within the soil drastically limits the above and belowground biodiversity, thus making agricultural soil dependent external inputs and human management (Barrios, 2007). Recognizing the role played by soil flora and fauna may be the crux to the issue of sustainable soil management. Through basic scientific inquiry, microbiologists and soil ecologists are beginning to scratch the surface of biological aspect of the soil which, “encompass[es] the collective biomass and activities of soil dwelling organisms” (Lehman et al,. 2015, p. 993). The authors argue that: “the pathway for mitigation and even reclamation of degraded soil is through an increased emphasis on research and education [of soil biology]” (Lehman et al., 2015, p. 995).

According to Barrios (2007), it is essential to study soil flora and fauna because of their high diversity and widely variable distribution across soil matrix; however, due to this complexity, it is difficult to know where to even begin. Lehman et al. (2015) discusses gaps in research and areas of highest priority in order to improve soil health and in turn reduce soil degradation. These include: genetic identification, understanding biological activities and interactions, ecological processes taking place, and the relationship between specific biomes and their relationship with aboveground plant communities. This barely scratches the surface of what is required of soil biological inquiry, but it provides a starting place. From a basic scientific perspective, we may better understand what soil ecosystems support healthy and productive crops, and how aboveground diversity can aid the healthy development of these communities.

While the need for basic scientific inquiry into soil biology has been well defined, very little research has considered what farmers know about soil biology, and what they need to know to manage the health of their soils. While the topic of farmers’ knowledge will be covered in great detail later in this review Bennett et al. (1999) found that from a sample size of 14 farmers in New Zealand, these individuals had little or no understanding of biological health indicators such as microbial biomass. While other studies have found farmers have a wealth of understanding of larger soil biota like earthworms (Zuniga et al., 2013), their understanding of complex soil microbiological processes is lacking, largely because these organisms are not visible with the human eye (Grossman, 2003). In addition, Pauli (2016) found that few publications overlap between soil biology and the social sciences, indicating a need for soil and agricultural scientists to bridge this gap and inform farmers of complex soil biological process. Research into the application of these sciences is necessary to further the development of agricultural scientific inquiry in general.

Soil carbon and organic matter

There is more organic carbon found in the soil than in terrestrial vegetation and the atmosphere combined (Lehmann and Kleber, 2015). While organic matter will be discussed in further detail later, the relationship between soil organisms, organic matter, and the total soil C pool is an area of extreme importance. In addition, many farmers express having the greatest knowledge of this soil component, and this can therefore serve as a starting-point for creating connections between farmers and scientists, further integrating both applied and basic sciences (Lobry de Bruyn & Abbey, 2002; D'Hose et al., 2014; de Souza Mello Bicalho & dos Guimaraes Peixoto, 2016). Much literature exists on the accumulation and decomposition of organic matter in both fresh and very dead forms (Bot & Benites, 2005; Fenton et al., 2008; Stockmann et al., 2013) others); however, as research into decomposing organic material delves deeper, theories we assumed to hold true are now under debate. Because of the massive size of the global C pool and the complex biomes within the soil, knowledge gaps within both labile (freshly decayed) and recalcitrant (decomposition resistant) forms of organic matter must be better understood (Lehmann and Kleber, 2015; Buneman et al., 2018).

For example, Lehmann and Kleber (2015) state that the previously upheld theories concerning humic substances (highly resistant to decay and essential for the holding and transport of nutrients) are nearly archaic, and as the knowledge base of soil biology broadens, our investigation of highly decomposed and recalcitrant material should be re-considered as well. This of course has implications for the measurement and modeling of a soil's capacity to sequester C, since a major push for improving degraded soils is for its potential to not only prevent the release of CO_2 into the atmosphere through degradative practices, but to also potentially sequester C from the atmosphere, thereby combatting climate change (find sources). As previously mentioned, because our understanding of SOM in its various forms of decomposition is not well-understood, our methods for modeling potential C sequestration are lacking. Stockmann et al. (2013) proposes that efforts should focus on models that link physical and biological processes through time; in so doing, our understanding of the functions of soil C will develop. As our understanding of soil organic matter within a basic scientific context grows, scientists should therefore aim to communicate this new knowledge as an applied field, increasing the knowledge and understanding farmers possess concerning organic matter.

Technological development

Soil sensing from a variety of spatial scales is necessary to further our understanding of the biological, physical and chemical processes taking place below our feet. *En* situ observations, like Visual Soil Evaluation (VSE) have been proposed to further the understanding of physical properties like soil structure (Guimaraes et al. 2017). Through a thorough analysis of the available literature, the authors suggest that VSE can be used over varying temporal scales to evaluate the effects of land use and soil management on soil; in order to recognize the full potential of this method, integrating VSE with other soil properties has the potential to create a more holistic understanding of a piece of land. The integration of this method with remote and wireless sensing technologies can help fill the gaps in our understanding as well.

Also referred to as precision agriculture, the incorporation of remote sensing and geospatial analytics can also be summarized as: “the use of [information technology] IT applications to electronically monitor soil and crop conditions and to target the treatment with high [a] level of detail” (Aubert et al., 2012, p. 510). While the development of this new technology through basic scientific inquiry is of value, it is necessary to understand how to encourage the adoption of new technology by farmers. Problems arise due to the expensive initial investment required for new technology by farmers and has been shown to encourage the corporatization of small-scale farmers into larger and fewer conglomerates (Gaemelke, 2001). In addition, Aubert et al. (2012) found that issues with compatibility arose with the widespread adoption of precision agriculture by Canadian farmers due to the importance of farmer’s expertise in the new technology[4]. Therefore, applied research efforts should orient towards increasing farmer adoption by maintaining low costs and providing education and outreach.

Through satellite imaging and spectral analysis, remote sensing procedures are capable of mapping vegetative cover, and offer a cheap and effective method to analyze

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[4] For more information on the role of experience and adoption of new practices in farmers’ groups, see the “Farmers: the creation and dissemination of tacit knowledge” section.

areas of soil degradation. Through "a review of the application of remote sensing technology on soil erosion", Sepuru & Dube (2018, p. 2) found remote sensing to be the most effective method for mapping soil erosion due to the scale, effectiveness and cost-efficiency. The authors recognized shortcomings with this method in the form of 'low spectral resolution' from previous models but affirmed that newer satellite technology and improved data imaging will fill theses gaps in the future (Sepuru & Dube, 2018).

On a smaller scale, Burgess et al. (2010) tested the efficacy of a wireless sensor network on its ability to satisfy the needs of forest and agricultural researchers. The three benefits suggested by the authors include: "improved experimental design via flexible equipment deployment, improved monitoring access in logistically challenging environments, and increased density of observations for better validation of models and hypotheses" (p. 30). Burgess et al. (2010) found the system to be flexible with other sensing operations, but challenges arose with too much variability in sustainable power sources and the complexity of software programs beyond the scope of computer scientists.

New technologies as defined as Precision Agriculture have been shown to: improve total plant nutrients, assess and monitor water infiltration and retention for specific plants, optimize pesticide and fertilizer applications, and monitor plant and crop health from both a micro- to geospatial scale (Gaemelke, 2001; Aubert et al., 2012). More research into the application of such technologies is necessary in order to truly improve the efficient use of both nutrients and water, as well as improve overall crop and soil health.

Transdisciplinary research

As previously discussed, soil science has its roots in both geological and agricultural sciences. However, during the 21st century, soil science developed as a sub-discipline of agricultural sciences, and most research efforts within the field were explored in an agricultural capacity, as a means for improving crop production and health (Wilding & Lin, 2006). Managing soil strictly for crop production and health puts a narrow focus on the field itself; as previously discussed, this has limited the amount of funding, new student interest, and subsequent research development within soil science (McDowell, 2003; Wilding & Lin 2006).

A number of publications have called for a *Soil Science Renaissance*, signifying a need for a shift on the research emphasis of the field (Hartemink & McBratney, 2008). Interdisciplinary research is therefore necessary in order to expand the field into a relevant earth science discipline. Reminiscent of the call for *A New Soil Science* proposed by P.E. Brown (1929), authors in this section recognize that in order to stay relevant and receive funding, transdisciplinary research for basic scientific pursuits will increase the knowledge base of soil and agricultural sciences. This new interdisciplinary approach should not be limited to 'higher' sciences, but within the realm of social sciences as well. By taking a sociological approach, fields similar to ethnopedology (understanding local soil knowledge) and rural sociology (the exploration of social issues in a rural context) will grant many physical, soil and agricultural scientists a better awareness of ways to increase outreach and education through applied sciences (Dawoe et al. 2012, Winklerprins & Sandor 2003).

I will consider two articles that call for inter- and transdisciplinary research in the field. Bouma et al. (2015) considers the UN's Sustainable Development goals and how the interdisciplinary research of soil ecosystem services can meet these goals; Wilding and Lin (2006) describe the need to consider soil science through a bio- and geo-science lens and propose that as a part of the Critical Zone, research into hydropedology may prove critical to other Earth Science fields, therefore showing the validity and importance of the inquiry into Soil Science. Considering soil science as the fundamental media for terrestrial and aquatic ecosystems and conducting research as that accurately represents its crucial role will propel soil science research into the future.

The Sustainable Development Goals (SDGs) as outline by the UN's Development Programme are a 'universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity' (UNDP, 2018). In order to position soil science as a relevant field deserving of further scientific inquiry, Bouma et al. (2015) considered the 7 soil functions that offer direct ecosystem services in conjunction with the 17 UN SDGs[5]. Through their consideration of six case studies in the Netherlands and Italy, the authors evaluated the role of soil science in inter- and transdisciplinary research in order to justify the further advancement of the field itself. Only one of the six inter- and transdisciplinary case studies provided sufficient soil science knowledge, and no further development in research was necessary. The objective of this study was to show the validity of further scientific inquiry into soil science, and how it can help meet the SDGs through its various ecosystem services. This article posits that soil science is a

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[5] See Table 6, Appendix, p. 344

valuable tool within inter- and transdisciplinary research and should continue to advance in conjunction with other fields to meet the SDGs described above.

Similarly to Bouma et al. (2015), Wilding & Lin (2006) seek to justify the development of soil science to meet inter- and transdisciplinary needs. This author takes these efforts a step further by emphasizing the need to consider soil science outside of an agricultural science, but as a part of general Earth Sciences. The authors describe the pedosphere, the surface layer of the Earth where soil forming processes take place, as a central facet to the Critical Zone, the portion of the earth's surface that also encompasses the atmosphere, biosphere and lithosphere (Wilding & Lin, 2006). The authors not only describe the important role that the soil itself plays in a functioning ecosystem, but also posit that soil scientists, those that understand the complex interactions taking place within the pedosphere, are a multi-faceted group with value not only in agriculture, but also environmental, ecological, bio- and geo-sciences.

Wilding & Lin (2006) argue for the further development of a specific field that represents the pivotal role played by soil science. Hydropedology, the amalgamation of soil and hydrological sciences, offers a more holistic take on pedological inquiry, (which was previously discussed). Through the study of water, soil, and rock interactions, hydropedology focuses on 'flow and transport processes in *en situ* soil systems as landscape bodies' (Wilding & Lin, 2006, p. 266). Not only does it incorporate pedology, soil physics and hydrology, it also encompasses other Earth science realms like geomorphology, geology, geography, hydrogeology, hydroclimatology, ecohydrology, biology, as well as other areas within soil science (Wilding & Lin 2006).

In order to assert its relevance within the Earth Sciences, such inter- and trans-disciplinary justifications are essential for the continued growth and support of soil science. By showing the relevance of soil science in this lens, the field can secure funding, encourage new student interest, and increase the overall advancement of the field itself. As discussed throughout this section, though, investment for purely basic scientific development is inadequate to meet the needs of the changing environment; increased outreach and education to farmers and land managers is necessary, and through a transdisciplinary lens, efforts to increase relationships with social scientists is necessary for the enhancement of agricultural and soil sciences in general.

This section considers how soil and agricultural scientists envision the expansion of their respective fields in the near future. By continuing research into soil biology, organic matter accumulation and decomposition, new technology, and transdisciplinary research, the soil and agricultural sciences will continue to garner more respect within the physical sciences in general. Maintaining the integrity of the applied research aspect of these fields is essential, though, and effectively communicating new developments to end users should be a priority as well.

Science, technology and innovation

This section identifies scientists as the science, technology and innovation (STI) mode of learning, and explains how knowledge is created and disseminated within the academic sphere. Scientists typically live in urban environments, specialize in one field, and focus their inquiry on analysis and theoretical development (Hoffman et al., 2007). Many follow a reductionist research model upheld by formal researchers to develop universally applicable theories and laws; however, these all-encompassing laws don’t typically take into account the heterogeneity of local environments where farmers and land managers inhabit (Biel, 2016). Hoffman et al. (2007) describe the knowledge created within scientific communities as explicit, since it is easily transcribed and recorded in text and visual accounts and is communicated through publications and conferences. Explicit knowledge is easily codified and replicable; re-emphasizing the point that scientific knowledge aims to be applied universally.

Jensen et al. (2007) describe the scientific mode of learning as Science, Technology and Innovation (STI), an epistemology based on the use of codified scientific and technological knowledge, which seeks to address the 'know-why' question as opposed to the 'know-who' and 'know-how' practiced farming communities. Ingram et al. (2010) believe that the 'deep view' upheld by soil scientists orients them towards isolated soil characteristics, like individual nutrients or soil structure in a singular form. Scientific knowledge is thought to be 'codified and institutionally legitimate'; it is a clear understanding which can be classified, described, written and transferred within academia" (Norgaard, 1984). Scientific contributions are indirect, providing guidance and clues for further exploration, as well as prioritizing innovation and new ways of thinking (Jensen et al., 2007).

According to Bouma (2018), traditional scientific knowledge is primarily limited to scientific institutions and is structured by scientific disciplines. This applies to the soil science community at large, where institutions conduct soil and crop research that does not always 'trickle down' for use by farmers and land managers or takes too much time to reach the end users. In agricultural and soil sciences, scientists trust that through the 'Research and Design Continuum', extension services in rural communities will communicate this knowledge to famers; however, outsider innovation is not always welcomed by farmer groups, and many farmers accept new information from trusted sources, like other farmers, neighbors, or people they know (Hoffman et al., 2007).[6] This can be problematic, especially if new and relevant research can replace old practices and can help mitigate or eliminate environmental degradation.

The dominance of the scientific model in agriculture

Soil Science as a field has vastly informed our understanding of the natural processes taking place below our feet and has the potential to provide useful information to a variety of disciplines; however, much new information does not 'trickle down' to end users until environmental degradation has already happened (Biel, 2016). This can be discerned through a lag in understanding from the point of view of the end users concerning complex chemical processes. For example, recent research has found that when applying manure to meet nitrogen demands, excess amounts of phosphorus can be applied, increasing the risk of eutrophication into waterways (Tomer et al., 2016). These over-application of nutrients on a large scale can result in massive dead zones, like the one found in the Gulf of Mexico (van Grinsven et al., 2014). These consequences represent of how a lack of understanding on the part of end users can lead to environmental degradation (Ingram, 2008).

Due to the emphasis of basic scientific development, it may appear that academia withholds valuable information, or does not facilitate the successful transmission of knowledge to end-users (Ingram et al., 2010). In addition, Biel (2016) and Kloppenburg (1991) argue that the pursuit of 'dominating nature' through science and technology has

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[6] For more information on this topic, see the 'Trust in Internal and External Groups' section that follows

silenced other forms of thinking, and what can be perceived as a hegemonic dominance over other forms of knowledge; only until recently are other forms of knowledge and modes of thinking earning credit (Jensen et al., 2007; Ingram et al., 2010). It is true that the scientific model of reducing biological systems to a sum of their parts has vastly informed our understanding of soils and other biological systems; however, issues arise because other forms of knowledge have not been valued historically, and only one perspective has earned credit when considering biological systems (Kloppenburg, 1991; Carolan, 2005; Biel, 2016).

The Cartesian method of reductionism has, until recently, been upheld as the best mode of knowledge useful in defining the natural world (Kloppenburg 1991; Biel 2016). As a field that has struggled to define itself as worthy of funding and scientific development, soil science has fallen prey to this trap; in order to receive funding and interest from prospective students, and to grab the attention of the academic world in general, soil science has sought to define itself as a higher science within its own right, not just as the study of soil as a medium for crop growth (Harteminck & McBratney, 2008). In so doing, soil scientists are trying to separate themselves further from modes of experience-based knowledge, as are most commonly upheld in farming communities (Jensen et al., 2007). While science has sought to create universally applicable models and methods, within natural sciences, and agricultural sciences in particular, this method has proven to gloss over the complexity of each local ecosystem and prescribes ideals and methods that may work within a laboratory setting but may not always work in many real-world scenarios (Kloppenburg 1991). This section begins explores the critique of the Cartesian method found in the literature, and how a Reductionist approach silences the intricacies of the knowledge upheld by individuals and groups concerning their local environment.

Reducing biological systems to a sum of their parts

I will first consider the case of Reductionism within science and how it has benefited industrial and human development; while this epistemology benefits industry, the practice of reducing complex biological and social systems or organisms to a sum of their parts, though, can lead to the loss of the life of the organism or system itself (Goodfield, 1972). Agricultural systems are part of their environment and are therefore part of their local ecosystems; by reducing the system to individual chemical or physical components, the essence of the system itself is largely ignored. As previously discussed, the aim of soil and agricultural sciences to establish themselves as a valid basic science has encouraged the reduction of complex agro-ecological systems to a sum of their parts (Brown, 1929; Wilson, 2001).

Scholars have argued that the Cartesian method (Reductionism) resulted in the Productivist mentality of modern agriculture, thus polluting local natural resources and degrading soil quality (Kloppenburg, 1991; Kvaløy 2004; Biel, 2016). In addition, I will consider a specific case study of Dutch farmers and agricultural scientists in the Netherlands, and the conflicts between two groups: those that support the superiority of science, and those calling for a more holistic approach to scientific inquiry. This case study highlights the role that experiential-based knowledge plays in agriculture, and that Reductionist science lacks in its ability to explain biological, and therefore, agricultural and soil systems.

In its broadest sense, the scientific method attempts to identify how activities of successful human inquiry are achieved; this is typically done through 'systematic observation and experimentation, inductive and deductive reasoning and the formation and testing of hypotheses and theories' (Andersen & Hepburn, 2015). This empiricism can be considered as the way in which the conscious individual, the subject, relates to the outer world, 'the material reality of nature', objectively (Brecht, 1979). As previously discussed, the over-emphasis on: empirical observation; theory formulation, testing and revision; the superiority of determinism and the endless pursuit of universally-applicable laws has resulted in the reluctance of science to recognize other modes of thinking (Bosch et al., 2007)

As a facet of the scientific method, Cartesian Reductionism (which I will refer to as reductionism from this point forward) is the method of dismantling an organization into individual components that are considered in isolation; from this reduced state, the isolated parts are then reconstructed to create the whole again (Klopenburg, 1991). This methodological reductionism refers to the belief that biologists can understand how organisms work from a micro-level, by disintegrating systems into individual components (Weber & Esfeld, 2004). Since the Scientific Revolution, humans have sought to increase human development throughout the economy; the agricultural sector has changed from one focused on custom and tradition to that in which humans attempt to control nature to respond to their wishes (Wilson, 1942).

In its attempt to master nature for the continued success of humanity, and to feed an increasing global population, increased productivity has been the focus of agricultural development for the past half-century (Kvaløy, 2004). Applying the scientific model through continued research within agriculture has been shown to increase productivity; Evenson et al. (1979) support this model and argue that increased federal spending on government research grants, laboratories and tax credits have been shown to spur productivity within agriculture. As previously discussed, this emphasis on focusing research to increase productivity during the 20th century was successful with a three-fold increase in the production of corn, wheat and rice, and the exponential increase in the human population.

Brecht (1979) asserts that this reduction has proven useful in the past, since it simplifies a given environment and widens the scope of application; however, in so doing, vital elements of the organism (or even the organism itself in some instances) must be dissected, modified, cut, ground and killed. This removes the essence, or life of the organism/object/system in question, because these biological entities are 'more than the sum of their parts'. The scientific method as a means to dominate nature and reduce systems to identifiable parts has served humanity by increasing crop productivity, but the result has been extreme soil and environmental pollution (Kvaløy 2004; Biel, 2016).

As part of the environment, agriculture as a functional component of a given ecosystem must work in relation to the soil, water, air, vegetation, and other organisms that exist within and around it (Doran, 2002; Bouma et al., 2015). In this framework, Kloppenburg (1991) has taken on the task of both the deconstruction of contemporary Productivist agriculture and offers insight into the reconstruction of what the National Research Council (NRC) and the National Academy of Sciences call for an Alternative *Agriculture* (NRC, 1989). As previously discussed, and described by the author, corporate agriculture and 'agribusiness' have since formulated the research conducted by agricultural sciences. Following the reductionist model, the agricultural system, including the soil within it, has been reduced to individual chemical and physical elements that have been considered within a laboratory setting (Kvaløy 2004). Due to the dominance of the 'academic bourgeois', the NRC has tasked those that oriented agriculture towards a reductionist model to 'recreate' an *Alternative Agriculture* (NRC, 1989*).* As argued by Kloppenburg (1991), maintaining the same forms of knowledge will not reconstruct a new agricultural model, but will reproduce it within the same model.

According to Brecht (1979), complex systems are aggregations of physical components that are interconnected in such a way that they form an entity; therefore, while there are individual parts to these systems, they make up a single unit within themselves. This concept is referred to as Holism, where it is necessary to study the complex system as a whole to grasp its essence. Methodological holism, therefore, emphasizes that biological systems be considered at a macro- or organismic level, and one does not comprehend the essence of the system from a reduced state. Zegar & Wrzaszcz (2017) argue that utilizing holistic approach in sustainable agricultural development is a useful method; conducting a horizontal analysis of different aspects, purposes and activities, in conjunction with a hierarchical vertical analysis from a macro- and microeconomic scale allows one to understand the complex social and biological system from a multi-faceted perspective.

Kloppenburg (1991) explores other forms of knowledge that incorporate a more holistic mode of analysis and apply it to an agriculture framework. With an emphasis on Feminist science, which aligns with forms of knowledge in African, Chinese, and Native

American cultures, the boundaries between humans and the natural world postulated by the Reductionist model are removed. Instead, the dynamism of natural systems is considered wholly, and the human is then considered to be a part of this system. In this mindset, those that interact sensuously with their environment, from the Peruvian Shaman to the hog farmer in Iowa, are experts of their given locality (Kloppenburg 1991). According to Wendell Berry, "It is the local knowledge that enables the competent farmer to mast the intricate formal patters in ordering his work within the overlapping cycles—human and natural, controllable and uncontrollable—of the life of a farm" (Berry, 1977, p.44, as quoted in Kloppenburg, 1991)

Again, by focusing one's inquiry into the local ecosystem and environment, one loses the ability to apply rules and laws universally, which Reductionism allows. But according to Kloppenburg (1991), Reductionism merely cultivates half-truths of any system, and the dissection of individual components removes much of the truth of these organizations. This suggests that the diffusion of universal 'truths' into a diversified complex and locally-based ecosystem, one can discern that there are intricacies of which are unique to that system alone. These intricacies are not easily understood when the components are considered outside of the system, in a lab or in another context; therefore, those that are experts in the field, that are hyper-aware of these intricacies, are those that interact with the systems on a daily basis. The famers and land managers that work the soil on a daily basis have vast amounts of knowledge that science as a whole is just now beginning to realize exists.

The disconnect

This section has covered the history of soil science, the rise and fall of Productivist agriculture, and they ways in which farmers and scientists differ in their modes of learning and knowledge dissemination. This review explains that a disconnection exists between the two groups, and that in order implement sustainable practices throughout the agricultural landscape, integration must take place. In order to forge and strengthen relationships in the future, it is therefore useful to understand what forces prevent this integration. I will first consider the expert/non-expert model of knowledge dissemination from universities to end-users and will explain how this creates both distrust and 'superficial trust' within farmer groups.

Carolan (2005) considers the phenomenological challenge of integrating sustainable practices into modern culture based on the embedded social norms involving people, state and other 'expert' institutions, as well as biological systems. In order to understand knowledge accumulation and transfer within 'sustainable' and 'conventional' farmer groups, the author compares the modes of interaction and knowledge dissemination to end-users within a sustainable program (the Practical Farmers of Iowa (PFI)) and a more traditional Land Grant university (Iowa State)[7]. The author found that within the university-extension model, an expert/non-expert relationship exists where farmers expressed a level of dependency on the information provided from the university. During a university-extension field day, interaction and discussion within farmer groups and with university-extension staff was minimal, and end users seemed to absorb information from the established experts (Carolan, 2005). While many farmers expressed

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[7] See 'Farmer Networks' for a more in-depth analysis of this article.

‘trust’ in the ‘science, knowledge and expertise of this system’, their level of dependence and lack of personal involvement could be described as ‘virtual’ or ‘as if’ trust.

Bouma (2018) explains that the elitism of the sciences over other forms of knowledge contributes to the distrust expressed by farmers. As described by the author, “large groups of increasingly well-educated citizens and stakeholders, now with access to much information on the internet and active on social media, don’t understand activities of the scientific community and have the feeling that their own opinions are not taken seriously” (p. 23). The dominance of Reductionist knowledge forms has been covered in great detail previously, but it is therefore useful to understand how it has impacted farmers.

It is believed that certain impediments within the scientific community prevent the relation of important scientific findings to the general public. Ingram et al., (2010) claim that the reliance on objective knowledge, scientific rules, principles, and tools replace hands-on, experiential knowledge because many scientists do not actually work the soil, nor confront the same challenges faced by farmers. Because this disconnect exists between objective research and the practical experience within soil science, farmers, stakeholders and policy makers are somewhat skeptical of the validity of certain scientific claims. Additionally, shortcomings recognized within the sciences include missing data, a poor understanding of environmental processes, and the reliance on models to express complex and unique ecological processes creates mistrust from farmers and other land managers (Ingram et al., 2010).

In addition, Sumane et al. (2017) explains that the hegemonic dominance of the scientific model in soil and agricultural information creation and dissemination inhibits farmers from trusting their own experience-based knowledge. This can be expressed in farmers' reliance on external inputs like synthetic chemical fertilizers; historically, farmers relied on inputs generated within the farm, but with the industrialization and 'scientification' of agriculture, off-farm inputs were favored. The author explains that while this isn't true in all cases, "the loss of tacit knowledge [transpired due] to the alienation from production processes and a reduction and standardization of skills" (Sumane et al., 2017, p. 3). Since farmers do not operate in formal scientific realms, their dependence on these knowledge bases results in a loss in locally based knowledge.

The path forward

The purposes of this section have been three-fold. First, I've described the valuable efforts that soil science has and continues to contribute to human growth and development, but also discussed how agricultural and soil sciences alone have historically reduced complex farm systems into a mere sum of their parts. Secondly, I've described how tacit knowledge produced and utilized by farmers and land managers has largely been silenced in favor of more explicit forms of knowledge; this is due in large part to how difficult it is to communicate and transfer experience-based knowledge in a timely and efficient manner. My third point articulates that we should not convert our farmers to scientists, or scientists to farmers. Instead, we should facilitate the convergence of these two areas; the generalizable principles of scientists with the local knowledge of farmers, to create truly sustainable and resilient agricultural and land management. Both groups have much to gain from each other, largely because they have differing priorities and modes of learning. When combining both perspectives, much can be gained. A shift can be observed over the past few decades away from this model, with many soil and agricultural researchers gaining context-specific knowledge from farmers and land managers.

The following section looks at specific examples of the benefits of farmer and agricultural researcher interaction to improve soil quality and prevent environmental and land degradation. I will also discuss Farmer Participatory Research (FPR) as a framework to create connections between both farmers and researchers. Including farmers and land managers at the decision-making table will allow for researchers and policymakers to make regulations and create technology that is relevant to them. Additionally, allowing researchers to elucidate the complexity of tacit knowledge will facilitate the spread of valuable knowledge to a larger audience. In so doing, we can create more balanced methods to manage land, fulfill the needs of a larger population, and improve overall soil and environmental health.

First step: Bring farmers to the decision-making table

It is clear that farmers and land managers should be included in the decision-making process, albeit within necessary and relevant research initiatives, or policy actions. As discussed earlier, knowledge trickling down from the academic sphere can be perceived by many in the general public, including farmers, as elitist knowledge that doesn't value the needs of the population. In order to remedy this misperception, Bouma (2018) focuses on the need to bring stakeholders like farmers and land managers to the decision-making table by making them partners in research inquiry and goal identification. By identifying questions and challenges that are relevant to end users, and by defining goals that are relevant to these same end users, policymakers may create a more effective plan of action.

According to Doran (2002), what must be of utmost importance within scientific inquiry is not establishing indicators for soil health, but instead creating tools for management. In addition, these tools must be economically viable for producers, since according to one farmer, “It’s hard to be green when you’re in the red” (Doran 2002, p. 123). As it is currently conducted, scientific research is not directly useful for technological advancement; instead, new inquiries arise in a seemingly endless circle of scientific development (Jensen et al. 2007). By increasing end user participation in new technological development, Croxton (1999) argues that widespread use and success is more likely, since the individuals utilizing the new technology are included at the decision-making table. Farmer and land manager participation is an essential step to create change at any scale.

From traditional science to complex systems thinking

As explained by Rogers et al. (2013), in order to truly adapt to a complex systems frame of mindset, both farmers and researchers must essentially unlearn the reductionist approach, since it is impossible to handle the complexity of ecological systems under this approach. The authors propose Participatory Action Research (PAR) as a replacement in which both researchers and farmers/land managers work together to design an approach first defines “a desired future, and undertake well-informed actions that will expand their knowledge, enhance their competencies and overcome challenges for moving through the future” (Rogers et al., 2013). But in order to do this, both researchers and farmers must recognize the complexity of local systems and instead “seek to understand systems in terms of the heterogeneity of their structure, relationships, and properties that emerge from interactions” (Rogers et al., 2013).

According to Rogers et al. (2013), the steps required to adapt to complex systems thinking, or PAR, involve: 1) a recognition of the dynamics between explicit and tacit knowledge frameworks; 2) an awareness of current knowledge deficits, 3) proceeding from single-loop learning (practical learning that results in ‘rules of thumb’) to triple-loop learning (where we ‘challenge our premises and frame of reference before taking action); 4) altering our levels of consciousness from unconscious incompetence (when people do not recognize learning deficits) to unconscious competence (when new skills become second nature) or even reflective competence (when people continually reconsider their unconscious competencies to adapt to new knowledge acquisition). Researchers creating action-based experiments should be aware of the different stages of participants and stakeholders and be able to meet them at their given stages (Rogers et al., 2013).

Finally, the authors propose new mental habits that must be cultivated by researchers and stakeholders to accommodate for complex systems research. These include: 1) an openness in which strong opinions are held lightly; 2) situational awareness and the role that V-STEEP (Values –social, technical, economic, environmental and political) plays in each specific context; and 3) respect for the restraint/action paradigm, where one has an understanding of when it is necessary to take action, but also the wisdom to wait for potential solutions, epiphanies or emergent ideas to arise and address the challenges at hand (Rogers et al. 2013). The authors consider challenges within a complex system not as a linear trajectory with a single solution, but as a series of knots where one must ‘unravel’ the issue at hand; even though pulling in one spot may loosen it, other areas could subsequently tighten. The entire ‘knot’ or system must be under consideration to address the problems at hand.

The PAR framework mentioned above applies to agricultural research models. As discussed previously, problems are viewed as isolated, and singular solutions are sought after to address them. But as complex socio-ecological systems, challenges within an eco-agricultural context are not singular, but must be considered within a wider frame of reference; V-STEEP informs this spatial and historical context. In order to address these complex challenges, researchers, farmers, and land managers must work together to rethink their approach to facing issues and expanding their horizons to incorporate the complexity of each farmer's unique circumstances. A constant cycle of decision, action and review will monitor the success of the proposed solutions to make sure they still apply to the system and situation at hand (Rogers et al. 2013). Although this model is a fairly new framework, I will explore one case study that has adopted similar approaches within complex agricultural systems.

Case study from the Netherlands

In the Netherlands, the VEL and VANLA Nutrient Management Project aims to address the main question: how to increase nitrogen efficiency in dairy farming systems and how to decrease (as cost-effectively as possible) the surplus of nitrogen emitted in nitrate and ammonia (Eshuis & Stuiver, 2005). Two components make up this project: the first being the interactions between farmers and researchers and how they interact with and among each other to discuss observations and formulate analyses; the second is the site-specificity of the research, performed in-the-field on dairies of the participating farmers. Through participatory inquiry, Eshuis & Stuiver (2005) sought to analyze how 15 scientists and 60 farmers interacted and learned together within the VEL and VANLA framework. Through learning, conflict and alignment analysis, and social learning interactions between the two groups, the authors examined how the development of knowledge directly related to problem solving affected both groups.

The authors found that both scientists and farmers worked together to develop a common framework, and that diversity existed within the group of researchers and the group of farmers. The analysis of conflict and alignment within the VEL and VANLA framework deserves special attention; when discussing proper manure and nutrient application, two new groups formed. The first group, consisting of some farmers, but primarily scientists, upheld the scientific model and institutional recommendations for nutrient applications, stating that the more one adheres to these rules, the better the result; this finding aligns with the expert/non-expert relay of information previously explained (Carolan, 2005; Sumane et al., 2017). The second group consisted of primarily farmers and some scientists and supported a relatively new model. The Van Bruchem Theory was formed based on the experiences of some of the farmers who participated in project; they argued that universal models and laws upheld by scientists do not apply to every actor and every case (Eshuis & Stuiver, 2005).

Major conflicts arose at this point, and because the second group could not use formal scientific justification for their beliefs, were seemingly refuted by the first group because of the lack of quantification of such variables like ‘good manure’ which lack codified scientific evidence. These new groups attempted to delegitimize the motives of the other group, but greater problems arose because both groups used different languages, preventing constructive communication and conclusion-development. The major point of alignment came when the second group emphasized that the experience from successful farmers with manure application did ‘work’ in those examples, and that science may be lagging behind the experiential knowledge possessed by farmers. By developing a mutually agreed-upon storyline, the first group showed more support for the second group, and the idea that scientific knowledge was superior was then abandoned. The two groups were then able to agree that existing scientific models alone were inadequate to realize environmental norms and goals of the project (Eshuis & Stuiver, 2005).

One-on-one interactions with farmers are a useful means to understand how they create and disseminate knowledge; however, scientists and agronomists must observe farmers in action, since these individuals are experience-based learners. Through this method, farmers are able to teach and show their practices through doing, using and interacting. Much information can be lost with farmers if purely utilizing verbal communication, since farmers practice an implicit form of knowledge, as opposed to the explicit and codified knowledge collected and disseminated in the traditional scientific model. Nevertheless, it is still useful to interview and speak with farmers to achieve a basic understanding of their Soil Health Knowledge.

Farmer empowerment in Tanzania

Other efforts have been made in developing countries to not only include farmers at the decision-making table, and to provide them the tools necessary to facilitate socio-economic benefits for themselves and their communities. In Tanzania, the Programme for Agricultural and Natural Resource Transformation for Improved Livelihoods (PANTIL) sought to improve the livelihoods of rural farming families through training, research, and outreach; in particular, the program sought to better understand how organizations and institutions oriented towards farmer participation could also empower farmers (Mwaseba et al., 2009).

Through key-informant interviews, sample surveys and focus-group discussions with participating farmers, the authors sought to understand how the implementation of various programs throughout Tanzania strengthened existing farmer organizations; supported the creation and dissemination of new information, training and skills within beneficiary groups; or connect farmers with a wide network of extension agents, institutions or other invested stakeholders. The programs and organizations under consideration included: The Member Empowerment in Cooperative Development Project (MEMCOOP), the Rural Financial Services Programme (RFSP) and the African Institute for Social and Economic Development (INADES) among others (Mwaseba et al., 2009).

The authors considered how well the organization improved farmer participation, self-confidence, increased access to resources, encouraged power negotiation and assisted in the acquisition of new knowledge (Mwaseba et al., 2009). The authors then asked beneficiaries to explain what they perceived empowerment to be, and how well the organization facilitated this process. To these individuals empowerment involved: the acquisition of new knowledge and skills, receiving new material and capital assistance, having a more substantial role at the decision-making table, as well as being more informed about operations and financial resources necessary for development. Interestingly, the most important ways the beneficiaries perceived empowerment was through the acquisition of new knowledge and skills as well as access to natural and financial resources (Mwaseba et al., 2009).

The author describes both positive and negative benefits attributed to farmer empowerment. For some individuals, upward mobility, increased political access and ascension to leadership roles were granted after participation in empowerment initiatives.

In addition, many farmers described an increased sense of autonomy in decision-making, encouraging these individuals to be less reliant on outsider participation from extension agents or other institutions. Finally, gender inclusion, with more women involved in leadership roles, as well as an increased sense of accountability in new development projects throughout the community were described as positive outcomes from the process (Mwaseba et al., 2009). On the other hand, negative outcomes included a polarization effect within the community between beneficiaries and non-beneficiaries; a sense of the 'haves' and 'have-nots' was described, since the beneficiaries now had access to more economic and political power (Mwaseba et al., 2009). Nevertheless, the authors explained that in order for these empowerment initiatives to be successful, capital and natural resources must not only be provisioned, but time and continuous interaction between organizations and beneficiaries must be facilitated to grant farmers a full sense of empowerment (Mwaseba et al., 2009).

While the authors don't cite how these programs can improve natural resource use and new technological implementation explicitly, the methods described provide a useful framework for other institutions and organizations that hope to improve farmer participation and create sustained positive change with the implementation of any new development. Mwaseba et al. (2009) described a sense of polarization resulted between the beneficiaries and non-beneficiaries, since participants were granted tools and access to upward mobility and political power that was not granted to others. While polarization is likely to occur when some groups are granted access to new resources, it is essential to consider including most individuals, if not all members of an agricultural community in these scenarios (Rogers et al., 2013). As previously discussed, Communities of Practice are intimate groups where farmers interact and share information on a daily basis; by identifying these groups and providing resources to all members of these intimate communities, these efforts will prove to be more successful and create less intra-communal tension, since the local socio-ecological system will be recognized and all members within this community will be granted equal access (Lobry de Bruyn & Abbey, 2002; Oreszczyn et al., 2010).

The path forward takeaways

In order to increase education and new technological development, and to encourage natural resource conservation, it is essential to bring farmers to the decision-making table in new research and technological initiatives. Through FPR, complex challenges presented within farmer communities are considered, and researchers can work alongside farmers and land managers to better address these issues (Rogers et al. 2013). Farmer participation initiatives like the VEL and VANLA organization in the Netherlands as well as the PANTIL program in Tanzania have proven to be largely successful efforts in the outreach, education, inclusion and empowerment of local farmer groups (Eshuis & Stuiver, 2005; Mwaseba et al., 2009).   In the context of improving agricultural sustainability and providing the tools necessary to farmers to increase new technological adaptation, both initiatives found that including farmers at the decision-making table was essential to create change (Lobry de Bruyn & Abbey, 2002). While more research into farmer participation is necessary, it is clear that farmers and scientists can work cooperatively to not only learn from each other, but to better increase the dispersal and success of new research and technology.

The soil itself

This section explores the contributions of soil and agricultural scientists and provides a rudimentary introduction to the established indicators of soil health. In addition, an investigation into various management practices and their impacts on these soil health indicators will be discussed, as well. Basic research into soil and agricultural sciences has greatly improved our understanding of the complex physical, chemical and biological processes taking place belowground; without this understanding, much of the empirical evidence behind soil health would largely be unknown. While basic research is an integral part to improving our knowledge of complex systems, it should not be the only epistemology practiced or recognized as valid. Therefore, a combination of both basic and applied science is essential to better understand complex systems and facilitate the dissemination of this information to end users and the public (Fox et al., 1987; Oosterlinck et al., 2002). While this point has been discussed in detail, it is worthwhile to recognize what contributions basic science has made to our understanding of soil and agricultural management in general.

The general definition upheld by the USDA's NRCS for soil health, or soil quality[8] is defined as: "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" (NRCS, 1995). In recent years, soil health improvement and maintenance has replaced general soil quality, since our understanding of soil and the role of living organisms has changed dramatically. Soil health differs because it describes the soil as a living, dynamic system that depends

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[8] Soil health and soil quality will be used interchangeably in this paper

largely on the biological diversity of the living organisms that play such a vital role to the functionality of a given soil. On the other hand, more static variables, like physical and chemical properties, are more often associated with soil quality, since these indicators are less dynamic and depend largely on climate and ecosystem functions (Doran & Zeiss, 2000). All three indicators, biological, physical and chemical, are all closely linked, and in order to truly understand the health or quality of a given soil, we must think of them as interdependent and manage these properties holistically.

The broad definition of improved functionality of soils has been further elucidated by Doran and Parkin; this includes a given soil's ability to: "accept, hold and release nutrients, chemical constituents and water; promote sustainable root growth; maintain a suitable biotic habitat; respond to management; and resisting degradation" (1994). It is clear that all of these functions depend on the health and quality of the physical, chemical and biological properties of the soil, and are intertwined. In addition, there are a number of services provided by the soil; in our value-driven market, it is therefore useful to explain the ecosystem services offered by healthy soil. With 25% of our world's land mass under some form of management, it is therefore imperative to understand what practices improve or degrade a soil's health. In addition, dead and decaying organic matter, generated by once-living plants, animals and other organisms, contributes greatly to a soil's health as well.

In order for an indicator to be useful to both scientists and farmers, it must meet certain criteria that accurately express the functionality of a given soil. According to Doran & Safley (1997), an indicator must: 1) be clearly understandable; 2) accurately express ecosystem processes; 3) integrate physical, chemical and biological characteristics of the soil in question; 4) be comprehensible by a wide audience, including farmers and land managers in addition to soil and agricultural scientists and policymakers; 5) respond to dynamic changes. By meeting these criteria, a given indicator can accurately communicate soil health to a wide audience and can effectively measure change over time.

At the turn of the 21st century, many soil scientists declared that soil and agricultural sciences should create indicators of soil health that are accessible to farmers and land managers. JW Doran (2002), a renowned soil scientist at the University of Nebraska Lincoln known for his contributions towards establishing indicators of soil health, explains that scientists play a necessary role in the relay of information to the producers and the public; the author suggests that it is essential that they establish tools that allow farmers and land managers to understand management that improves soil health or degrades it. The ultimate determinant of soil quality and health, according to Doran and Zeiss (2000) are the farmers and land managers responsible for managing the soil; therefore, the indicators should be tailored to meet the needs of these land stewards. While there are many indicators that are outside of the scope of the producers, particularly those that require laboratory analysis, the authors argue that creating sustainable management practices with corresponding indicators is the most effective way to allow farmers and land managers to monitor their soil health and quality.

This section first establishes basic parameters upheld by both farmers and soil scientists as healthy soil; through biological, physical and chemical explanations, I will describe how healthy and unhealthy soils function in both agricultural and unmanaged soils. In order to rationalize the benefits of healthy soil, I will consider the ecosystem services provided by soils that are not degraded. Since humans manage large portions of land globally, it will be essential to explain what management practices improve the soil or degrade it, and how degraded soils not only become unusable by humans, but also contribute to overall global environmental issues like greenhouse gas emissions and water pollution. I will then explain the role that soil organic matter plays in overall soil health, and what practices improve or degrade the state of a soil's SOM. Finally, I will examine three methods of measuring soil organic matter, and consequently, overall soil health, and how effectively they can communicate soil health to the general public.

Indicators of soil health and quality

Biological indicators

Soil biology is one of the most underexplored properties, most likely due to the post-WWII industrial agriculture emphasis on soil physical and chemical properties (Doran & Zeiss, 2000; Barrios, 2007; Lehman et al., 2015). Within one gram of soil, there are at least 1 billion bacterial cells from thousands to millions of different species, one million fungi from hundreds of different species that can produce over 100 m of mycelial hyphae (the mass of tubular filaments of fungi). In addition, the soil contains thousands of algal species, millions of protozoa, tens to hundreds of species of microscopic nematodes, as well as a great diversity of meso- and macro-biota invertebrates. Lehman et al. (2015) states that there may be as much belowground biomass as there is on the earth's surface. But we are just beginning to scratch the surface of our understanding of soil biological components.

Soil organisms play specific roles that influence chemical and physical properties of the soil. The key functional groups of soil organisms include: mycro-symbionts (nitrogen-fixing bacteria and mycorrhizal fungi), decomposers (cellulose and lignin degraders), elemental transformers (nitrifiers and denitrifiers), soil ecosystem engineers (earthworms and termites), soil-born pests and diseases (white grubs, parasitic nematodes, root rot), as well as microregulators (grazers, predators and parasites) (Barrios, 2007). Soil organisms provide important ecosystem services, which will be considered further in this section: they cycle nutrients, modify the soil structure, and manage pests and diseases (Barrios, 2007). These functions are not only greatly connected to other chemical and physical properties, but also to overall soil health and quality, which have a great impact on the productivity and subsequent profitability of a given agroecosystem.

In regard to the benefits of biota to improve soil chemical factors, Lehman et al. (2015) explains that microorganisms regulate the availability, abundance and heterogeneity of nutrients for uptake by plants. With respect to nitrogen and phosphorus, which are two of the most limiting (and most poorly utilized) nutrients in agroecosystems, microorganisms like Arbuscular Mycorrhizal Fungi (AMF) and Biological Nitrogen Fixers (BNF) play a significant role in bio-regulating the availability of these nutrients (Barrios, 2007). In temperate climates, studies show that the total fixed nitrogen from mixed stands of clover and tall fescue, a leguminous cover crop and grass combination, can increase N availability by as much as 300-390 kg/ha/year (Barrios, 2007).

Cover crops, which will be discussed in further detail in the management section, can help limit the amount of synthetic inputs required for crop production by utilizing soil biological nutrient cycling. With respect to phosphorus, a mineral nutrient found in the bed rock only in certain areas of the world, AMF have been found to directly affect P procurement in the soil. As endomycorrhizae penetrate the cells of plant roots, they generate hyphae which have the ability to extend deeper into the soil column, where phosphorus is typically found. These hyphae, along with other bacteria, not only are able to access nutrients in deeper soil horizons, but also assist in the acquisition of other limiting nutrients like nitrogen, potassium, calcium and magnesium, which when available in adequate quantities, have been shown to positively impact crop productivity (Barrios, 2007). This shows that although historically considered separately, soil biota directly impacts chemical properties belowground.

Soil structure and aggregation, major indicators of soil physical quality, are also largely influenced by soil organisms. Micro- and macrofauna play a significant role in the formation and disintegration of soil aggregates. Through the breakdown and restructuring of particulate organic matter, detritus at varying sizes and processes undergoes decomposition through microbial and macrofaunal activity. This decomposition creates ‘biological macroaggregates’ which are largely formed by bacteria, roots, fungi and macrofauna (Barrios, 2007). Macrofauna, frequently considered the engineers of the soil column, include ants, termites and earthworms. These organisms regulate soil water and nutrient dynamics; for example, the addition of organic matter and the subsequent breakdown and restructuring by termites has been shown to recuperate surface crusted soils, which prevent the efficient infiltration of water into the soil column.

The tunnels, channels and pathways formed by earthworms render these organisms ecosystem engineers (Pulleman et al., 2012). There are three ecological groups of earthworms: anecics, endogeics, and epigeics; Epigeic earthworms breakdown plant detritus at the soil surface, anacecics burrow into lower horizons and create permanent tunnels between different layers, and endogeics consume more stable organic matter and mineral soil. Both endogeic and anacecic earthworms significantly contribute to soil structure formation (and subsequently reduce erosion), enhance water filtration and also help to remediate pollutants. Since endogeic and anacecic earthworms are extremely sensitive to soil disturbance through tillage, they are often considered useful indicators of soil physical health (Pulleman et al., 2012). While this topic will be covered in more detail in the physical indicator section below, it is evident that both micro and macro-organisms significantly contribute to overall soil physical quality.

Historically, soil biology has had much less interest in the scientific field due to the dominance of soil physical and chemical properties, and the extreme diversity of organisms within a given soil (Doran & Zeiss, 2000; Barrios, 2007; Lehman et al., 2015). As previously addressed, though, both soil physical and chemical properties depend greatly on the health of soil organisms. There are innumerable contributions made by soil organisms that have barely been considered in this section; however, based on the evidence provided, soil biota plays a significant role in overall soil health. As our knowledge of soil biology expands, these organisms should be used as useful indicators of the status of a given soil. If we consider the 5 criteria specified by Doran & Safley (1997) earlier in this section, some issues can be encountered with the accessibility and interpretability of some soil biological indicators. Due to the complexity of biological systems, it may be difficult for farmers and land manager to comprehend how biological indicators in isolation contribute to soil health. Nevertheless, I will discuss the important role of organic matter as an indicator and management tool for improving and maintaining soil health; the relationship between soil organisms and organic matter will be discussed in detail later in this section.

Physical indicators

Soil structure consists of the arrangement of sand, silt, clay and organic matter into a wide array of solids and voids, with aggregate formations of different sizes formed by both organic and inorganic agents (Bronick & Lal, 2005; Barrios, 2007). As the main function for soil physical quality, soil structure impacts plant growth by influencing the distribution of roots within the soil column, therefore having an impact on the ability of the plant to take up water and nutrients. As such, poor soil structure is indicative of soil degradation; although it is frequently considered a more static component of soil quality, soil structure is highly dependent on land management practices (Doran and Zeiss, 2000; Bronick & Lal, 2005).

Soil physical structure is determined by inherent properties like terrain, climate, biota, parent material and time, in addition to more dynamic properties, like organic matter content, aggregate stability, infiltration and fertility, which are largely dependent on the type of management employed (Kuykendall, 2008). Texture, a soil's composition of sand silt and clay, in addition to organic matter content, determines a soil's initial physical structure. In terms of porosity, the presence of air and water within a given soil, textural porosity occurs between primary mineral particles (Dexter, 2004; Bronick & Lal, 2005). Structural porosity, on the other hand, consists of microcracks, 'bio-pores' and macrostructures, which, when disturbed by tillage or other management practices, is more dynamic than textural porosity (Dexter, 2004). The symptoms of bad soil physical quality include the presence of poor water infiltration; run-off of surface water; hard-setting; poor aeration, rootability, and workability. Alternatively, good soil properties are the complete opposite: soils that absorb and retain water, are well aerated, allow for plants to explore the soil column with minimal compressibility and are easily workable without clodding (Dexter, 2004a/b).

Dexter (2004 a/b) uses the slope of an *S* curve, which expresses a soil's water retention, as a measure of soil physical quality. In their first publication, the author measures the *S* curve in terms of soil texture, density, organic matter and the effects on root growth. Under compaction, the reduction of the volume of a given mass of soil (which usually occurs from too many passes of heavy machinery on overworked soil)[9], the volume of pores is greatly reduced, thus changing overall pore size and impacting the soil's ability to retain water. In addition, organic matter also changes a soil's water retaining abilities. For root growth, the compressibility of a soil is also indicative of soil physical quality; a given soil's compressibility is positively correlated with the slop of the water retention curve *S*.

In terms of management, aggregate size, stability and structure largely determine what makes a soil easily workable. Dexter (2004b) used the retention *S* curve to measure friability, tillage and hard-setting of agricultural soils. Friability is determined by how crumbly a given soil is, or in other words, the 'distribution of flaws or weakest links within the soil' (Dexter, 2004b, p. 216). If a given soil contains fewer large clods, more smaller aggregates, and crumbles without completely losing its structure, then the soil is considered 'workable'; the workability and friability of the soil are formed more so by

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[9] Tillage and compaction will be discussed in further detail in the *Management to improve SOM section, p. 82*

the physical quality of the soil than the implement used during tillage (Dexter, 2004b). The author found that the friability of a dry soil is positively correlated with the slope of the water retention curve *S* since both depend on soil microstructure which makes up the foundation of soil physical properties[10].

Hard-setting or soil crusting, is a dense hardened layer at or near the surface of the soil which develops due to high levels of disturbance through tillage and poor soil structure. Crusts prevent the water from properly infiltrating the soil; if water cannot penetrate the soil, it is not only difficult for plants to grow, but also increases the risk of water erosion due to run-off. If more topsoil is lost due to erosion, the topsoil cannot be built back up, and soil quality continues to worsen. Hard-setting increases with increased bulk density, a sign of poor structure and aggregate stability (Dexter, 2004b).

As discussed in the *Biological Indicators* section, aggregate formation and disintegration is largely dictated by soil flora and fauna. Arbuscular mycorrhizal fungi (AMF) produce a glycoprotein called glomalin' which contributes to soil particle aggregation. As AMF infiltrate plant roots, they continue to grow small root hairs called hyphae to further explore nutrients in the soil column. Acting as a tough glue that take decades to decompose, glomalin serve to protect the hyphae and to keep water and nutrients within the root system. A dynamic interplay of hyphal exploration into the soil column paired with the gluing capacity of glomalin, soil particles not only stick together to form aggregates, but increase aggregate stability and become less resistant to breakdown. As a function of aggregate stabilization, hyphae and glomalin serve to

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[10] The relationship between management practices and physical properties will be addressed later in this section.

prevent wind and water erosion, increase water infiltration and water retention, improve nutrient cycling and root penetration by reducing compaction (Wright & Nichols, 2002).

Soil chemistry also plays a role in soil physical quality. Udom and Omovbude (2018) studied the effects of legume and grass cover crops on soil physical structure; the authors found that the structural properties increased with increasing carbon and nitrogen from plant residues, which led to improved overall soil structure, decreased bulk density, increased porosity and increased water holding capacity. Soil pH and saline or sodic conditions also greatly influence soil physical structure. Sodic soils are characterized by the displacement of calcium ions on soil colloids by sodium, due to highly salinized irrigated water or arid climates; if more than 5-15% of sodium ions are adsorbed to soil colloids, then a soil is considered sodic (Dexter, 2004a). Sodicity increases clay colloid dispersion, rendering soils devoid of structure and aggregation and highly susceptible to wind and water erosion. This clearly has an impact on the workability of the soil, since most sodic soils are hard-set, impermeable to water, and non-friable (Dexter, 2004a).

Soil physical qualities are largely determined by inherent and dynamic factors. The soil's structure, permeability and ability to hold water impact a soil's ability to support plant and animal life above and belowground. With good soil physical structure, ample pore space allows for adequate amounts of air and water which support roots and soil biota; these soils are typically easier to work, yield a more robust seedbed, and are able to transport water and nutrients for optimal crop cultivation. (Brady & Weil, 2010). Soils with poor soil structure are more dense, unable to retain or allow water to infiltrate, are highly susceptible to wind and water erosion, and cannot support flora and fauna above and belowground. It is essential that farmers and managers are conscientious of their soil physical structure since it greatly impacts overall soil health.

Chemical indicators

Costanza et al. (1997) cites chemical indicators such as total soil organic carbon (SOC), available macro-nutrients (nitrogen, phosphorus and potassium), electrical conductivity, cation exchange capacity and mineralizable nitrogen as the most well-understood and well-documented indicators of soil quality. Also referred to as fertility, soil chemical characteristics have been considered the most important determinant for successful crop cultivation (Brady & Weil, 2010). While the ability of a soil to hold and transport nutrients is essential, there are many other factors that must be considered, as previously explained in the last two sections. Here, I will address the major components of soil chemical quality, including pH, cation exchange capacity (CEC) and electrical conductivity (NRCS, 2011)[11]. As a well-understood and measured soil and crop indicator, it will also be useful to see how chemical properties impact overall soil health.

Soil acidity or alkalinity is largely determined by a given soil's pH, or the presence or absence of hydrogen ions; if a soil is below a pH of 7, it is considered acidic with more hydrogen ions, while soils above 7 are considered basic and have fewer hydrogen ions. The availability of macro- and micronutrients is largely determined by a soil's pH (NRCS, 2011). Under acidic conditions, more hydrogen ions are attached to cation exchange sites on soil colloids, displacing mono- and divalent cations like calcium, magnesium, potassium, and various forms of nitrogen and phosphorus. Micronutrients like manganese, iron, copper, zinc and boron, on the other hand, are more available as

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[11] SOC and C sequestration will be addressed in the *Soil Organic Matter: The life of the soil* section, p. 73

soil pH decreases (Mckenzie, 2003). As soil pH increases, the presence of calcium and other cations increases, as well. Under cultivation, and in particular irrigated agriculture, most soils become acidic over time due to the higher presence of hydrogen ions from water; however, in arid or calcareous soil, saline irrigated water may actually increase soil pH. While most crops and soil biota prefer a near-neutral pH, there are management practices to either increase soil pH (through the addition of lime or gypsum) or decrease pH (with sulfate or ammonium fertilizers) (Mckenzie, 2003). It is clear soil pH plays a major role in creating an inhabitable environment for both crops and soil organisms, and therefore is essential for overall soil health.

As discussed in the previous paragraph, nutrient availability is largely determined by the amount and exchangeability of given cations. These positively charged ions are held onto or exchanged at cation exchange sites on soil colloids. Inherent physical properties like texture play a significant role in determining a soil's Cation Exchange Capacity (CEC); if a given soil has higher amounts of clay and stable organic matter called humus, then they will have a higher CEC (Ketterings et al., 2007). Humus, the highly decomposed portion of organic matter, can have 4 to 50 times the amount of exchange sites of clay particles; however, since the organic acids associated with the negatively charged exchange sites of humus are pH-dependent, pH also contributes to in a given soil's CEC. Since macro-nutrients like potassium, phosphorus and calcium are more available in soils of a higher pH, a soil with a higher pH and high contents of clay and organic matter will have sufficient quantities of these nutrients; however, as pH and CEC decrease, deficiencies of these nutrients will increase (Ketterings et al., 2007).

According to USDA NRCS (n.d.), soil electrical conductivity (EC) measures a soil's salinity or sodicity and has an impact on crop yields, plant nutrient availability and the activity of soil microorganisms, it can also be used as an indicator for nutrients like nitrates, potassium, sulfate and ammonia and potentially toxic elements like sodium and chlorine. EC varies with the ability of particles to hold moisture, which is largely dependent on soil texture. Larger particles like sand have low EC while smaller particles like clay have high conductivity. In addition, other soil properties affected by EC include: water-holding capacity and drainage, porosity, CEC, salinity and temperature (Grisso et al., 2009). In terms of water-holding capacity and drainage, medium-textured silty soils may be the most productive in terms of EC since they hold adequate amounts of nutrients for high crop yields. As a product of the amount of clay and OM, CEC has been shown to be correlated with EC; in addition, the presence of clay also increases the amount of pore space in a given soil, and consequently indicates a higher EC (Grisso et al., 2009).

It is clear that many of the indicators of good soil chemical quality are interconnected. pH largely determines the availability of nutrients for specific crops, in addition to creating an accommodating environment for both plants and soil microorganisms. Variation in soil pH and a given soil's CEC determines what nutrients are available for uptake by plants. EC is also dependent on pH and influences CEC; the more saline or sodic a given soil, and therefore lower EC, the fewer exchange sites are available for uptake by plants. Texture plays a role in a soil's overall chemical quality; the soil's inherent properties (texture) and dynamic characteristics (presence of OM) determine a given soil's EC and CEC. More clay and OM provide more exchange sites for cations, and OM has between 4 and 50 times the amount of exchange sites as clay. For EC, more water is available with decreasing particle size, therefore silty and clayey soils can hold more water, and are therefore more electrically conductive (Brady & Weil, 2010).

In terms of overall soil health, soil chemistry both depends on and impacts soil physical and biological properties. As described in extensive detail, texture and porosity determine the nutrient and water availability of a given soil. Saline or sodic soils influence the flocculation or dispersion of clay particles, and also influence nutrient availability. pH regulates the quantity and quality of soil flora and fauna, since most soil microorganisms prefer a near-neutral pH. In addition, the available pore space in soils with a higher EC (as determined by clay) also creates a more hospitable environment for soil biota (Brady & Weil, 2010).

Synthesis of indicators

In summary, soil biological, chemical and physical properties are highly interdependent; it is nearly impossible to consider a single property as a separate entity. If a given soil has good structure, stable aggregates, absorbs and retains water well, has ample pore space, a neutral pH, good EC, a high CEC, in addition to a large diversity of soil flora and fauna, this same soil would most likely produce large yields and high-quality crops (Brady & Weil, 2010). If these same properties were the opposite, with poor structure and aggregation, hard-setting and high amounts of water runoff, an extreme pH (on either side) and highly saline or sodic soils, a soil environment is not hospitable for soil biota or aboveground plants.

Organic Matter, the living, dead, and very dead components of the soil, is the most significant indicator of soil health that can be used as a tool to connect soil scientists and agronomists with farmers and land managers (D'Hose et al., 2014; de Souza Mello Bicalho & dos Guimaraes Peixoto 2016). In accordance with Doran & Safley's (1997) criteria for soil health indicators, SOM satisfies all five of the specified measurements. Organic matter is easy to see and understand within any management system, can serve as a representation of complex biological and ecosystem processes unobservable with the human eye, integrates all three components of soil functionality, can be discerned by farmers, land managers, scientists and even policymakers, and is sensitive to changes in management.

This soil component serves as an indicator for all three of the properties previously discussed in this section. It is both produced and consumed by soil microorganisms. It greatly improves soil aggregation and structure, and without it, renders soil homogenous and highly susceptible to wind and water erosion. It increases water retention, prevents hard-setting, and creates a workable, friable seedbed. In terms of soil chemistry, it buffers pH, and helps alleviate saline or sodic conditions. In more stable forms, it can increase a soil's CEC by 4 to 50 times that of clay and provides ample nutrients for plants and microorganisms. Not only is it one of (if not the) most important constituents of soil health, but it is also well-understood by both farmers and soil scientists alike.

Soil organic matter: The life of the soil

Soil organic matter (SOM) in the soil consists of plant and animal tissue in various stages of decomposition: the living, the dead, and the very dead (Fenton et al., 2008). The living fraction includes living plants like root systems, algae and lichen as well as animals like fungi, bacteria, protozoa and insects, to name a few. All of these living organisms play a role in the breakdown of plant residues, which make up the largest part of SOM (Bot & Benites, 2005). This detritus, or dead fraction, consists of varying stages of decomposing material, like sugars, starches and proteins that undergo rapid decomposition, slowly decomposing components like cellulose, fats, waxes and resins, as well as the very slow materials like lignin; the rate of decomposition of these residues depends largely on the soil organisms, the environment and the quality of the decomposing OM (Bot & Benites, 2005). Through repeated microorganismal decomposition and turnover, this dead fraction begins to stabilize. The very dead fraction of OM refers to the highly decomposed and stable humus, which takes decades to centuries to decompose and cannot be broken down any further by microorganisms (Stockmann et al. 2013). As will be discussed in the following sections, the living, dead and very dead organic material found in the soil are recognized by both farmers and scientists as some of the best determinants of soil health (D'Hose et al. 2014; de Souza Mello Bicalho & dos Guimaraes Peixoto 2016).

These varying stages of SOM consist primarily of soil organic carbon (SOC); approximately 58% of SOM is SOC, or elemental C. As the second largest C sink on the planet [the ocean being the largest at 38,400 Gt (1 gigaton = 1 billion tons) C], soils contain 2344 Gt in the first three meters, 1500 Gt in the top meter, and 615 Gt in the top 20 cm; these numbers are not consistent throughout the planet, with certain ecosystems (like cooler humid climates with large amounts of aboveground biomass) containing more SOC than others (Stockmann et al. 2013). While soils can serve as a large sink, anthropogenic emissions of CO_2, or liberated 'C', through fossil fuels and other greenhouse gases, land use change and ecosystem degradation have reached 9 Gt of C lost to the atmosphere per year (Stockmann et al. 2013). As will be discussed in later sections, improving soil health through sustainable management practices and land use change can help to sequester these excessive emissions of carbon from the atmosphere back into the soil.

Within undisturbed ecosystems, balances exist between inputs and outputs of organic matter; the soil is covered with living plants, ample amounts of detritus feeds a diverse array of organisms, there is a thick web of living roots below the ground, and efficient nutrient cycling occurs because plants demand only as much as what is lost (Bot & Benites, 2005). Typically in moist, cooler climates, more organic matter can accumulate within the soil than in drier, hotter areas. The rate of decomposition as mediated by soil microorganisms is largely dictated by the amount of water and temperature, with an increase of SOM correlated with increases of mean annual precipitation; however, highly saturated anaerobic environments slow decomposition rates of organic matter (Bot & Benites, 2005). In terms of texture and topography, a higher presence of clay typically results in more organic matter; in addition, basalt-based parent material which is richer in nutrients and minerals typically yields more vegetative cover and leads to more OM accumulation.

Indicator of soil health

These ideal nutrient balances are difficult to maintain in managed landscapes and agroecosystems. Inherent losses result from agriculture, since nutrients and biomass are exported from the land as salable crops. According to Janzen et al. (2005), "In order to increase SOC, one must either increase Primary Productivity, increase the proportion of primary productivity returns to the soil, or decomposition suppression must be employed". Therefore, to efficiently manage SOM, a farmer or land manager must be conscientious of the short and long-term effects of their management: first of all, mineralization of C and N in SOM for crop and microorganismal uptake must be considered, in addition to adding to the long-term C and N pools for soil health maintenance and improvement. While this topic will be discussed later, it is of value to explain how SOM is one of the best indicators of soil health, since it has been shown to improve soil chemical, physical and biological properties.

Biologically, the availability of easily-decomposable SOM impacts the size, composition, and activity of a microbial community; having a larger community with more diversity that's highly active can enhance the availability and retention of nutrients, improve the soil's physical structure and water retention (Lehman et al., 2015). In a study conducted in the Atlantic Forest Biome of Brazil, Nogueira et al. (2016) found that land converted from forest to cropland, then followed by natural regeneration (converted back to forest or pasture) had high levels of microbial biomass carbon, which is most likely associated with higher OM input and high floristic diversity in the forest, and belowground root abundance in pastureland. In addition, the authors also found that although the naturally regenerated pastureland had lower levels of glomalin and SOM than the undisturbed forestland, there was still stimulated production of AMF seedlings which contribute to plant species diversity and ecological succession. In general, a diverse array of organic matter provides ample food and nutrient sources for soil biota, enhancing biodiversity, and as previously discussed, further contributing to physical and chemical properties.

The enhanced physical properties of the soil through OM accumulation are largely dictated by soil biological activity. As previously discussed, soil microorganisms produce glomalin and other binding agents that influence the soil physical structure and aggregate stability. With higher levels of organic matter, and more biological diversity, physical benefits include: increased aggregate stability, improved water infiltration, adequate soil aeration and reduced runoff (Fenton et al., 2008). In addition, SOM lowers bulk density and decreases the risk of compaction, allowing for adequate aeration and water infiltration in addition to strong root development. In terms of tilth and friability, a high presence of organic matter makes soils less prone to clodding, increasing their workability and creating an ideal seedbed for cultivation (NRCS, 1996). Subsequently, more organic matter prevents crusting and prevents the loss of topsoil through erosion by maintaining soil structure. Having ample biological diversity and strong physical structure allows consequently allows for the effective availability and transfer of nutrients from soil colloids to plants.

A soil's CEC determines the amount and availability of nutrients for uptake by plants. Soils with a high clay content have more exchange sites to hold nutrients; however, as previously addressed, humus has 4 to 50 times the exchange sites as clay. This means that soils high in organic matter not only are able to supply more organic matter, but consequently prevent the loss of nutrients through leaching. A soil's buffering capacity prevents an extreme change in soil pH based on levels of saturation or amendment additions. This is important for soil biota, since both extremes of pH can negatively impact the abundance and diversity of microorganisms. As a food source for microorganisms, an abundance of OM increases the nutrient abundance for plant uptake, since the soil organisms consume and mineralize a variety of nutrients to be used by crops. Largely comprised of C and N, organic matter abundance contributes to the availability of these two elements in the soil, adding to the C and N pool of the soil and further improving overall soil health.

Bulk density, carbon and nitrogen as OM measurements

As the most important indicator of soil health, it is necessary to find measurement tools that accurately quantify the amount of organic matter present in a given soil. According to Barrios (2007), “As soil organic matter influences soil structure, soil nutrient availability, soil water holding capacity, and cation exchange capacity, it can be used as a management tool to favor greater soil heterogeneity and more diverse soil (biological) communities that are associated with the natural regulation of pests and diseases” (p. 279). While there are a number of methods that can be used, I will consider the high temperature combustion method for chemical analysis of total carbon and total nitrogen contents. In addition, soil bulk density, or mass by volume, will also be considered as an effective measure of organic matter content in a given soil.

According to Dieckow et al. (2007) it is necessary to have the most reliable measurement methods of carbon and nitrogen in soil organic matter studies because these two elements are the ‘first analytical step’ in quantifying and characterizing soil organic matter. In addition, Avramidis et al. (2015) states that measuring soil total C and total N are the major determining factors in agricultural soils since they indicate soil fertility, productivity and overall soil health. While there are a number of methods that can be used to measure C and N, I will consider the dry combustion method for the purposes of this study. This method combusts soil samples in an induction furnace with a stream of pure oxygen. Temperatures can exceed 1000 degrees C, which ensures that all carbon forms within a given soil sample are completely incinerated (Schumacher et al., 2002). Through an analysis of different C measurement methods, Schumacher et al. (2002) found that for the purposes of total organic C, the use of a high temperature, automated, dry combustion method was the ideal method for quantification. Therefore, for the purposes of my study, I have also used the high temperature combustion method to measure total C and total N.

Bulk Density is one of the most commonly used indicators of overall soil physical quality; as a measure of mass by volume, it can communicate the integrity of the soil physical structure, aggregate stability, as well as the friability and tilth of a given soil (Kuykendall, 2008). Variation within bulk density measurements can be attributed to the proportion of organic and mineral particles to porosity and the impact of gravity; as such most mineral agricultural soils have a bulk density between 1 to 2 grams per cubic centimeter (g/cm^3). According to Hossain et al. (2015), heavily compacted soils with high tractor traffic (for example) have a bulk density between 1.4 and 1.6 g/cm^3 while open and friable mineral soils with good organic matter content have less than 1 g/cm^3.

Soil organic matter has been shown to improve dynamic physical properties of the soil like aggregate stability, water infiltration and bulk density; therefore, a correlation between higher organic matter and lower bulk density can be observed (Kuykendall, 2008). In an analysis of indicators of soil physical quality, Kuykendall (2008) found that bulk density is the best physical indicator of soil quality since it accurately assesses the functionality of a given soil. In addition, bulk density expresses a soil's ability to provide good physical structure for efficient water infiltration and plant root-ability, which in turn sustains biological activity through adequate aeration and saturation.

Measuring organic matter is essential to understand the health of a given soil. The dry combustion of total C and total N, in conjunction with measurements of bulk density are useful tools in assessing the amount of organic matter present in mineral agricultural soils. Therefore, I have chosen to use these methods to determine organic matter content of the soils under study. While soil sampling is an important component of this project, it is not the only variable being measured. Since farmers' perceptions of soil health affect their management practices, it is essential to understand how they perceive organic matter and its relationship to healthy soil.

Binding the soil, scientists and farmers

Many publications describe the important role organic matter plays not only in determining soil health, but also in improving degraded soils (Hijbeek et al., 2017; Janzen et al., 2005.; Bot and Benites, n.d.; Avramidis et al., 2015; Fenton et al. 2008; Nogueira et al. 2016). As previously represented, it is well-understood within the agricultural and soil sciences that improving organic matter content improves overall soil health. But what do farmers know about the role of organic matter in the health of their soil? According to a number of articles, focused particularly in the Netherlands, (Hijbeek et al. 2017; Hijbeek et al. 2018), farmers are well aware of the importance of soil organic matter; however, their perception of SOM varies, in addition to the depth of their soil health knowledge in general.

In a survey of 435 participants, Hijbeek et al. (2018) evaluated what factors prevented or encouraged Dutch arable farmers to increase SOM on their farms based on their own attitudes, the influences of their social circle, and their 'perceived behavioral control'. The authors found that 90 percent of the participants intended to increase their SOM content, however there were a number of factors contributing to attitudes towards outcomes of OM addition. Differences were recognized based on texture: farmers with sandier soils believed they benefited from OM because of water-holding capacity and soil structure, while farmers with loamy or clay soils rootability and workability (in addition to structure). Interestingly, soil physical structure was viewed as an important consequence of organic matter additions. In addition, farmers which earned the highest economic output (high intensity) per hectare valued the long-term effects of SOM more-so than the medium and low-intensity farmers (Hijbeek et al. 2018). In sum, the authors found that a vast majority of Dutch farmers surveyed in the study intended to increase SOM content, and their justification for doing so depended on texture as well as economic goals.

Another study conducted by Hijbeek et al. (2017) attempted to quantify risk indicators of SOM deficiencies based on texture, land use and other environmental factors and compared these responses to farmers' perceived SOM deficiencies. By matching the actual and perceived risks of SOM deficiencies, the authors attempted to 'establish threshold values for SOM content based on farmers' perceptions'. The study found that countries in Southern and Eastern Europe with drier climates, steeper slopes, coarser soils and more cultivation of specialized horticultural crops had higher SOM deficiencies. In addition, farmers with steeper slopes had perceived higher SOM deficiencies; however, farmers that had similar SOM contents perceived a wider range of SOM deficiencies (Hijbeek et al. 2017). The authors also found that farmers with high perceived SOM deficiency have environmental extremes; in terms of land use, the more intensive specialized horticultural crops had more SOM deficiency, but higher SOM was found for grain crops like cereals or grasses. The authors found correlations between the risk indicator and the farmers' perceived SOM deficiency, suggesting that environmental and land use extremes were easier for farmers to perceive than more moderate environmental and land uses.

While these two articles describe the perceptions of farmers and SOM on their farm, the literature is generally lacking in examples of farmers and their understanding of Organic Matter and its benefits to their soil; however, I do not believe this is because farmers are unable to perceive OM and its benefits. In Hijbeek et al. (2018), the authors found that 90% of respondents in the Netherlands were aware of the benefits of higher OM levels in their soil and were actively working towards increasing it. The other article cited in this section found variation in farmers' perceptions of SOM, with more accurate deficiency identification under extreme land use and environmental conditions. More research is necessary to understand what farmers know about SOM, what practices contribute to its accumulation in addition to what practices increase SOM loss and subsequent soil degradation.

Management to improve SOM

Thus far, I have illustrated the biological, physical and chemical indicators of soil health with a strong emphasis on the role played by SOM. There are a number of ways to improve SOM accumulation and subsequent soil health, since the two are clearly connected. General rules of thumb include: minimizing soil disturbance, maximizing residue accumulation, maintaining vegetative cover, utilizing the 4 R's of fertility management (Right source, Right rate, Right time, Right place), and implementing water use efficiency (Bot & Benites, 2005; The Fertility Institute, 2017) . These five principles not only increase SOM, but simultaneously improve overall soil health. It is now necessary to examine management practices that execute these principles. In this section, I will consider five management practices that improve soil health: minimum and no-till; perennial crops; cover crops; manure, compost, and biosolid applications; 4 R's of soil fertility, and water use efficiency.

Tillage

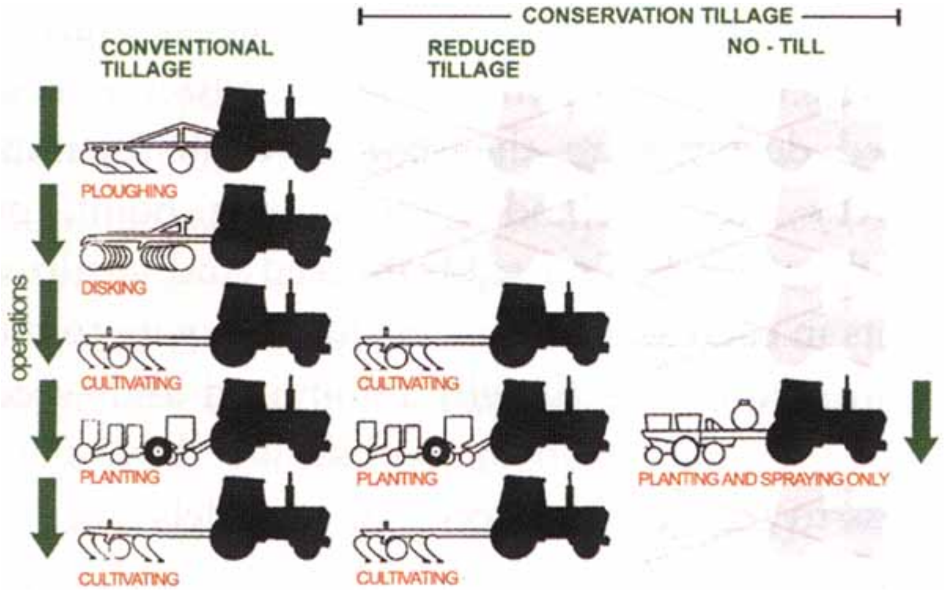

Figure 1: Tillage practices from conventional (full tillage) to minimum and no-till

(From Faidutti & Zhang, 2003)

Tillage is the practice of exerting force on the soil to break up and rearrange the topsoil structure, providing a seed bed to plant arable crops; this practice has been employed since the advent of agriculture at least 10,000 years ago (Faidutti and Zhang

2003). As illustrated in Figure 1, conventional tillage requires the passage of multiple types of machinery to prepare the soil for planting. While tillage promotes the rapid oxidation of crop residues (allowing soil microorganisms to quickly consume and release nutrients for uptake by plants), this practice can increase wind and water erosion, deplete SOM, reduce structural and aggregate stability and increased surface runoff. In addition, the multiple passes of heavy machinery can increase compaction and surface crusting, destroying pore space and preventing proper water infiltration. For maintaining or improving soil health, conventional tillage practices are strongly related to increased soil degradation (Bot & Benites, 2005).

Minimum or no-tillage, on the other hand, exerts much less physical disturbance and fewer passes with heavy machinery. By minimizing ploughing and disking, structure is left nearly intact, and residues are kept in place to protect the soil from compaction, erosion and runoff. Reduced, minimum and no-till practices have been shown to increase surface SOC by as much as 7.5 Mg C/ha in 10 years; however, it must also be noted that minimum and no-till practices are not for every operation (Janzen et al., 2005). Especially in organic farms which minimize the use of herbicides, minimum and no till operations face weed challenges compared to conventionally tilled farms. In addition, yield may be affected by minimum or no-tillage due to lower soil temperatures resulting in slowed microbial activity.

Jokela and Nair (2016) conducted a two-year field study comparing conventionally-tilled (CT), strip-tilled (ST: maintaining soil coverage with a tilled strip in the row for planting) and no-till (NT), organic bell pepper production. The authors found no difference between marketable yield between all three treatments for the first year, but increased yield in the second year for CT; this could be due to decreased soil temperatures. In addition, no differences between soil microbial biomass and diversity among the three treatments were found; however, the NT and ST treatments showed reduced concentrations of Nitrate-N concentrations in leachate, meaning that less Nitrate-N was being lost and at risk of polluting waterways. The authors noted that overall soil health measurements were not easy to compare in such a short timeframe but suggested a more long-term study to measure other indicators of soil health between the treatments (Jokela and Nair, 2016).

Economic returns, as represented by higher yields, are typically preferred by farmers when considering preferences for specific management practices; however, the authors also suggest that many farmers, especially those with high intensity cropping systems, make management decisions with a long-term focus, specifically the accumulation of organic matter (Mandyk et al. 2014). Minimum and no-till management systems, as described earlier, can prevent erosion, maintain aggregate stability, and increase infiltration rate (Smith, 2016). Infiltration, a soil's ability to permit the flow of water through the soil column, aids in the temporary storage of water for use by plants and animals (NRCS, 2014). According to Smith, infiltration was 43 times greater in NT than CT systems, although the author notes that this is atypical; through a case study analysis, the author found some evidence of increased yields in NT systems in the Midwest, which could be attributed to improved infiltration and water storage.

Regardless of what studies have shown to increase yields, a short-term benefit of specific management practices, minimum and no-till practices increase the long-term sustainability and resilience of soils. Through minimal or no disturbance, soil biological abundance and diversity is left in-tact, with AMF hyphal networks left unobstructed. Water is able to infiltrate without pooling or running off, erosion is minimized, and pore space is maintained. Nutrients are less likely to be lost through leaching, and the mineralization of C and N is minimized, keeping reserves for use by microorganisms later. In summary, minimizing tillage, in conjunction with other soil conservation management practices, has been shown to improve soil health in the long-term.

Cover Crops

Cover crops typically involve the cultivation of a grass or legume plant that maintains soil coverage during a fallow period or between cash crops. They can be used in conventional tillage during fallow periods, when the vegetative cover is plowed under and disked in in preparation for an upcoming crop; this practice, however, can leave soils vulnerable to erosion and runoff. In conservation and no-till systems, cover crops may also be used, although fears of weed suppression have been cited. Other techniques, like mowing or using a roller-crimper to terminate the cover crop, allow for continuous soil coverage with the added benefits of weed suppression and mulch coverage (Jokela & Nair, 2016). Due to establishment and management costs, competition with cash crops and issues with residue management and irrigation, many farmers are hesitant to use cover crops, especially in year-round continuous cash crop systems like California's Central Valley (Mitchell et al., 2017).

Maintaining soil coverage is one of the best ways to prevent soil degradation. With permanent aboveground coverage and thick root systems, soils can be held in place in high-saturation periods, like during the winter and fallow seasons and can prevent the splash effects caused by raindrop impacts on bare soil. During the wintertime when cover crops are typically planted, freezing of aboveground biomass limits the plants' aboveground capacity to mitigate erosion loss. De Baets et al. (2011) compared 5 different types of cover crops and their abilities in reducing erosion loss: white mustard (*Sinapis alba*), phacelia (*Phacelia tanacetifoli*) ryegrass (*Lolium perenne*), oat (*Avena sativa*), and fodder radish (*Raphanus sativus* subsp. *Oleiferus*). The authors found that cover crops with thick roots, like the white mustard and fodder radish, were less able to prevent erosion loss in the wintertime than 'fine-branched' root systems like ryegrass. An important point to be made is that while cover crops are generally beneficial to overall soil health, the selection of cover crops based on individual land and soil needs should be considered.

Using a legume or grass cover crop during fallow periods improves soil properties like increased C and N, increased SOM, erosion mitigation, and reduced erosion (Udom & Omovbude, 2018). Different types of cover crops provide different benefits; for leguminous crops like alfalfa, clover or vetch, these plants work with symbiotic N-fixing bacteria to increase the soil's pool of organic N. In a study conducted in the Goiana-Ceres Campus in brazil typified by low levels of OM, a number of legume varieties (*Crotalaria spectabilis* L. and *Mucuna aterrima* L.) added 46 kg/ha of N to soils (Sousa et al. 2013). Grasses with deep roots, on the other hand, are able to seek out nutrients that could be lost through leaching. In the same study, Millet (*Pennisetum glaucum* L.) extracted 3.9 kg/ha of N to grasses through intercropping (Sousa et al. 2013).

In addition, Cover crops have been shown to increase infiltration rates, improve soil aggregation, enhance porosity and hydraulic conductivity, as well as reduce runoff (Smith, 2014). In a 15-year study conducted by Mitchell et al. (2017), various cover-cropping and tillage systems were compared in California's San Joaquin Valley. With a cover crop mix of Juan triticale (*Triticosecale*), Merced rye (*Secale cereale)* and common vetch (*Vicia sativa*), in conjunction with either conventional tillage (CT) or no-till (NT), the authors yielded 2.8 times faster infiltration rates with CC regardless of tillage system; this is most likely due to the development of root channels in addition to the continuous supply of C to fungi and bacteria, which aids in aggregate stabilization (Mitchell et al., 2017). The average surface residue accumulation was highest in the no-till cover crop trials with 92% accumulation over time. Cultivating and maintaining trash cover, as previously explained, is a necessary part of management and a primary goal of sustainable agricultural production. The cultivation of surface residues reduce erosion, provide C and N to soil organisms, reduce water evaporation and lower soil temperatures (Mitchell et al., 2017).

The authors also measured bulk density, %C and %N for the 4 tillage and cover crop trials. Interestingly, bulk density was lower in the no-till no cover crop trials than the cover crop trials at a depth of 0-15 cm; at 15-30 cm, though, there was no difference. For both %C and %N, cover crops had a positive influence on the accumulation of both nutrients; however, no-till systems had a more significant impact on %C and %N. For %C, there were on average between the two sampling dates 16.5% more C for the CC treatments than not. For %N, approximately 11% N increase was attributed to cover crop inclusion in management practices. (Mitchell et al., 2017)

While all four treatments yielded total C accumulation over the length of the fifteen-year study, no-till with CC had the greatest overall increase in total C: 29.1 tons/ha for NTCC, 21.6 tons/ha for NT with no CC, 16.8 tons/ha with CT and CC; and

11.5 tons/ha with CT and no CC. These results show that both cover crops and tillage reduction have a positive impact on C accumulation in soils (Mitchell et al., 2017). As previously discussed, since SOM is largely made up of C (around 60% SOC in SOM), one can deduce that cover crops and tillage contribute to OM accumulation in arid climates.

Since yield is clearly of high priority to producers, the study also measured impacts on yield based on cropping systems. Cotton and tomato rotations along with one rotation of Sorghum and garbanzo beans with subsequent yields were measured throughout the study. From 2000-2009, tomatoes had a 5.7% higher yield without cover crops and 4.8% greater yield for cotton without cover crops as well. The authors attribute this period to a learning curve for adoption of new management practices. For the sample period between 2010-2013, though, there were no yield differences between trials (Mitchell et al., 2017). While maintaining yield stability is an important pre-requisite for farmers in implementing sustainable agricultural practices (Boehm & Burton, 1997), the benefits of improved soil health with the implementation of a cover crop (increased infiltration rates, aggregation, respiration and increased soil C and N) paired with lower production costs, reduced inputs, water conservation, higher C and N stored in the soil and plants, as well as lowered dust and particulate matter emissions are all benefits that should be considered aside from increased profits from higher yields (Mitchell et al., 2017).

Perennial crops

Perennial plants include grains, oil seed legumes, trees and forages that can be cultivated intensively with minimal to no soil disturbance. These plants are able to regrow and continue to produce fruit, seed, grains or biomass every year, as opposed to annual crops which are planted, create above and belowground biomass in a single season, produce fruit, and then die. The difference between perennial and annual cropping system is the length of time the crop is alive. With annual crops, the above and belowground biomass production is limited to one season. For perennial crops, conversely, both types of biomass are able to continue to grow for multiple years; because of this, OM will undoubtedly increase (Leakey, 2011).

The inclusion of perennial trees in agroforestry initiatives is beneficial for habitat niche biological diversity, since within perennial systems, minimal soil disturbance and maximized living plant biomass encourages belowground organismal abundance and diversification and can help improve nutrient, C and hydrologic cycles and can help make the crops themselves more resilient to disease and pest pressures (Leakey, 2011). Other benefits to overall soil health include: reduced soil erosion and additions of SOM, increased rates of infiltration and storage, buffering to environmental and pH changes, as well as above and belowground C sequestration (Dixon & Garrity, 2014).

In a study conducted by Ernst et al. (2018), a crop-pasture rotation of three or four-year annual cash crops production of wheat paired with a three or four-year grass-legume pasture under no-till management were then converted to a continuous annual cropping rotation of wheat under no-till management in the eastern Pampas of South America. The authors measured the impact of agricultural intensification of annual cropping systems on soil properties (in addition to overall crop yield) which included: SOC, soil P, exchangeable K, mineralizable N (nitrate concentration), texture, and field water infiltration rate. After 10 years of continuous cropping, the average yield loss was

1.4 Mg/ha, a 21% decrease; in addition, the authors found an increase in ‘platy structure’ of the soil by 51%. Platiness is often associated with increased runoff and reduced root-ability and water infiltration rates. The Amount of mineralizable N was reduced gradually after conversion to a continuous annual cropping system, as well (Ernst et al., 2018). Switching from a crop-pasture system to continuous cropping negatively impacted soil physical structure and N availability, as illustrated in the previously cited study.

Other studies highlight the benefits of Agroforestry initiatives; including diversified trees and cropping systems with both annual and perennial crops and may sometimes include livestock (Barrios et al., 2012). Agroforestry systems have been shown to increase habitat niches, contributing to soil macro and micro-fauna diversity; increased species abundance includes: earthworms, beetles, centipedes, millipedes, termites, ants, collembola, mites, and both parasitic and non-parasitic nematodes (Barrios et al., 2012). These complex above- and belowground agricultural systems have also been found to increase the amount of C in plants, roots, and the soil as well as aid in nutrient cycling. Through the promulgation of species abundance and diversity, increases in SOM and C sequestration have been found in agroforestry initiatives; in addition, nutrient availability as a by-product of soil microbial and fungal processes, like N availability, have also been found (Barrios et al. 2012). In summary, the inclusion of perennial crops into agricultural systems has been shown to improve overall soil health. Another method to improve soil biological properties is by diversifying crop rotations.

Crop rotation

As previously discussed, increased above and belowground biodiversity has been shown to have a number of benefits for soil biological, physical and chemical properties (Barrios, 2007). Incorporating diversified cropping systems into a farm management plan provides a variety of residues are incorporated into the soil, diversifying available organic matter, supplying a wider range of nutrients (Rangarajan, 2005) In addition, incorporating multiple crop types into an agro-ecosystem may also diversify production, allowing farmers and land managers to benefit from different crops at different times; however, it can be tricky to create a good rotation system that produces the type and quantity of desired crops (Johnson & Toensmeier, 2009). Regardless, the soil health benefits of diversified cropping systems include: improved crop yields, workability and soil tilth; increased water availability and and organic matter content; reduced soil crusting, erosion, as well as fertilizer and insecticide inputs (NRCS, 2009).

Nunes et al. (2018) quantified the long-term tillage and cover crop/crop rotation effects on soil health in a temperate climate in New York State. Over 24 years, the four treatments included plow tillage (PT) and no-till (NT) paired with a continuous corn crop and a 6 year corn, 6 year grass followed by twelve year corn rotation. While tillage had the largest positive impact on soil health (17% more OM, 65% more protein in OM, 95% more P, 66% more Zn, 76% increase in water aggregate stability, and 17% increase in respiration), the inclusion of cover crops and crop rotation augmented these benefits. The 24-year continuous corn rotation had 17% lower OM and 17% lower respiration rates than the 12-year corn mono-crop after grass; most notably, crop rotation, NT and cover crops had the largest positive impact on soil biological properties (Nunes et al., 2018).

According to the authors: “from a bio-physical-agronomic perspective, no till systems, especially when adopted with diversified cropping systems offer farmers opportunities to improve soil health while maintaining intensive crop production” (Nunes et al., 2018, p. 42). In addition, crop yields also increased under NT and crop rotation for the loamy fine sand and silt loam soils; however, since NT usually results in poor drainage for clay soils, there was no increase in yields for this soil type. Not only does the inclusion of crop rotation (along with other sustainable farm management practices) potentially improve yield but the improvement in SOM levels, diversification of crop nutrients added to the soil, and mitigating potential disease and pest infestations, farmers can also potentially save money on fertilizers and pesticides (Johnson & Toensmeier, 2009).

The application of manure and biosolids on soil quality indicators has also been heavily researched. Karlen & Obrycki (2018) conducted a study on four field-scale treatments in Iowa, measuring the effects of different crop rotations paired with varying amounts of a biosolids/manure mixture. The soil quality indicators measured included: bulk density, microbial biomass C, pH, electrical conductivity, organic C, aggregate stability, extractable nutrients, and various forms of N.

Compost, manure and biosolids application

Applying organic materials (crop residues, compost, manure, and biosolids) to the soil is a common practice used to improve soil quality and serve as a means for waste disposal. According to Brown et al. (2011), people in Washington State on average generate 60 pounds of biosolids (digested solids from wastewater treatment systems) and food waste, and 150 pounds of yard waste annually; in addition, each person consumes animals that generate 10,000 pounds of manure! Crops like mint and hops, for example, also generate large amounts of waste; herbs used to distill essential oils, or plants that are processed for beer, leave large quantities of crop residue that can be applied to fields in an essentially digested state. What's most beneficial in the application of these specific organic materials is the microbial digestion that takes place, oxidizing or breaking down residues for easy uptake by soil microorganisms. In so doing, these microorganisms supply both macro- and micronutrients to plants in a readily-available state.

Amendment	C:N Ratio	NH4-N	PAN (%) Field	PAN (%) Lab
Dry boiler litter	9	6.3	41	45
Composted	9	7.3	38	45
Dairy solids	27	1.5	9	1
Composted	20	0.6	5	8
Yard trimmings	13	3.0	19	25
Composted	17	0.7	5	5
BioGro	5	1.1	77	57
Canola meal	8	0.1	60	41
Feather Meal	4	2	99(?)	74
Mint slugs	10	0.4	7	3

Table 1: plant available nitrogen (PAN) of organic soil amendments
(adapted from Granatstein, 2012-2013.)

Compost, manure and biosolids are all materials that have varying nutrient contents depending on the nutrient content and treatment process of the added materials. Compost is frequently used as a blanket term for decomposed plant waste, manure, and biosolids, but for the purposes of this study, I will refer to it as vegetable waste. For compost, materials include: food processing residuals, agricultural by-products, forestry residuals, and yard waste (Farrell & Jones, 2009). Manure originates from dairy and livestock feedlots, and if not disposed of or contained properly can have serious negative impacts on local streams and waterways. Biosolids, or sewage sludge, is a solid material by-product of the wastewater treatment system. All three products have been shown to increase SOM, and consequently improving a number of other chemical, physical and biological properties of the soil (Farrell & Jones, 2009.). The following section considers all three organic materials and their benefits to improving soil health.

In a six-year field experiment, D'Hose et al. (2014) compared the relationship between crop production and soil quality based on the application of compost amendments to a loamy sand alfisol (a soil order characterized by higher clay contents and slightly higher acidity). Four crops (fodder beet, forage maize, brussel sprouts, and potato) were grown with equal applications of plant-available N, P and K from both fertilizers and compost. SOC, hot-water extractable C, total N, extractable P and K, bulk density, penetration resistance, aggregate stability, microbial biomass, and presence of earthworms, nematodes and ergosterol (an indicator of fungal biomass) were used to measure soil health. In addition, crop yields were measured throughout the duration of the experiment. The study found that repeated applications of farm compost improved SOC and total N levels, extractable K, lowered bulk density and increased aggregate stability, and positively influenced biological diversity and abundance (D'Hose et al., 2014). The authors also found correlations between increased SOC content and higher yields for fodder beets and potatoes, with yields of potatoes and fodder maize expected to increase the most with increases in SOC. According to this study, compost applications have been shown to improve overall soil health (D'Hose et al., 2014).

Animals produce massive amounts of waste that need to be disposed of in a safe and efficient matter. As highlighted by Brown et al. (2011), people in the state of Washington contribute to an average of 10,000 pounds of animal-generated waste per person. If not properly disposed of, this waste runs the risk of contaminating waterways with excess N, P and other nutrients that contribute to eutrophication and other environmentally degradative effects. The benefits of manure are that aside from transportation and application costs, manure is free; it has been shown to improve a variety of soil health indicators like increased OM, improved structure and water-holding capacity, increased CEC and reduced erosion; and provides both readily available and slow-release macro- and micronutrients for uptake by soil organisms and plants (Farrell & Jones, 2009).

In Yunnan, China, Zou et al. (2017) conducted an 18-year study monitoring the effects of crop rotation and manure amendment on tobacco production. Eight treatments were observed: two rotations of tobacco monocrop and tobacco with a two-year rice rotation, paired with varying fertilizer applications: 0, 75, and 112 kg N fertilizer per hectare with one treatment of 60 kg N fertilizer and composted swine manure applied at a rate of 15,000 kg/ha. Soil quality indicators measured included: soil aggregate stability, SOC, total soil N and bulk density; all were observed in the 8 treatments at 0-10 cm and 10-20 cm. The authors found that fertilizer and manure applications paired with crop rotation increased soil aggregate stability and organic matter content; however, the manure-applied treatments had higher bulk density than was expected, possibly due to variation in soil texture or land use due to tillage intensity. In addition, the manure and fertilizer treatment increased SOC and total soil N compared to the typical fertilizer application rate for tobacco of 75 kg N fertilizer/ha. Aside from the bulk density measurement, manure application paired with crop rotation improved aggregate stability through the addition of organic matter, in addition to increasing levels of SOC and soil N (Zou et al., 2017).

While manure has been shown to add benefits to the soil, there are some significant drawbacks. The most notable being that if applied in excess, nutrients can be lost through volatilization (NH_4 lost to the atmosphere if not incorporated properly or applied during wet conditions) but can also leach through the soil layers (Brady & Weil, 2010). This leaching not only results in a loss of money due to lost nutrients but has been shown to contribute to the eutrophication of above and belowground water sources. The dead zone in the Gulf of Mexico is an example of the ill-effects of improper nutrient management which can result from either synthetic or organic fertilizers (van Grinsven et al., 2014). Manure is challenging to transport, especially when wet. Also, if not stored under proper conditions or exposed to contaminating bacteria, may be host to pathogens like fecal coliform or E. coli. Recently, the use of high levels of antibiotics have been considered for both biosolids and manures, which may have negative impacts on soil microbial and fungal populations (Xie et al., 2018; Yang et al., 2018). If purchased from sources that use minimal antibiotics, is stored properly, and is applied using the 4 R's (which will be discussed later), manure can substantially benefit soil health.

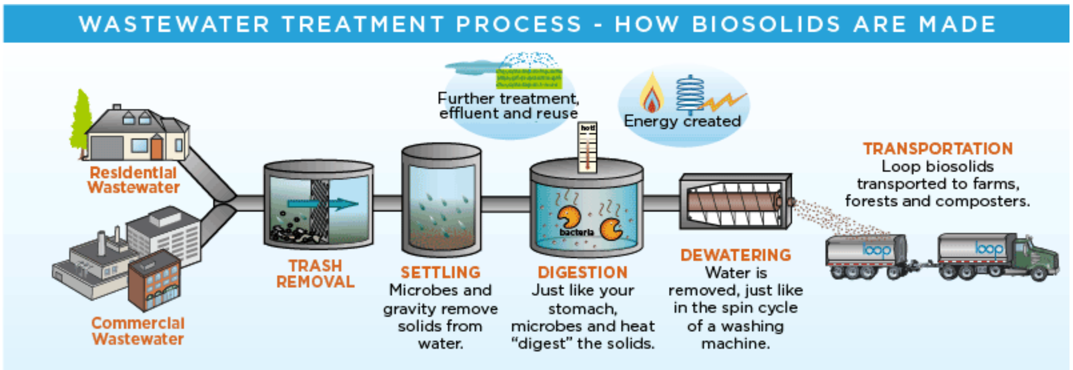

Figure 2: Biosolids treatment process from source to agricultural application

(Courtesy of King County Wastewater Treatment Division, 2016)

Biosolids are the culmination of organic solids from the wastewater treatment process. As illustrated in Image 2 waste from residential and commercial sources is ran through a number of filtration systems to remove non-organic trash and allow microbes to process the waste; once the final product meets all of the EPA's standards for biosolids, they are then applied to at least 15,000 acres of land in Washington state (Loop). Biosolids have a controversial past: when waste streams from manufacturing were mixed with residential and commercial sectors, high levels of toxic chemicals and heavy metals were found. Understandably, the public was outraged, and sustainable agricultural initiatives like the Organic movement prohibited the use of biosolids (Sharma et al. 2017, Rodale Institute 2013).

In the past few decades, the EPA and other monitoring agencies have increased their monitoring of biosolids production, which now must meet a number of stringent ceilings for heavy metal content as well as pathogens (Walker, 1994). As illustrated in Image 2 Loop Biosolids, King County's by-product of the wastewater treatment process, is well below the EPA's ceiling for heavy metal concentrations in biosolids. In addition, Class B biosolids (which make up the majority of biosolids applied in Washington state) must test to prove that the products are at least 95% free of potential pathogens and bacteria that can harm humans and animals. Biosolids have a controversial past, it is clear that measures are being taken, especially in Washington state, to ensure that biosolids applied to the land are safe for humans, animals and the environment (Loop).

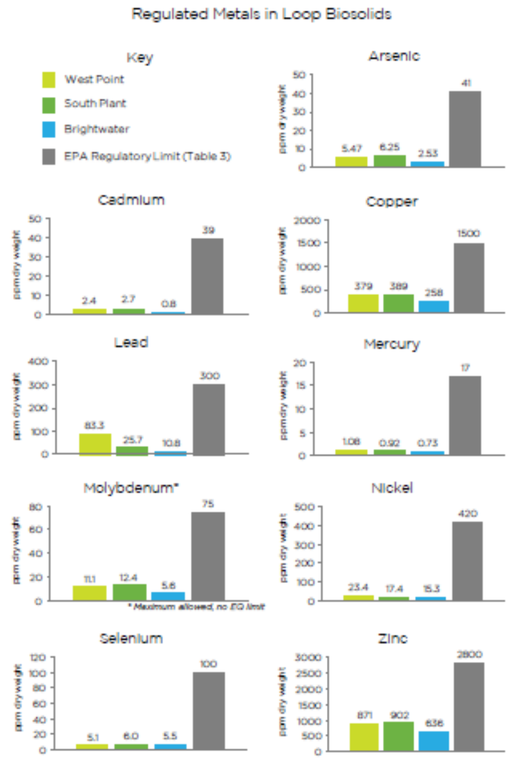

Figure Ex-1. Average 2016 metal concentrations in Loop from three King County treatment pants compared to the most stringent limits set by EPA for metals in biosolids. Data are presented on a dry weight basis in parts per million (ppm, or mg/kg).

Figure 3: Permitted levels of regulated metals in Loop Biosolids

(Courtesy of King County Wastewater Treatment Division, 2016)

Biosolids have been shown to increase a number of soil properties which include: physical components like aggregate stability, increased water-holding capacity, and decreased bulk density; chemical factors like increased macro- and micronutrient concentrations, electrical conductivity, Organic C levels and the presence of humic acids; biological characteristics like increased abundance and diversity of soil organisms (Sharma et al., 2017). Biosolids have also been shown to increase SOC, and subsequently SOM; Wijesekara et al. (2017) compared biosolids-amended soils with un-amended soil in New South Wales, Australia. There were a total of four cropping systems including: canola, wheat, fodder sorghum, and a fallow plot. Soil properties measured in the treatments included: soil pH, electrical conductivity, total C, total N, total S, and soil microbial respiration. Results indicated that biosolids-applied sites had increased total C, and a positive effect on soil microbial activity; however, biosolids amended sites had increased CO_2 emissions, indicating an inability to sequester C for the given sites. Even without the added benefits of soil C sequestration, biosolids applications proved to be beneficial for soil microorganism populations and for increasing total C.

Organic amendments are useful tools that can contribute to a number of soil chemical, physical and biological properties. The proper sourcing, application and management of these materials are necessary for truly beneficial impacts to the soil and plants, and to minimize negative impacts to the soil. This section indicates that while organic amendments are a worthwhile option for the soil and plants, they may not be right for every operation. Synthetic fertilizers have received significant criticism in the recent past, and rightfully so; they're wide-scale production and application has contributed to greenhouse gas emissions, and their misuse has resulted in contaminated ecosystems. Regardless, when used in conjunction with other sustainable management practices, synthetic fertilizers can contribute to soil and plant health. It is necessary that whatever nutrient source is used, farmers and land managers follow the four R's of nutrient management: Right Source, Right Rate, Right Time and Right Place.

Right Source, Right Rate, Right Time, Right Place

Each farm and farmer have unique circumstances in regard to nutrient imports and exports; however, with any agricultural system, nutrients and organic materials are produced from the soil, but are harvested and removed for sale. This results in an inherent nutrient deficit, which needs to be resupplied by either the addition of organic or synthetic amendments. In a post-industrial agricultural mentality, and with the advent of organic agriculture, much of the public views synthetic fertilizers and conventional practices as contributors to climate change, environmental degradation, and public health risks. Historically, these practices have contributed to these factors, but largely through their misuse. Synthetic fertilizers, in general, provide a highly concentrated amount of many of the macro- and micronutrients necessary for crop production (Brady & Weil, 2010). While it's true that they are intensive to mine and manufacture, they can offer a more direct nutrient benefit to crops than organic amendments and cover crops alone.

Since it is nearly impossible to create a one-size-fits-all approach to nutrient management on any farm, the 4 R's of nutrient management have been proposed. Applying the right source at the right rate during the right time and in the right place ensures nutrient use efficiency and minimal impacts to the environment (The Fertilizer Institute, 2017). These factors are not isolated, but are frequently interconnected, like for placement and timing; for either organic or synthetic fertilizers, it is essential that the source is incorporated in the best location for plant uptake, as well as at the proper life stage of the plant (Hochmuth et al., 2014). The following section will explore each of these factors and will address how farmers can decide what's best for their specific operation.

Right source refers not only to the most cost-effective nutrient available, but also to selecting the material with the ideal, texture, quality, state (wet or dry), pH, and nutrient content for their operation (Hochmuth et al., 2014). For instance, it would be difficult for a farmer to use a granular fertilizer if he only has a liquid sprayer or doesn't have the appropriate machinery to spread manure on his fields. This also refers to the needs of the soil; if soil sampling reveals a P deficiency as well as low levels of organic matter, compost, manure or biosolids may be appropriate; however, if a farm is certified organic, they must follow specific guidelines for the type of compost or manure applied and cannot use biosolids. The inclusion of cover crops may also be considered if a farmer wants to add N with legumes or scavenge for nutrients throughout the soil profile with grasses. Finding the most ideal source is very important to proper fertility management.

Right rate is determined by calculating plant needs and subtracting nutrient results provide by soil samples (NRCS, 2014). Unfortunately, nutrient availability is not always as easy as a simple calculation. Some fertilizers are more readily available than others, and certain climatic conditions have a significant influence on most macro- and micronutrients. Heavy rainfall and high temperatures increase the potential for ammonium (NH_4) to volatilize into ammonia (Nh_3) and be lost to the atmosphere (Brady & Weil, 2010). This can also refer to the application of fertilizers and amendments throughout the growing season. Farmers do not typically apply all fertilizers during the pre-plant phase; they may apply a portion during pre-plant and may supplement with side-dress applications (which will be covered in the right placement section) at some point during the growing season.

Right rate is closely linked with timing, since climatic conditions and crop stages depend on time. Timing also varies with each crop. NRCS (2014) recommends applying fertilizers with crop growth rates to reduce potential nutrient losses through leaching and runoff; therefore, having an understanding of the right timing for nutrient application allows an individual to maximize use efficiency and minimize losses (The Fertility

Institute, 2017). In reference to climatic conditions, predicting weather patterns can present an added challenge. Farmers should therefore pay close attention to rain events when applying nutrients and should have an understanding of how their intended amendment reacts with varying amounts of rain (Hochmuth et al., 2014).

Right place is also crop and farm-specific; fertilizers should be placed where plants can access them easily with minimal losses through volatilization, leaching, or runoff (The Fertility Institute, 2017). According to Hochmuth et al. (2014) the most effective placement is typically in the rhizosphere (or root zone) of the crops under cultivation since most nutrient uptake occurs through the roots. There are four methods for fertilizer application: band application, pop-up, broadcast or top-dressing and side-dressing (Strub et al., 2012). Band applications are frequently within 2 inches from the seed, typically called the starter method; this provides for efficient nutrient supply to the plants since it is in nearly direct contact with the seed itself. Pop-up applies fertilizer at the same time as seed-planting; however, farmers must be mindful of the rate of application, since seeds are at risk of burn from N and P. Broadcasting and topdressing are the most common applications (and are typically the easiest) since they are applied on the soil's surface. They can be applied by hand or with machinery; however, most fertilizers must be incorporated immediately with tillage or a similar process to prevent volatilization or runoff. Finally, Side-dressing is performed during the growing season, but have been pre-determined based on crop needs. For N specifically, this application process is intended to supply N at the appropriate time when crops will need it for the most efficient use of the fertilizer as possible (Strub et al., 2012).

Utilizing the 4 R's of nutrient management allows the farmer to supply adequate nutrients to their crops, maximize the use efficiency of their fertilizers and amendments, and minimize negative impacts to their local environments. It must be noted that these actions are very complex, and farmers must be aware of a number of factors simultaneously. Best management practices like these require much forethought and planning on the part of the farmer, as well as an ability to identify constraints and address problems as they are presented. In summary, farming is not an easy pursuit, especially if it is done to maximize profits and minimize environmental impacts. However, it is possible, and with the right support and motivation, farmers can maximize their profits and minimize their impacts on local ecosystems.

Why we study the soil itself

As previously defined, Doran and Parkin (1994) define soil health as a soil's ability to: "accept, hold and release nutrients, chemical constituents and water; promote sustainable root growth; maintain a suitable biotic habitat; respond to management; and resisting degradation". This definition shows that soil and agricultural scientists have begun to understand the complex interplay of physical, chemical and biological factors within the soil, and that no single indicator is sufficient to understand the soil's functional capacity (Doran, 2002). While great contributions have been made within the basic research of soil and agricultural sciences, how can these findings prevent soil and environmental degradation if research into the widespread dispersal or application of this new knowledge is not emphasized?

It is therefore essential to combine basic and applied scientific inquiry in order to truly understand how farmers collect information, where that knowledge originates, and how education and outreach can inform knowledge gaps. In addition, by broadening the academic definition into other forms of knowledge collection and dissemination (i.e. local and traditional ecological knowledge), academia can not only better identify how best to inform farmers and land managers of new information but can also gain valuable insight into the local and experience-based knowledge upheld by farmers. By combining applied and basic research within a typical scientific framework, which emphasizes universally applicable rules and laws, with the locally-based and site-specific knowledge of farmers and land managers, scientists, agronomists, farmers and policymakers can work cohesively to conserve natural resource use, mitigate ecosystemic and environmental degradation, and improve soil health across local, regional, national and global scales.

Farmers: The creation and dissemination of tacit knowledge

The prevalence of explicit knowledge in academia is largely due to the fact that it is easy to communicate and collect, unlike tacit knowledge (collected by farmers) which requires socialization and extensive time and energy to acquire (Hoffman et al., 2007). In keeping with Jensen et al.'s (2007) definition of the different modes of learning, farmers acquire knowledge through Doing, Using and Interacting (DUI). Farmers prioritize experience and application ('know-how', 'know-who' and 'broad view'), and constant trial and error as well as interacting with actors from a range of experience levels and backgrounds can foster strong relationships and understanding concerning a particular issue (Ingram, 2008). Farmers have a much more diverse understanding of phenomena than researchers in terms of climate, vegetation, resident macro- and microbiology, soil type, etc., which focuses on a specific region or locality. Therefore, innovation within these groups pertains to the local environment, and are not universally applicable (Hoffman et al., 2007).

According to Sumane et al. (2017):

> "farmers' knowledge is a subset of local knowledge that enables [these individuals] to farm in specific local conditions. It is based on practical experience and often linked to a practical skill. As agriculture is highly dependent on the local environment, local farmers' knowledge is of particular importance as it contains an intimate understanding of the particular set of local cultural and natural resources." (p. 2)

This consideration of the entire system, which includes social, environmental, economic or even spiritual components, highlights the complexity of agricultural communities, and even the farm system itself[12]. As a holistic and dynamic system, farmers have acquired the skill to consider a multitude of factors when determining how to best operate an agro-ecological system.

In addition to the DUI model described by Jensen et al. (2007), Okali et al. (1994) considered 74 examples of farmer experimentation and found three forms of 'local learning': learning during action, learning from chance, and structured experiments similar to conventional experimentation. The most valuable form of structured experimentation is learning during action, in which farmers make rolling adjustments as part of their daily practice. This dynamic process is performed both consciously and subconsciously, and because farmers live and work on their farm, they have more time and direct contact with their observations than researchers (Okali et al., 1994). Replication in a farm system occurs over time, rather than space, since farmers must utilize their space to produce crops and maximize profits (Hoffman et al., 2007).

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[12] For further information, see: 'Experience' and 'Trust in Internal and External Groups' in the "Interviews" section.

In terms of the potential knowledge gained by farmers and other land managers, Knapp and Fernandez-Gimenez (2009) state that rancher knowledge may even be able to inform scientific insight into ecosystem processes, sustainable management practices and interactions between human and natural communities; however, few studies have considered the potential of rancher (or other land manager) knowledge regarding range and farmland ecosystems. Scientific inquiry into crop development began 100 years ago, and the first anthropologist to document farmers and crop experimentation took place in 1972, even though farmers and land managers have been experimenting with cropping systems and the optimization of specific crops since the beginning of agriculture (Hoffman et al., 2007). While it is possible for farmers to communicate their knowledge, some of this information acquired through practice is lost. Hoffman et al. (2007) argues that the externalization of tacit knowledge from expert farmers, by converting an implicit knowledge-base into an explicit format, should be the focus of agricultural researchers; in order to do so, researchers should develop new working tools that have been created through their observation of practice-based action, as well as formulate instructions based on these observations. Essentially, it is the agricultural researchers' job to explicate implicit knowledge. This will be covered further later in this review.

Unlike researchers who search for causation in experiments, and are prone to failure when isolating variables, farmers practice 'black-box' experimentation, where they can vary inputs into their system and observe outcomes without the need to explain what's happening within the system (i.e. black box). Although a valid form of investigation, Hoffman et al. (2007) suggest that it is possible for farmers to arrive at false conclusions under this model, since they do not seek to understand the 'know-why' method practiced by scientists. For example, farmers may apply an excessive amount of nitrogen fertilizer to their fields to ensure that they have a higher crop yield than the previous year. Without the knowledge of the nitrogen cycle, and how excess nutrients not taken up by plants can be lost to the atmosphere through ammonification or leached out to groundwater sources, they may not know the environmental impacts of this practice. If they do, however, observe an increase in crop production, they may continue the practice without the knowledge of the potentially detrimental environmental impacts. Scientists are therefore necessary to provide the 'know-why' of these natural processes but need to develop ways to work with farmers in this capacity.

Hoffman et al. (2007) explain that there is great validity within farmer's tacit knowledge, and scientific inquiry into these types of knowledge is necessary to further our overall understanding of agroecological systems. This point will be discussed in greater detail in the next section; what must be stressed is that although tacit knowledge contains technical elements, the complexity, time and effort necessary to accumulate and communicate the tacit knowledge of expert farmers is extremely difficult, and due time and effort constraints, scientists up to this point have neglected to explore this knowledge base in great detail. "An expert generally knows what to do, he or she does not see problems in some detached way and work at solving them… based on mature and practiced understanding when deeply involved in coping with this environment. When things proceed normally, experts don't solve problems and don't make decisions, they do what normally works" (Hoffman et al. 2007, p. 362). As explained by the authors, experienced farmers should be viewed as experts who have developed an intuitive and 'non-reflective' understanding of their environment.

Pasquini and Alexander (2005) considered the soil fertility practices of farmers in the Jos Plateau of Nigeria. As a site in need of reclamation due to land degradation from decades of tin mining, the Mines Land Reclamation Unit deemed the land unsuitable for reclamation. However, local farmer groups still worked tirelessly, and found that a combination of animal manure, organic urban waste ash and inorganic fertilizers proved successful in reviving the land. The authors point out that, as discussed earlier, "each farmer had a complex and different strategy the he believed was optimal for his land, suggesting that the farmers have learnt over the course of the years what produces the best results in terms of satisfactory crop growth and development, and through experimentation and careful observation" (Pasquini & Alexander, 2005, p. 115) . Based on their own understanding of their land, expert farmers were able to improve soil fertility through a combination of amendments that was replicated over time (Pasquini and Alexander 2005)[13].

As described by Hoffman et al. (2007), there is a need to better understand these forms of knowledge and make them more explicit and usable by others. The following section will address this point in great detail, but what must not happen is the 'scientification' of these forms of knowledge; scientists must not transform expert farmers and land managers into scientists but must instead observe and translate their tacit knowledge into more readily-communicable forms (Hoffman et al. 2007). The authors considered the CIAL (Committees of Local Agricultural Investigation) model of Latin America, a community-based research initiative that feeds local results back into a formal academic system. Hoffman et al. (2007) points out that it can be useful to teach

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[13] For more information, see the role of intuition in the *Experience* section, p. 118

farmers some principles of formal experimentation; however, the most knowledge can be acquired from expert farmers and land managers if scientists respect their ‘tried and true’ epistemologies and be the actors to translate this knowledge for use in a broader sense.

Lack of knowledge depth in farmers’ broad understanding

As previously discussed, farmers’ typically practice ‘black box’ experimentation, which can explain how farmers are more aware of crop production as opposed to soil function, since plant health is typically easier to identify than soil health (Lobry de Bruyn & Abbey, 2002; Ingram et al., 2010). This can be especially problematic in a time of environmental and soil degradation due to agriculture. New sustainable management practices must replace the old Productivist model that supports intensive tillage, mono cropping, and the excess application of synthetic nutrients. Ingram (2008) sought to understand how well-equipped farmers are in adapting and adopting new farming practices to increase soil conservation.

Especially in sustainable farming practices, which are locally based, and context-specific, Ingram (2008) examined whether or not farmers had the intellectual tools necessary to meet the demands of sustainable agriculture. The author used two methods of data collection: they first conducted semi-structured interviews of 17 farmers and 64 agricultural advisors, in addition to surveying 304 advisors. In so doing, the author considered how well-educated farmers were of best management practice (BMPs), and how agronomists perceived farmers’ capabilities for more sustainable agricultural practices. The author found a range of competencies with farmers, with most being professional, highly-skilled and have a bachelor’s degree; these individuals could effectively prepare fertilizer recommendations, use and interpret research results, and also had a relative grasp of the soil nitrogen cycle (Ingram 2008). However, only 40% of advisors surveyed and interviewed believed farmers were equipped to meet the challenge of implementing sustainable agriculture on their farms.

While farmers have a broad understanding of ‘good husbandry practices’, they lack the depth of understanding required to see causal relationships between their actions and environmental impacts. Ingram (2008) found that farmers were able to explain problems and identify mismanagement like erosion and runoff, although many did not connect their own practices with environmental degradation. As previously described, farmers exhibited a broad ‘working knowledge’ of their own soil and understood the texture, drainage patterns and physical properties on their own land. They could also identify spatial and topographical variation as well as the physical properties and soil’s responses to management (Ingram, 2008).

The author argues that since Productivist agricultural practices are easily applicable and do not necessarily account for context-specificity, many farmers fall back on these methods when lack of knowledge in sustainable practices exists. When considering the application of manure, a sustainable management practice which requires some knowledge of nutrient cycling and the ability to budget nutrients, many farmers are reluctant or unable to measure the amounts of manure applied, and farmers use rough estimations or no estimation at all when applying this nutrient (Ingram, 2008). In addition, as farms continue to grow in size, farmers are interacting with their soil less, resulting in a loss of personal accountability of their own management practices.

While farmers have a breadth of knowledge acquired through experience, their lack of depth results in a loss of personal accountability, reluctance to change, and challenges when thinking in terms of site-specificity in relation to sustainable management practices. A paradox arises here, because farmers, as historically local practitioners of tacit knowledge, work within specific contexts on a daily basis. Ingram (2008) argues that with the rise of the Productivist era, farmers replaced locally based soil knowledge with advanced science and technology originating from academic settings, resulting in universally-applied prescriptions with the goal of commodification and increased yields. The dominance of the scientific model, as previously discussed, provided increased yields and an array of technological advances, but at the cost of extreme environmental degradation.

Understanding Tacit Knowledge: Interview Analysis

Many publications have attempted to explicate farmer's implicit knowledge through semi-structured interview analysis. This method has provided a better understanding of the knowledge possessed by farmers concerning: conservation practices, local soil taxonomies, management practices that improve or degrade soil health, among other important measurements of soil health knowledge (Knapp & Fernandez-Gimenez, 2009; Dawoe et al., 2012). Many of these inquiries attempt to understand farmers' non-scientific knowledge forms by analyzing their demographic, educational and social characteristics; they then compare these responses with management practices or incentives for implementing sustainable agricultural and soil management. According to Burton (2014), who will be discussed throughout this section, farmers' management decisions cannot be understood from a single factor but must be thought of as existing in complex systems with unique constraints specific to each person and each farm. It is still of value to consider these factors in relation to farmers' soil health knowledge; the following section reviews previous literature and considers the demographic information, education, experience, social influence, trust in private and public sector agricultural support, farming philosophy, and aversion to risk as potential influences on farmers' soil health knowledge.

Demographic Information

This section contemplates previous research findings concerning the age, gender, birthplace and occupation of farmers and land managers and how these factors relate to their farming philosophy, management practices, and soil health knowledge. Burton (2014) conducted a meta-analysis of 53 publications that sought to find causal relationships between demographic characteristics (age, experience, education and gender) and farmers' adoption of environmentally conscious agri-management schemes. As defined by the author: "environmental behavior thus refers to engagement with agri-environmental/conservation programs or farming practices that are widely accepted as more environmentally benign than intensive agriculture or that improve biodiversity on the farm"[14] (Burton, 2014, p. 20). This investigation of multiple causal explanations of agri-environmental management yielded interesting results; while the most commonly tested variables were age and education, at least 30% of publications reviewed for this analysis showed no causal relationship between age, experience, education or gender. This lack of certainty with variables suggests complexity with farmers' adoptions to agri-

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[14] For more information on sustainable management practices, see the *Management to improve SOM*, p. 82

environmental management practices, and that in many cases, no single factor completely influences farmers' management decisions (Burton, 2014).

As a key reference to this review, Burton's (2014) identification of complex factors influencing farmers' decision-making can be expressed in the inter-play between age, education, and experience. According to the author, age relates to education through the 'cohort effect', experience serves as a direct representation of age, and education and experience are linked since both increase social capital and influence what is socially acceptable within farmer groups[15]. The author therefore cautions against the consideration of isolated characteristics for six reasons: (1) these relationships are clearly connected; (2) there are too many causal pathways within these relationships; (3) it is necessary to consider how the diversity of 'scheme factors' influence 'farmer factors'; (4) there is a need for a more in-depth analysis than normally occurs; (5) the number of years of education or highest education attained should not be considered since quality is more important than quantity for this factor; and finally, (6) demographic characteristics are generally considered linearly, which is not the case (Burton, 2014). The following sections will consider separate demographic variables and will emphasize the connections and inter-play between different characteristics.

Age

While Burton's (2014) findings suggest that younger farmers may be more environmentally-oriented than older generations, experience with specific agri-management regimes, or type of education, complicate one's ability to consider this

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[15] For more information on social capital and social influence on farmers' management decisions,*Farmers' internal and external groups,* p. 125.

factor in isolation. In regard to the younger cohort's prevalence towards agri-environmental management, Wilson (2001) discusses the prevalence of Productivism with older generations. The author found that the Productivist paradigm, as previously discussed, gained popularity after World War II, coinciding with the rise of the Green Revolution. This era limited regulation on environmental degradation, allowing farmers to manage their land as they pleased, which typically involved more mechanization and a greater use of biochemical inputs. Although some young farmers and land managers uphold some of these Productivist practices of intensive agriculture, much of the agricultural community is experiencing a shift towards sustainable practices.

Brodt et al. (2006) found that farmers that were 45 or younger were more likely to be considered 'environmental stewards'. By using a Q methodological approach, the authors asked 21 almond growers and 19 wine grape growers in California's Central Valley to sort 48 statements that reflected their beliefs, management goals and overall values. With the help of agricultural researchers, public policy agents and farmers, the authors carefully crafted each statement to include one of three economic factors (profit, stability, and growth) and one of four satisfaction factors (family, leisure, type of work environment, and social responsibility for resource conservation). Based on their findings, the author grouped farmers into three categories: environmental stewards, production maximizers, and Networking Entrepreneurs (Brodt et al., 2006). 41% of farmers that selected more environmental stewardship responses were under 45 years of age, while 64% were considered production maximizers; for the network entrepreneurs, 56% were 56-55 years of age.

The most telling piece of information though are the similarities between each group. The authors found 4 statements that resonated with all three groups: "Working outdoors and watching my crop develop is the best part of farming. The profitability of the farm is important to me because I want to preserve it for future generations. Field days and workshops help me to be innovative because I can exchange the latest information with farmers. Investing in new technology such as precision type spray equipment is a good way to reduce pesticide use and protect the environment" (Brodt et al., 2006, p. 95). This shows that most farmers participating in the study identify with all of these categories, and while some may align more closely with one group than another, information may be lost when categorizing farmers in this matter.

As expressed by Burton (2014), the case for finding correlation within individual demographic variables is complex and usually must be used in conjunction with other factors; the author argues that age may be used as a proxy for experience. Farmers that have more experience or education with environmental stewardship, including soil health maintenance, may be more likely to incorporate similar programs into their management regime. As previously discussed, different time periods emphasized different trends; during the second half of the 20th century, academics and agricultural advisors emphasized Productivist management regimes, while the 21st century shows signs of a 'soil health renaissance' with an emphasis on sustainable practices to improve soil quality for crop production. This suggests that age, experience, and social capital are all impacted by these trends, further suggesting that single-variable analysis may dilute the complex nature and individuality of each farmer.

Sense of Place and Connection to the Land

Two additional demographic features of consideration are original birthplace and occupation. Birthplace refers to where the individual was born, and where they spent their early years. This concept was referenced earlier within Local Ecological Knowledge; it is of value to consider whether or not a person has more soil health knowledge if they were born on the same property where they currently farm. In addition, considering the occupation of the farmer or land manager in question may also provide insight into their soil health knowledge as well. Whether or not they are a full or part-time farmer, a manager or fertility specialist in a farming operation may impact their soil health knowledge, since they may not have the personal connection to the land that an owner or full-time farmer may have.

Sense of Place theory, as expressed through place dependence and place identity, describe both a functional relationship (through dependence on a given environment) as well as the mental, spiritual and emotional attachment one feels for an area. Mullendore et al. (2015) explored these topics in a survey of 341 participants as a means to understand the relationship farmers and land managers feel towards the environments in which they 'inhabit, recreate and manage'. Through an analysis of the role of place identity, place dependence and place attachment, the authors compared the employment of a variety of conservation practices (conservation tillage, buffers and grassed waterways) with conservation program enrollment (Mullendore et al., 2015).

51% of the respondents were enrolled in at least one government-sponsored program like the Conservation Reserve Program (CRP), the Environmental Quality Incentive Program (EQIP) or the Environmental Stewardship Program (ESP). In terms of conservation management practice used, 74% used conservation tillage, 46% use buffer strips, and 78% use grassed waterways. Place identity significantly predicted enrollment in a conservation program and the employment of buffers and grassed waterways, while place attachment was a better predictor for conservation tillage, but not the other two management practices; place dependency, on the other hand, was not as significant as the other two scales measured (Mullendore et al., 2015).[16] This article demonstrates the value of increased awareness of the relationship between a farmer or land manager's place of origin, connection to their home, and how this bond may be used as a predictor for the use of various conservation practices.

Experience

As discussed earlier, the LEK of farmers is of great value (Davis & Wagner, 2003). The role of experience, either through the number of years of farming, the amount of time one inhabits an area, or the tendency to stick with certain familiar management practices, will be considered here. The LEK of farmers, and subsequently, their soil health knowledge, is largely influenced by their experience in farming, the amount of time they've lived in a given area, and the family in which they were raised (Goulet, 2013; Iniesta-Arandia et al., 2014). According to Hoffman et al. (2007), "Intuition is understood as neither wild guessing nor supra-natural inspiration, but as the understanding that effortlessly occurs upon seeing similarities with previous experiences" (p. 362). As a Doing, Using, and Interacting (DUI) mode of learning, experience is essential to the accumulation and expression of a farmer's soil health knowledge (Jensen

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[16] For more information on intrinsic vs. extrinsic motivations for environmental management, see the *Voluntary incentives for sustainable management*, p. 155.

et al., 2007). In addition, experience may be tied directly to an individual's practices; if someone is more familiar with a given practice, like conservation tillage, for instance, they are more comfortable carrying out that practice.

Farmers possess embedded knowledge that originates from inhabiting an area and observing the natural processes taking place over time (Knapp & Fernandez-Gimenez, 2009). It can be argued that this knowledge, derived largely from experience, is intuitive, since many of the decisions made do not undergo formal analysis, but are based on trial and error (Nuthall & Old, 2018). This intuitive knowledge, therefore, may hold greater weight with individuals that have inhabited a given area for longer periods of time. Iniesta-Arandia et al. (2014) found that farmers in a semi-arid region of Spain possessed the greatest Local Ecological Knowledge if they spent more time living in a particular area. As discussed in the previous section concerning Sense of Place theory, this suggests that the longer amount of time a person inhabits a certain area, the greater knowledge they may have of their local environment (Mullendore et al., 2015).

In a study conducted by Knapp and Fernandez-Gimenez (2009), all 26 participants in a particular watershed in Colorado cited experience as one of the most important factors when making management decisions. As a group that values tacit knowledge over more formal, scientific methods, experience is a central role in collecting and communicating knowledge for the individual farmer. In order to meet their diverse and usually context-specific needs, farmers and land managers frequently rely on their own knowledge, considering themselves to be the most prominent and trusted knowledge source (Sumane et al., 2017). In addition, Sumane et al. (2017) explains that when compared to more formal scientific and research-based modes of knowledge, farmers are more likely to trust a practice-based knowledge. This divide between formal and informal modes of knowledge and their relationship to farmers and land managers has been discussed in detail earlier; even so, highlighting the value of experience-based knowledge within farming communities is essential to understanding how they acquire and practice the information they collect.

Although this topic will be explored in the context of sharing knowledge communally, the ways in which farming families collect and transmit knowledge amongst themselves should not be overlooked. This, in turn, translates as experience, since many farmers and land managers raised in farming families have early experiences with agriculture. Sumane et al. (2017) states that farmers that come from farming families obtain their early agricultural knowledge from parents or grandparents, and in most cases, are encouraged by family members to explore their own curiosity and creativity in the field. In addition, this knowledge and experience is passed on from generation to generation as a successor continues the legacy of the farm (Joosse & Grubstrom, 2017).

This leads us to the value of practice, and the likelihood that a farmer will continue their management regime based on past experiences. According to Burton (2014), farmers that are familiar with a specific management regime, albeit practices that maximize production or are environmentally oriented, are more likely to continue that same practice; conversely, the greater the familiarity with a specific farming practice, the less likely a farmer or land manager is to alter their management regime. As intuitive thinkers, farmers rely on experience with management practices to make unconscious decisions based on current conditions. For many, this combination of intuition and experience renders them successful (Nuthall & Old, 2018).

A double-edged sword within experience arises at this point; if farmers have performed a certain practice consistently and their desired outcome has been achieved consistently, why change? While this ‘if it ain’t broke, don’t fix it’ model may work in some instances, it may also prove detrimental to local environments. If farmers are most familiar with maximized sustained yield and Productivist practices of intensive tillage, minimal crop rotation, and over-applying synthetic inputs, it may be difficult to encourage them to change their practices (Burton, 2014).

This is an important point to consider; as previously mentioned, farmers trust what they know, and what has worked for them and neighbors based on trial and error. If they have always managed their land with the sole intention of increased crop production, and they’ve used methods that have yielded consistent results for a number of years, how do we expect them to change based on the latest science coming from a formal, laboratory setting? According to Burton (2014) there is a dichotomous effect when environmental degradation occurs due to harmful environmental practices. Sometimes, this degradation is normalized for farmers, and many believe it to be a necessary consequence of modern agriculture. On the other hand, some farmers have adapted to more environmentally sensitive management practices after witnessing the harmful effects of Productivist agriculture on their local ecosystem. Again, observation and trial and error are the primary tools utilized most frequently by farmers. These experiences are then communicated and transmitted through their networks and communities of practice, which will be discussed later.

Stuart et al. (2018) found that when considering the amount of nitrogen fertilizer to apply to one's land, personal experience was the most commonly described internal source of information utilized by farmers. Based on previous farming experience, what has worked for them and for other trusted sources (neighbors, family members, etc.), and their own on-farm research trials, farmers tend to rely on this information as a significant source for their management decisions. The importance of proximity to one's own operation, in regards to on-farm trials and experience, were highly influential. According to one farmer in Iowa: "Well, I'm on the internet looking at sources… Iowa State [University]'s research, Iowa Soybean Association research. The most important research is on my farm and you know the farther they get away, its maybe less valuable to me" (Stuart et al., 2018, p. 292). The concepts of sense of place, as previously discussed, and particularized trust (which will be discussed in detail later) as well as personal experience are expressed in this statement.

Experience-based knowledge is an integral part of a farmer or land manager's management regime. The longer amount of time a farmer inhabits a particular region, the greater the chance of them possessing higher LEK of the area (Iniesta-Arandia et al., 2014). As observers of the Doing, Using and Interacting mode of knowledge, they value and trust practice-based knowledge over formal, traditional scientific inquiry (Sumane et al., 2017). Farming families collect this experiential knowledge and pass it on from one generation to the next (Jossee & Grubstrom, 2017). Through trial, error and observation, they develop an intuitive sense of what works and what doesn't for their specific context (Nuthall & Old, 2018). With respect to environmental degradation, this intuition may normalize the negative effects of modern agriculture but has also been shown to promote change against destructive practices (Burton, 2014). Experience and practice-based knowledge are integral to the collection and transmission of information amongst farmers and land managers.

Education

While formal education plays a role in soil health knowledge, the content and relevance of the education may be more influential than the quantity; in addition, as previously discussed, contemporary trends in agricultural and soil sciences, as well as within the culture itself, influence the content taught in schools. In Burton's (2014) consideration of the role that education plays in the use of agri-environmental and conservation schemes for farmers and land managers, he explained that higher levels of education are typically associated with more environmentally-minded practices; however, he also discovered other studies where no correlation or even an inverse correlation were found (Burton, 2014). As the author points out, the type and content of education is closely linked to practices that improve the impact of agriculture on the environment, including improved soil health; the author found multiple studies explaining that a general or broad agricultural degree compared to a specifically conventional agricultural degree correlate to different management practices.

In a study conducted by Fielke & Bardsley (2014), a survey of farmers and land managers in the state of South Australia looked to understand the value of education in agricultural decision-making. The survey respondents were broken up into three groups: school certificate (equivalent to high school diploma in the US) or lower; TAFE (vocational education) certification; and university degree. Of the 262 participants, those with TAFE certification or a university degree were more likely to value the impacts of socio-environmental agricultural land use than less-educated individuals. In addition, respondents with a higher education were less concerned with governmental support mechanisms in general but believed government support will be necessary to help farmers adapt to climate change. Farmers with a TAFE certificate or university degree also anticipated incentives for positive environmental land use decisions. For farmers with a high school education or less, more anxieties about governmental support were highlighted, including financial support for the supply and availability of inputs, the government's ability to prevent import competition, and to offer direct payments to farmers (Fielke & Bardsley, 2014).

In terms of education and its impacts on soil health and agri-environmental management, the quality of the education, whether oriented towards Productivism or resource conservation, may influence soil health knowledge and sustainable management adoption rather than the degree of education completed. As previously discussed, there are considering a characteristic like age outside of a greater web of variables may prevent research from considering the bigger picture. Within education, the type of education, as well as age influences social capital and cohort effects, since different time periods emphasize or have an understanding about different concepts.

Gender

In modern western culture, agriculture is considered a masculine occupation, and the vast majority of farmers are male (Haugen and Brandth, 1994). Because of this, cohort effects and social capital accumulation can be observed, where female farmers have not historically been considered to be a 'good farmer' because farming is a male-dominated industry (Hatch, 1992). According to the 2012 USDA census, less than 14%

of all principal operators are female (USDA Census, 2012); however, the true amount of female contribution cannot be quantified due to varying degrees across countries and regions (SOFA team and Doss, 2011). According to Sachs et al. (2016) an increase in female farm operators and principle owners can be observed between 2002 and 2012, and the primary justification for this would be older female farmers pursuing a second career or that women began claiming the role of 'farmer' as opposed to relegating the title to spouses, sons, or other male relatives.

In terms of environmental stewardship, many studies have found women to be more environmentally minded than men (Haugen & Brandth, 1994; Burton, 2014; Sachs et al., 2016). Women have historically explicated more concern for environmental issues through an increased awareness of environmental risks, and understandings of environmental problems than men; even though research consistently shows an increased awareness of environmental impacts by females, the justification for this is still unknown (Sachs et al., 2016). While female farmers make up a much smaller proportion of large-scale industrial farm owners and operators, these individuals are more prominent in small-scale and organic operations; in addition, it has been shown that female farmers are more likely than their male counterparts to produce organically-certified foods (Sachs et al., 2016). Although little data exists regarding the soil health knowledge of female farmers as opposed to male farmers, it is of value to consider whether or not gender influences environmental stewardship and would therefore translate to increased soil health knowledge.

Farmers' involvement with internal and external groups

Farmers depend heavily upon the social and business networks and communities in which they inhabit. There are a number of different groups that farmers work with, and much of their learning and information transfer originates within different circles. This section first defines the different communities, networks and influencers that impact farmers' transfer and generation of knowledge. An analysis of these different networks will follow, including: agricultural communities, marketing orders and cooperatives, university extension offices, government agencies, and privatized corporations and consultants. In addition, the role of generalized and particularized trust will also be discussed when considering individual, institutional and organizational information resources utilized by farmers.

Oreszczyn et al. (2010) investigated what influenced the creation and transfer of new technology (particularly genetically modified crops) within farmers groups in the UK. The authors identified three of these circles: communities of practice, networks of practice, and webs of influencers. Within communities of practice, individual knowledge is situated within communities and social interactions; this, in turn, is an essential aspect of both explicit/formal knowledge as well as implicit/tacit knowledge realms. Networks of Practice, on the other hand, are more loosely bound than communities of practice, since a shared identity is not an integral part of these relationships. Rather, they serve to connect individuals through repeated and enduring exchanges. Webs of influencers are a much wider network of people and organizations, which impact the actual practices of the farmers, not just their attitudes and views.

According to Oreszczyn et al. (2010), farmers more closely resemble networks of practice, since there are many small operations that are widely distributed, promoting a diversity of views, needs, interests and priorities. While many farmers share the same identity with common concerns and similar viewpoints, many suggest that they learn very little from those within their community. While they rely heavily on each other, and believe they have strong connections with farmers in their community, many farmers don't believe they learn much from their neighbors (Oreszczyn et al., 2010). Within communities of practice, though, farmers are interested when members of their community integrate new technologies into their management regime. This could serve as a uniting front for farmers, although opposing views and attitudes could create greater rifts within these groups. The authors suggest that webs of influencers, particularly with trusted individuals from trusted organizations, have the greatest sway over their motivations to change practices and acquire new knowledge (Oreszczyn et al., 2010). These secure relationships with trusted influencers encourage learning within networks and communities of practice. Because these webs of influencers cross boundaries established within the other two frameworks, more knowledge can be transferred and disseminated. Further in this section, we will discuss the influencers that impact the knowledge and decision-making of these farmers, whether they originate from a trusted source or not.

Even if direct knowledge transfer does not occur frequently within farmers groups, social standing and relationships within agricultural communities does impact farmer motivations to some degree. In terms of establishing social standing, farmers are evaluated by others in their community regarding at least two factors: their perceived farming ability and, to a lesser extent, their wealth (Hatch, 1992). Many farmers use their neighbors and communities as a point of reference for themselves and compare their own practices to others and the group as a whole Hoffman et al., 2007). In addition, much of what farmers learn and practice arise from the norms within their community. By observing each other's' fields from the road and through other social interactions, farmers notice what others in their community are doing, and for the most part, uphold what others in their community are doing. For those on the social or geographical periphery, however, establishing social capital may be difficult, although some farmers prefer to separate themselves from their communities (Hatch, 1992).

Social standing, or social capital, influences the trust upheld by other members of the community. According to Kizos et al. (2014), social capital involves the specific characteristics, functions and attributes of social networks, and is expressed by "social trust, social norms, cultural perceptions and values, and the character of social networks". Much of what farmers adopt originates from trusted sources within their communities that have a reputable social standing, or are considered 'good farmers'; therefore, it is of value to better understand the networks and circles in which farmers interact with each other.

According to Hatch (1992), farmers exist in local, historically variable cultural systems concerned with social hierarchy, and an individual's concept of self-worth as a farmer and member of the community is largely grounded in these groups. Through an evaluation of a small agricultural community outside of Christchurch, New Zealand, the author asserts "everyone in the district… was placed by others within this hierarchy. People in the locality had their reputations at stake, or their local sense of personal worth and identity, and the dynamics of the community reflected this principle" (Hatch, 1992, p. 2). Within the town of South Downs, there were multiple divisions of hierarchy, from the ‘haves’ (land-owners) and the ‘have-nots’ (non-property owners). As the dominant economic force, farmers held the highest standing, while some other groups also earned respect. These include: firms, chemical dealers or agricultural consultants, stock agents (for sheep/cattle) or farm managers.

Within farmer groups, social standing originates from personal wealth, but most importantly, farming ability. When compared to another study the author conducted in California, the reverse was true (Hatch, 1992). While many farmers in the New Zealand community could identify the wealthy farmers, they were not always considered to have the highest social standing. The esteemed members of the community were good farmers that may not have the best land but invest time and energy into their farm. When asked if farmers in the community rank their neighbors based on their perceived farming ability, one farmer replied: “Oh yes. We’ve all got a fair idea of how good we all are and how good our neighbors are. We all farm our neighbor’s farm better than he can. I’ve got a little spot here where I stand up and look around. I always look around and say, ‘What’s so and so doing, why’s he doing that?’ And no doubt everyone’s doing the same with my place” (Hatch, 1992, p. 119).

Farmers observe each other’s land through a number of different means. Many farmers drive through the country and keep tabs on their neighbor’s land. These ‘drive-bys’ allow farmers to observe what their neighbors are doing, and provide gossip to be shared at the local pub. The straightness of an irrigated farmers’ rows will be a point of contention within his community, and if a farmer changes his management practices, you are sure he’ll hear about it at the local coffee shop or café. While very few publications describe the ways in which farmers observe each other’s land or where they meet on a regular basis, this point is of value for further consideration, since information, social standing, and trust is developed through these avenues.

Certain boundaries exist within agricultural communities, delineating individuals that are part of the group and isolating outsiders. In Hatch's study (1992), South Downs farmers almost unanimously identified two families as outsiders, who were also considered to have poor farming ability. This is largely because they were isolated from the group; while these farmers isolated themselves from others, their neighbors still used them as a point of reference within the community. Although it could be argued that social separation was the only factor contributing to their isolation, some farmers did participate regularly in the community and still had a 'poor farmer' ranking. Isolation in conjunction with divergence from the norm was observed as contributing factors to the lower ranking. In addition, geographical proximity to other farmers also informed members of the community of who was a good farmer and who wasn't. Hatch (1992) asked the participants of his study to rank farmers from other townships; while many farmers were able to identify the best and worst farmers, their knowledge of outside communities was much smaller than individuals within their own groups. This suggests that even if individuals outside of geographical bounds are good farmers, their limited interactions with others in the agricultural community, and the inability for those within the community to observe and drive-by that individual's land regularly, exclude them from consideration.

While geographic and social proximity influence the social standing of farmers within agricultural communities, it is of value to understand how farmers with different management practices form their own farming identities through the influence of other trusted farmers; however, in keeping with the literature review up to this point, delineating farmers into different groups over-simplifies the complex nature of farmer's knowledge creation and dissemination, and one must proceed cautiously if labeling farmers in specific groups. Carolan (2005) investigated the trust upheld by different farmer groups within social, organizational, and governmental networks (and webs of influencers).

By observing two separate 'field days' in which farmers converge to observe new practices and technology and to share ideas, the author delineated two types of farming networks, the Productivists and the Conservationists, and consequently two types of trust. First, the author observed a field day with Iowa State University, a traditional Land Grant university with a heavy focus on the scientific expert to non-expert model of knowledge transfer. Through informal interviews, the author determined that farmers in attendance at this field day possessed 'as-if' or virtual trust; they passively trusted the superiority of higher science institutions, organizations and corporations, and did not question the information relayed to them. According to one farmer, "I'd like to think I trust them [Iowa State University]. I mean, when I think about trust I usually think of it being between two people. Not between a person and an organization or university. But I can't really think of any other word for it, so, sure, I guess you could say I trust Iowa State" (Carolan, 2005, p. 332). The author argues that this trust is somewhat superficial, since those that practice conventionally trust that science has been right up to this point but have not cultivated deep trust with specific individuals; instead they depend on the experts in the system but have not created real trust with the experts that relay this information.

The author argues that Conservationists, on the other hand, develop a deeper trust with other sustainably-minded farmers and larger organizations; at the Practical Farmers of Iowa field day, farmers were encouraged to touch and observe the different management practices, fostering connections with other like-minded individuals through embedded ecological experience. As one farmer described it, "This is not just about learning, but about sharing ideas and information. There are no experts here" (Carolan, 2005, p. 332)[17]. Interestingly, even though Iowa State does focus much of their research on sustainable practices, many of the Conservationists separated themselves from the University mindset. The author defines this as identity correspondence, a phenomenon in which individuals perceive themselves as aligning with one group, thereby separating themselves from another, even if that other group may have some similar interests or pursuits.

By segregating these two groups, the author is over-simplifying the complex nature of farmer interactions, knowledge accumulation and transmission, and he does not consider other impositions on farmers' management decisions. As previously discussed, farmers gain knowledge not only through social networks, but through education, personal experience, and a wide variety of other avenues; in addition, their management practice may not always reflect their farming philosophy due to economic or other human capital constraints[18]. While it is true that farmers have devalued their confidence in their own experience, observation, and local knowledge accumulation due to the prevalence of western scientific epistemologies, the author seems to create a narrative in which farmers

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[17] The Productivist-Conservationist divide will be discussed in the *Farmer identity and farming philosophy* section, p. 153.

[18] For more information, see the *Risk management and aversion* section, p. 172.

that attend university-led field days are less intelligent than those that attend events put on by organizations like the Practical Farmers of Iowa. There are a number of factors to consider with farmers management decisions, and this simple segregation of farmers into two groups does not sufficiently express the complex nature of farmer knowledge creation and dissemination. Nevertheless, Carolan (2005) highlights that management practices facilitate social interactions, knowledge collection and transmission, as well as the formation of a farming identity.

In addition, it is necessary to understand the impact of social capital and social groups on local environments. Since ecosystem health and functioning depends heavily on social capital, the actions and preferences of specific groups has been shown to impact the well-being of local environments (Kizos et al., 2014). Through an analysis of the motivations and actions of livestock farmers of the Asteroussia region of Crete, Greece; Kizos et al. (2014) noted a correlation between land degradation and the disintegration of social capital.

As a result of increased subsidies for increased flock size during the 1980s, the authors observed a decrease in bridging social capital, which is associated with the enhancement of trust and cooperation among different social groups. As flock sizes increased through ‘informal patron-client networks’, farmers earned income not from the maintenance of land quality, but by increasing flock size. As social inequalities were exacerbated, since those with more economic capital and financial capital were more capable of increasing their flock, both social capital and land quality degraded rapidly (Kizos et al., 2014). This shows that social groups, as an integral part of social ecological systems, have the power to influence the rate of environmental degradation due to the actions and motivations of group members.

This section has defined the different operative farmer groups, from more intimate Communities of Practice, which extends out to more formal interaction and exchange-based Networks of Practice, to the even broader network of Webs of Influencers (Oreszczyn et al., 2010). Social capital plays an important role in the formation and maintenance of farmer networks, since individuals that share a common identity, utilize similar management practices, and uphold similar perspectives, are more likely to be a part of the same community (Hatch, 1992). In addition, Individuals within farming communities almost unanimously identify good and bad farmers, and many of the farmers that were considered ‘bad’ were either on the periphery or upheld different management practices or overall values (Hatch, 1992). While Carolan (2005) identified different ways that farmers communicated, received and transmitted knowledge, his segregation of farmers into two groups over-simplifies the complex dynamic of farmers’ knowledge collection and decision-making processes. At this point, it is of value to take a closer look at the larger network of farmers’ Web of Influencers, in particular the public and private sector institutions that provide information and impact their management decisions

The Role of Trust

As previously discussed, farmers interact through various networks, which extend out from more intimate Communities of Practice, through Networks of Practice and into Webs of Influencers (Oreszczyn et al., 2010). Trust changes within these groups, since farmers have a different level of trust for individuals in their immediate community compared to those that influence their management decisions. According to Delhey et al. (2011), trust develops through “socially learned and socially confirmed expectations that people have of each other, of the organizations and institutions in which they live, and of the natural, moral, and social orders that set the fundamental understandings of our lives”. What has been previously discussed is trust in individuals within one’s immediate and extended agricultural communities, with family members, with one’s own experiences, etc. Stuart et al. (2018) found similar results to Hatch (1992) when referring to trusted individuals within the community. Through the collection of 1200 survey respondents and over 150 interviews with farmers in Iowa, Indiana and Michigan, the authors investigated what sources of information these Midwestern farmers trusted for Nitrogen fertilizer recommendations. Participants trusted neighbors and family members that they considered to be ‘good farmers’; they evaluated the management practices of these farmers either through in-person communication or observations of their fields (drive-bys) (Stuart et al., 2018).

This particularized trust expands beyond one’s social and cultural groups to other individuals associated within both the private and public sectors. Stuart et al. (2018) found that while more farmers valued nitrogen fertilizer recommendations from the private sector (fertilizer and seed suppliers, crop consulting firms, etc.) more-so than recommendations coming from the public sector (governmental agencies, university extension, etc.), they expressed trust with individuals within both the private and public sector, not just one or the other. In addition, the authors found that generalized trust, or trust in the greater organization, institution or company, was not as strong as trust with particular individuals that they worked with closely.

While some farmers were skeptical of the biased research coming out of the private sector (in order to support the purchase of more products, etc.), many explained that their own crop advisors or agronomists were trusted sources that had the farmers' best interests at heart. According to one farmer from Indiana when referring to his own agronomist, a fertilizer consultant from a private company: "He knows our acres, he's been involved, he's walked the fields, he knows what kind of weed pressure we've got and all this, so he has a kind of history of our farm, he can go back and look at our soil samples from the last 30 years and make recommendations… so we kind of look at him as our go-to guy" (Stuart et al., 2018, p. 293).

The issue of trust plays an important role in the adoption of conservation agriculture practices. Luloff et al. (2012) interviewed 192 key informants in 13 different watersheds across the United States to understand their 'beliefs, attitudes, perceptions and experiences' with conservation agricultural practices and water quality. Two important questions addressed by the authors concerned what determined the effectiveness of conservation agricultural practices and what educational resources were available to farmers and land managers. It may be of value to consider what resources are available to farmers, what avenues they choose to implement these practices, and what influences their choices.

Similarly to Stuart et al. (2018), Luloff et al. (2012) found that variation existed among types of educational resources available to farmers, and which resources farmers chose. What also must be noted are the different perceptions held by both farmers and agents of available and trusted sources of conservation agriculture information. Farmers and land managers for the most part believed personal efforts and experiences in conjunction with farmer-to-farmer interactions either through formal or informal groups were the driving force behind their adoption of such practices. Another contributing factor to the increased implementation of new practices involves the trusted companies that create new technology to facilitate this change (Luloff et al., 2012). With respect to the adoption of conservation tillage, almost all farmers interviewed in Ohio implemented this practice when John Deere, a trusted source of agricultural machinery, created a no-till planter. No governmental programs or ‘zeal’ influenced the adoption of conservation tillage, but when a trusted private sector company created a machine that was efficient and effective, it was much easier for farmers and land managers to convert to conservation tillage (Luloff et al., 2012). It would be interesting to note whether or not these farmers had a trusted source at John Deere that persuaded them to try something different, as Stuart et al. (2018) found with generalized and particular trust.

Some farmers explained that they used USDA NRCS, Conservation Districts and university extension services to acquire new information on conservation agriculture practices; however, many farmers considered extension and NRCS to be unreliable sources (Luloff et al., 2012). This was largely due to conflicting regulations, inconsistent agendas, insufficient technical assistance and funding. While farmers may have trust in a single individual within a governmental organization, the lack of consistency with regulation, policy and personnel limits the amount of trust within the government sector itself (Oreszczyn et al., 2010). Even so, another study conducted in Australia, found that over half of the farmers interviewed utilized district agronomists; while the relay of information in the public sector in Australia may be different than what is practiced in the

United States, this shows that some farmers do find these resources useful (Lobry de Bruyn & Abbey, 2002).

On the other hand, Luloff et al. (2012) found that many key informant extension and government agents claimed their resources were frequently used, but some recognized their shortcomings. According to one federal agent, “There’s a problem working with NRCS because of their restrictive rules about data. This hinders discussions with peers. [You] can’t create good working relations with the rules. Further NRCS employees need more training to simplify the legal entities for farmer payment. NRCS should change the structure of its organization because the expertise of its employees is not being used” (Luloff et al., 2012, p. 25).

Like Stuart et al. (2018), Luloff et al. (2012) found that there were some farmers that spoke of specific individuals within the government programs or agencies that offered assistance. One Ohio farmer stated that his early adoption of conservation practices came from his father, his personal interest in science and the environment, and from his work with one Conservation District specialist (Luloff et al., 2012). This is where the strength of particularized trust resurfaces; farmers have less trust in an overarching entity, like all federal government programs, but when working with a trusted source within the community, they are more likely to learn from the individual. Due to these discrepancies, the authors suggest that extension and government agencies should look beyond their own programs to see whom farmers are working with.

Government Regulation and Policy Enactment

The Natural Resource Conservation Service (NRCS) is a government-sponsored agency ran by the United States Department of Agriculture (USDA). Originally formed in 1935 as the Soil Conservation Service, NRCS "helps people help the land" by providing information and assistance that helps farmers prevent the contamination of the local environment through degrading practices and conserve water and soil resources (NRCS). Through the NRCS, there are a number of programs that incentivize conservation practices. Since the 1930s, the USDA has focused on two separate forms of conservation programs, with the primary means of implementing these programs through financial 'incentivization' (Reimer, 2015).

The land retirement and easement programs that the NRCS offers include the longest-running Conservation Reserve Program (CRP), which provides funding to farmers who remove marginal land from production and show through a 10-year conservation plan how they will plant perennial coverage instead of agricultural crops; this type of conservation program is utilized largely by smaller farms that have a gross annual income less than $100,000 (Reimer, 2015). On the other hand, working lands programs include the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP). EQIP provides cost-share in addition to technical assistance that helps facilitate conservation practices on working land while the CSP provides payments to farmers for continuing conservation programs over an extended period of time. These programs are used largely by large-scale operations with the goal of maximizing agricultural land productivity while simultaneously improving the local environment (Claassen, 2006).

Reimer (2015) noted a shift in the 2014 farm bill from land retirement and easement towards improving productive working lands. The author suggests this shift may be in line with Ecological Modernization, which emphasizes technological and regulatory innovations that happen in conjunction with a shift in producer and consumer attitudes towards environmental conservation. Ecological Modernization through regulatory action involves the decentralization and deregulation of government actors, a greater focus towards markets, and fostering relationships between the state and local stakeholders (Reimer, 2015). The shifting emphasis towards working lands conservation programs aligns with farm sector preferences, since most large-scale farmers supply over 80% of agricultural products produced in the US. Simultaneously, it reinforces the Ecological Modernization theory that individual economic producers play a pivotal role in the drive to ecological reform (Reimer, 2015). While analyzing the implementation of conservation programs within governmental bodies can be effective, the fact that most programs are voluntary means that they may not be the ideal means of implementing conservation practices for farmers and land managers.

As previously discussed, farmers bear the burden of a number of interests; they are expected to keep prices low while increasing productivity, in addition to maintaining environmental quality and aesthetic (Michel-Guillou & Moser, 2006). At an increasing rate, policy and governmental regulation continually impacts farmers, and many would argue that these regulations are imposed with little input from farmer groups. According to Oreszczyn et al. (2010), governmental regulation is viewed as a negative strong influencer on decision-making. As the article suggests, there are “increasing unrealistic expectations made of [farmers]. Increasing regulation meant increasing costs, and farmers were finding it progressively more difficult to satisfy regulators” (Oreszczyn et al., 2010, p. 412). Due to the lack of operational knowledge of farm life from policymakers and governmental regulators, they are considered to be a poor source of information, sending farmers and land managers to public and private sector agricultural organizations as well as research institutions.

Through a survey of 225 farmers in the tropical Savannah of Australia, Greiner & Gregg (2011) considered the motivations and incentives of farmers in this area[19]; they considered how effectively government regulation and policy enactment influenced farmer conservation decisions. Interestingly, government regulation was rated as the least effective incentive; however, interview data revealed that even though it was the least effective incentive, regulation is a necessary element of policy strategy since it establishes minimum standards that must be upheld. Additionally, it instills in farmers the responsibility of environmental care. The authors also found that highly motivated respondents believed that there was value to implementing conservation-minded policy. Another interesting point to be made is that differences in the motivations and effectiveness of policy reflected the presence or lack of specific conservation practices in a given area. This suggests that governmental regulation and policy makers do play a significant role in the conservation actions of farmers (Greiner & Gregg, 2011).

An example of the hindrances of legislation are explained in a survey of 435 Dutch farmers. Hijbeek et al. (2018) found that farmers perceived certain legislation as an impediment to their ability to increase organic matter content in the soil. The Dutch Manure and Fertilizer Act of 2016 took measures to minimize the amount of manure applied to the soil by farmers in order to limit the amount of nitrogen and phosphorus leaching into waterways (Bleeker and van Grinsven, 2017). While nitrate and phosphate leaching decreased, farmers looking to increase their organic matter content believed the

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[19] Farmer motivations and incentives follows in the "Voluntary Environmental Incentives" section

new legislation was one of the largest hindrances to improving overall organic matter content in their soils (Hijbeek et al., 2018). While the Dutch Manure and Fertilizer Act accomplished its goal, it created additional obstacles for farmers in respect to adding organic matter and improving their soil health. This provides evidence that legislation should be enacted that considers its effects on all stakeholders.

Market Demands

Market and consumer demands play a major role in farmers' management decision-making. The following section begins with an exploration of the transition of many small-scale farms with a market emphasis on 'costless coordination of production and distribution' (Zylbersztain, 2017) to the rapid decrease in the number of farms and exponential increase in farm size with an emphasis on globalized trade and consumer-driven markets. This transition into a neoliberal market, while initially appealing to farmers, has infiltrated many of the cooperative organizations that prevent social and subsequently environmental degradation (Dmitri et al., 2005; Kizos et al., 2014). Many farmers are left to fend for themselves in a free-market economy, while truly autonomous cooperative groups have been suggested as a means to ensure farmer support in unstable markets (Stock et al., 2014). In the neoliberal agricultural model, larger farms are able to withstand market fluctuations, while smaller farmers have little support or capital to 'weather the storm'; a result is a reduction in the number of small farms and an increase in the size of larger farms (Reynolds, 2015). Federally-mandated marketing orders are popular amongst many specialty crop farmers, and many of these individuals believe their participation in these organizations offer support in regulation compliance and also offer protection for market fluctuations (USDA 2017; Williams et al., 2008). In addition, consumer preferences towards environmental sustainability and certification will also be considered in this section.

From small-scale diversification to globalized agribusinesses

As discussed throughout this section, agriculture in the United States has experienced a massive change over the past 100 years; while the size, scale, crop-diversity and amount of food produced has changed drastically, the relative amount of land being farmed has stayed the same (Dmitri et al., 2005). During the turn of the 20th century, nearly half of the population was employed on-farm with over 22 million work animals and producing an average of 5 different commodities per farm; today, less than ¼ of the population inhabits rural areas, less than 2% of the population farms, 5 million tractors have replaced work animals, and the average farm grows only one commodity crop (Dmitri et al., 2005). The authors argue that technological development, the growing influence of consumer choices on agricultural markets, and a shifting focus towards national and global markets has completely altered the face of the agricultural economy in the United States, which has in turn changed global markets as well.

With increased mechanization and the use of off-farm chemical inputs, shifting "'economies of scale' instigated a rapid growth of on-farm productivity by 1.9% annually from 1949-1999; this was largely due to 'increasingly integrated national markets for labor, capital, goods and services" (Dmitri et al,. 2005). Simultaneously, as more individuals moved away from the farm and sought off-farm employment, their affluence increased, and their time availability diminished. This signaled an increase in consumer influence on the agricultural sector, and as land use efficiency increased due to technological development, consumers expected food prices to stay low. A shift has occurred more recently, where these affluent consumers are becoming aware of the environmental and social impacts of increased on-farm production, yet again signaling a new focus towards environmental sustainability and natural resource conservation (Dmitri et al., 2005).

In the 1960s, the authors describe an intensification of agricultural exports, with a steep rise occurring in the 1970s due to exchange rate adjustments and the increased demand of grains and oilseed from the Soviet Union. Increased globalization at this time marked the rise of imports and exports, but as more developed and developing countries adopted the new technologies of the United States agricultural sector, global competition expanded, as well. This further intensified the neo-liberal model experienced in the United States, shrinking farm numbers and increasing farm size (Dmitri et al., 2005).

Policy change arose with these shifting market trends; in the 1950s, farm policy maintained high price supports and supply controls by the government, with the mandatory forfeit of surplus goods to governmental storage facilities. This shifted with the Food and Agriculture Act of 1965, with a new reliance on 'income support payments to protect farm income', recognizing a change of emphasis allowing farmers to adapt to fluctuating markets (Dmitri et al., 2005). With the 1985 Food Security Act and the 1990 Food, Agriculture, Conservation and Trade Act, further incentives were created to encourage the marketing of commodities, allowing farmers to plant what they wanted.

These neo-liberal policies decrease regulation, increase privatization, and allow for open markets and free trade, created new ways for financial capital and transnational corporations to invest in international enterprises (Rosset & Martinez-Torres, 2012). The networks in which small-scale farmers existed originally struggled to compete in this rapidly changing economy; this led to the further decrease in farm numbers and increase in farm size, since many small-scale farmers did not have access to a transnational economy. These globalized neo-liberal markets were in direct conflict with local, small-scale farming efforts, since the emphasis of small-scale farms on 'short and decentralized circuits of production and consumption with strong links between food production and local and regional ecosystems and societies' were in direct conflict with the popularized globalized agribusiness trend of the second half of the 20th century (Rosset & Martinez-Torres, 2012).

Stock et al. (2014) would argue that the production focus of farming today originates from the infiltration of neoliberal autonomy into agricultural and rural societies. As an inherently autonomous group, farmers are drawn to neoliberalism because of its emphasis on the individual, the power of free trade, and its encouragement of competition. As one farmer within this particular study described his peers: "They're a very independent breed… And by default, if they start working together, you know, I think that is the biggest obstacle. It's a state of mind, it comes down to personalities… the whole idea of being a small farmer is you are independent" (Stock et al., 2014, p. 415). This clearly represents a neoliberal autonomic perspective; however, the authors also point out that farmers in the English uplands believed the best means to protect the environment was to ensure that farmers could earn a decent wage, and that farmers had to work with other farmers to maintain the quality of their landscape.

To this end, the authors argue in favor of actual autonomy. In support of collective organizations like cooperatives and marketing orders, farmers can work together to resist the 'sweeping mandates' of neoliberalism to maintain social and environmental quality (Stock et al., 2014). As defined by the authors, territorial cooperatives support three methods of liberation: 1) regional cooperation which integrates farming practices towards environmental protection, 2) rural governance, and 3) a move away from expert systems towards the innovative abilities of members within the cooperative. These lofty goals were investigated through different cooperatives in 4 countries: England, Switzerland, New Zealand and Brazil. The authors found that most of these cooperatives offered paradoxical objectives: neoliberal autonomy and collective emancipation.

Interestingly, all four countries' governing bodies have instated neoliberal legislation that removes market support and governmental subsidies while simultaneously increasing competition amongst small farmers (Stock et al., 2014). In response, and in particular within the dairy industry, most developed countries utilize cooperatives to provide support in autonomous neoliberal markets; however, in some instances, these groups have neoliberal underpinnings. In New Zealand, for example, two of the largest cooperatives merged in 2001 to form one single 'cooperative': Fonterra. With over 11,000 farmers and an emphasis on exporting goods, this model has been called 'cooperative monopolization'. While some efforts were made by Fonterra to improve environmental degradation by dairies (water quality in particular), their Clean Streams Accord was more a political move than one ensuring social and environmental protection (Stock et al., 2014).

The most successful grassroots example came out of Brazil. With massive neoliberal restructuring, the country began to focus on producing high profit commodities like cotton, soybeans and sugarcane; however, a group called the Landless Rural Workers

Movement (MST) is working to resettle over 400,000 families on small-scale farms while simultaneously attempting to mitigate the effects of Productivist agriculture on the environment. This paper suggests that in order to confront the restrictions of a neoliberal agricultural economy, farmers should work cooperatively to ensure actual autonomy.

While not an entirely autonomous group, marketing orders may serve as a means to support farmer interests in the free market. According to the USDA, marketing orders connect producers within fruit, vegetable and specialty crops so they may "leverage their own funds to design and execute programs that they would not be able to do as individuals" (USDA AMS, 2017). By unifying producers of the same product, marketing orders are able to address the needs of specific industries by: 1) helping farmers navigate and create markets, 2) driving consumer demand, and 3) improving producers' profitability (USDA AMS, 2017). Powers (1990) states that federal marketing orders use collective action of a group of growers to contribute costs and efforts to benefit the growers, marketers and consumers when faced with market failures or 'economies of scale that individual growers cannot recognize'.

Through statistical analyses of price level and variability, Jesse and Johnson (1981), found that fruits and vegetables covered by Federal marketing orders have not yielded higher or more stable farm prices. Even so, the authors found that producers are still in favor of these orders, since many believe that without them, the markets would be highly volatile and farm prices would be lower. However, Williams et al. (2008) found that sufficiently differentiated crops, like the Texas grapefruit, may benefit from promotion programs instituted by Marketing Orders. This finding suggests that growers of specialty crops like hops and mint in the Yakima Valley that are also members of

Federal marketing orders may benefit from promotion programs if the "group chooses to allocate its promotion funds among alternative promotion activities" (Williams et al., 2008, p.391). Although some farmers do believe they benefit through their participation in marketing orders, I suggest that many farmers are left to 'fend for themselves' in the free market and face pressures from market and consumer demands largely by themselves.

As previously discussed, there are few support mechanisms or cooperative groups in place to help farmers in a neoliberal economy. Even some cooperatives have adopted a neoliberal agenda that offers little support to farmers (Stock et al., 2014). While some farmers believe marketing orders are an effective means to combat unstable markets, some studies have found little financial benefit for farmers except for those growing specialized cash crops (Jesse & Johnson, 1981; Williams et al., 2008). With few support mechanisms in place, many farmers may feel more prone to financial risk; while this will be discussed later in this review, farmers are less likely to implement or adopt a new management regime like conservation agriculture if they are not financially stable (Boehm & Burton, 1997).

Certifications and Consumer Preference for Sustainability

Market demands are largely dictated by consumer choices; in regard to the advent of the sustainable agricultural revolution of the 21st century, consumer preference for sustainably sourced local goods, in addition to the re-orientation of the system to a farm-to-market organization has contributed to this change (Bianco, 2016). As the public becomes increasingly concerned with their environmental impact, environmental policy is shifting towards pollution-control and orienting towards market-driven tools that encourage sustainable consumption (Liu et al., 2017). Organic certification has become one of the most economically viable certifications globally and consumer demand continues to increase exponentially (Pimentel et al., 2005). In terms of sustainable certification and labeling, much research has focused on organic products. Not only is it of value to consider consumer preferences towards sustainable certification, but to understand to what degree these preferences influence farmers' motivations to pursue organic or sustainable certification. The sustainable certifications considered here (certified Organic, Global GAP, and Salmon Safe) are voluntarily participatory, so it is of value to understand their motivations for certification.

According to the National Organic Program (NOP), "Organic is a labeling term that indicates that the food or other agricultural product has been produced and processed using approved methods. These methods integrate cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance and conserve biodiversity. Synthetic fertilizers, sewage sludge, irradiation and genetic engineering may not be used" (§CFR 205.105, 2018). As a marketing initiative, organic certification and material registration is entirely voluntary; producers, processors, handlers, and material manufacturers may choose to follow the organic rules and regulations to receive premium prices for certified or registered organic products. According to USDA National Agricultural Statistics Service (NASS, 2012), U.S. farms and ranches in 2016 sold $7.6 billion dollars of certified organic products, representing an increase in sales by 23% from the previous year. It is clear that consumers' preference for organic products is increasing at a fairly rapid rate; however, it is unclear what contributes to these shifts in agricultural economic trends.

In a survey of 200 organic consumers in the Campania region of Southern Italy, Annunziata & Vecchio (2016) attempted to understand consumers' motivations for purchasing sustainable and organic products. The authors attempted to quantify four main areas: general food and purchasing trends, their knowledge and attitude towards organic products, and their level of confidence in the region. Their preferences for choosing organic products were largely concerned with personal and familial health, with 46% of the respondents mostly concerned with whether or not the food was healthy for them and their families. Other important factors included: respect for human rights (43%), no exploitation of women and children (41%), produced in an uncontaminated environment (35%), obtained in an environmentally friendly way (26%) and locally produced to support local farmers and subsequently the local economy (23%). The least important factors included: low carbon emissions, animal welfare and environmentally friendly packaging (Annunziata and Vecchio, 2016). This shows that consumers purchased organic products because they were concerned with personal and familial welfare and were willing to pay for locally produced organic products.

Aside from organic labeling, Global GAP (Good Agricultural Practices) offers an Integrated Farm Assurance Standard, for agriculture, livestock and aquaculture in addition to offering quality assurance along other points of the food supply chain. With the goal of safe and sustainable agricultural production, the Global GAP certification addresses: "food safety and traceability; environmental sustainability; workers' health, safety and welfare; animal welfare; includes Integrated Crop Management (ICM), Integrated Pest Control (IPC), Quality Management Systems (QMS), and Hazard Analysis and Critical Control Points (HACCP)" (Global GAP, 2017). Consumers favor

Global GAP certification for food safety reasons, and Lind & Peterson (2011) found that it was beneficial for farmers in Kenya because it encouraged safety for workers and increased farming efficiency and environmental practices.

Another commonly selected sustainability certification on the West Coast is Salmon Safe. With a focus on water quality management through land stewardship, salmon safe certification standards include: water use optimization, creating and maintaining healthy riparian habitats, using soil conservation techniques, using best management practices for fertilizers and pesticides, while enhancing on-farm productivity and environmental quality (Salmon Safe, 2018). There are seven categories that producers who achieve Salmon Safe certification must follow: "In-stream Habitat Protection and Restoration, Riparian and Wetland Vegetation Protection and Restoration, Water Use Management, Erosion Prevention and Sediment Control, Integrated Pest Management and Water Quality Protection, Animal Management, and Landscape-level Biodiversity" (Salmon Safe, 2018).

It is of value to consider whether or not consumers have a preference for other eco-labels outside other than organic and where those motivations originate. Liu et al. (2017) surveyed 435 participants in four Chinese cities (Zhejiang, Shanghai, Jiangsu and Guangdong) concerning their preference for eco-labels, price, and geographical origin of rice. The majority of participants (52.3%) expressed a preference for eco-labels and was willing to pay a higher premium for these products. Their eco-label preference reflected interests in personal health and safety as well as improved environmental quality (Liu et al., 2017). This study shows that most individuals prefer to purchase eco-labeled products for health and environmental concerns; however, individuals that are price-sensitive and prefer locally sourced products are willing to pay higher premiums for eco-labeled products, as well.

Another study aimed to understand how consumers defined ‘sustainably sourced’, how important it is to them, and how the market can adapt to these preferences (Sackett et al., 2011). In a survey of 1002 participants, the authors used a Best-Worst analysis (which asks participants to identify the most and least significant drivers for their decision-making) to address environmental, price and sustainability concerns for apples and meat. For apples, the most important factors included: small farm size with minimal corporate involvement, pollinator management, and production, distribution and sale done locally; interestingly, farm size was 5 times more important than food price. For beef, small farm size with minimal corporate involvement was also most important with production, distribution and sale done locally was the second-most important factor; animal health and safety had the lowest score, and affordable food prices were also low (Sackett et al., 2011). This article shows that sustainably sourced food is closely connected with the size and proximity of the producers and processors in the eyes of the consumer.

This section highlights the importance of consumer choices and describes in brief detail three of the most commonly used certifications by producers in Washington State. Through the analysis of three different studies, it was shown that consumers’ preference for organic and eco-labeled products originate from their preference for personal health and safety, as well as environmental protection. Local sourcing is also a major contributor to their purchasing of eco-labels, and many consumers are more than willing to pay a higher premium for products originating from small, locally sourced producers.

Consumer preferences plays a significant role in farmers' management decisions over the past century, since more people have moved off the farm and have gained more wealth and subsequent purchasing power (Dmitri et al., 2005). At this point, it is necessary to understand producer preferences and incentives for implementing sustainable practices and choosing to market their goods with eco-labels. Since most eco-labels are entirely voluntary, are their preferences for higher premiums, or do their motivations originate from other factors?

Farmer Identity and Farming Philosophy

In this section, I will explore how farmers' practices inform their farming philosophy and subsequently farming identity. Many of the studies proposed in this section, including those previously cited, prefer to segregate farmers into two different camps: the conventional Productivist farmers that support intensive mono-crop agriculture and heavily rely on off-farm chemical inputs for soil fertilization, and the sustainably-minded farmers that incorporate crop rotation, minimum tillage, and use naturally-derived inputs to improve their soil health (Carolan, 2005; Michel-Guillou & Moser, 2006). In addition, some authors argue that farmers who choose to incorporate voluntary programs into their management regime based on intrinsic factors are more 'durable' as opposed to extrinsic factors (Mills et al., 2018). Nevertheless, authors like Lobry de Bruyn & Abbey (2002) find validity in identifying how farmers value soil health, regardless of their segregation into the Conservationist or Productivist camps.

According to Burton (2014), there are a number of factors that influence farmers' management decisions; they work with complex biological systems on a daily basis and must earn a living and support their families by managing dynamic and unpredictable ecological systems (van den Berg et al., 2018). In a study conducted in the Zona de Mata region in Brazil, van den Berg et al. (2018) sought to study farmers' perceptions of Ecosystem Services by contrasting individuals with different farm types (agro-ecological family farmers, conventional family farmers and large-scale farmers). Using a fuzzy cognitive map (FCM), 'a semi-quantitative modeling tool' that compares knowledge upheld by 'non-technical' experts, the authors used interviews to create these maps, which accumulate key factors that drive their management system and drawing arrows indicating causal relationships (van den Berg et al., 2018).

While the 'agro-ecological' (conservation-oriented) family farmers had the most complex perception of Ecosystem Services, the most significant differences were between the family farmers and the large-scale farmers. The author explains that the "peasant way of farming is characterized by a co-production with nature…" (van den Berg et al., 2018). In addition, since conventional family farmers work with pesticides themselves, they are aware of the stronger negative impacts of pesticide use; however, since they see no other alternative to pesticide use and have outside pressures (like landlords that force them to apply pesticides), they do not change their management practices. The most significant finding, though, was that for all three groups of farmers, their management of Ecosystem Services was highly complex and interconnected (van den Berg et al., 2018).

The following section explores what incentives encourage voluntary participation in sustainable agricultural management movements, further exploring how intrinsic and extrinsic motivators influence management decisions. The role that profit maximization and market fluctuations play on farmers' use of sustainable management practices will be discussed. The concept of intrinsic and extrinsic motivators will be considered with regards to the implementation of management practices. In addition, farmer identity will be explored in great detail, and how one's identity informs their farming philosophy.

Voluntary incentives for farmers and sustainable management

As previously described, consumers have called for a shift in preference; more and more people are purchasing products from small, local, and environmentally conscious producers. While there are some governmental incentive programs (NRCS' CRP and EQIP, to name a few) supporting agricultural conservation, most if not all of these programs are voluntary. Choosing an eco-label like Organic, Global GAP or Salmon Safe is also a voluntary measure and farmers and land managers choose to comply with these regulations. What, therefore motivates farmers' decisions to implement sustainable practices?

Mills et al. (2018) has laid out a series of extrinsic and intrinsic factors that influence farmers' adoption of environmentally sustainable practices. Extrinsic motivations are extenuating circumstances or influencers, which include: financial incentives and the desire to maximize profit, security, developing and investing in capital, social standing within a community and regulation. According to the authors, these factors, which depend on the actions and motivations outside of the individual, are less durable as intrinsic factors, which include: responsibilities as a land steward, commitment to local environments, and feeling a sense of personal accomplishment and enjoyment from their work (Mills et al., 2018). In terms of durability, the authors explain that such intrinsic factors influence the durability of management practices. For example, if a farmer's primary motivation for sustainable management concerned profit maximization and this was not realized, they would be more likely to forego this practice than someone who was motivated by their own responsibility as a land steward.

Through a survey of 1345 farmers and 60 semi-structured interviews, Mills et al. (2018) sought to identify motivations for farmers to implement unsubsidized environmental management practices, including: leaving marginal areas and corners uncultivated, providing bird and pollinator habitats, implementing buffer strips, maintaining residue cover over winter, leaving land uncultivated, maintaining hedges, and restoring and maintaining ditches. The authors then broke down extrinsic and intrinsic motivators into five groups: financial (maintaining capital and farm appearance, contributions to farm business, and other financial incentives), environmental (protecting environment for future generations, long-term business sustainability, interest in sustainable farming practices); agronomic (maintaining ground conditions, improving farm rotation/system, control pests naturally), factors outside of their control (regulation, landlord/owner wants it, has always been a part of farm) and other points (Mills et al., 2018).

These authors found that extrinsic and intrinsic motivators frequently overlap, and a complex matrix of motivators influences farmers' decision-making. The most influential extrinsic motivations were financial, especially for wild bird and pollinator habitats for game shooting, as well as establishing and maintaining hedges and ditches to increase their farm's 'curb appeal'. Agronomic motivations favored the establishment of overwinter crop residue, aligning with crop rotations. The most influential intrinsic motivator was environmental maintenance, and leaving corners uncultivated, establishing buffer strips, and creating bird and pollinator habitats were motivated by intrinsic environmental factors. Alternatively, the authors found that both subsidized and un-subsidized activities frequently take place simultaneously, suggesting that the case is frequently more complex than singular intrinsic and extrinsic motivators alone (Mills et al., 2018).

In a study of 12 farmers in England, Darragh & Emery (2018) investigated whether intrinsic or extrinsic motivators as separate entities motivated participation in England's Entry Level Stewards (ELS) Agri-Environment Scheme (AES). The termination of the program prompted the authors to examine whether or not the end of payments would 'crowd out' the financial motivations for conservation practices, and would encourage farmers to re-institute more environmentally destructive regimes.

The authors found that all 12 participants were financially motivated to participate in the ELS program, and all but one farmer admitted that the adoption of the new program had little impact on their current management regime (Darragh & Emery, 2018). Notably, the farmers indicated that the financial incentives did not cover the cost of implementation, and many stressed that payments alone were not sufficient motivators for participating in the schemes. As described by one farmer: "I think they [farmers] do it because they really want to do it, they really want to produce the effects of this, its not about the scheme or the money, they want to do it… they'd still do it anyway" (Darragh & Emery, 2018, p.15). In addition, all farmers intended to continue with some form of subsidized environmental management practice after the conclusion of the ELS program; this may imply a 'crowding in' effect in which newly acquired behaviors act as intrinsic motivators even after the termination of the plan.

The authors concluded that both crowding-in and crowding-out theories provided only superficial evidence for the motivations of farmers to implement or discontinue environmental management practices. It is of importance to note that farmers consider themselves environmental stewards, and they have never had the intention of being 'environmental villains'; all farmers indicated a genuine concern for the environment in which the inhabit (Darragh & Emery 2018). The authors argue that it is over-simplistic to assume that farmers are motivated by a singular intrinsic or extrinsic factor; as indicated by their responses, all farmers interviewed initially participated due to financial incentives (which would be considered an extrinsic motivator); however, because most of the practices changed relatively little within their management regime (extrinsic motivator), and they considered themselves to be environmental stewards (intrinsic motivator) many of them will continue to practice these conservation management techniques. It must be noted that whether or not farmers continued to practice the ELS management regimes or not was solely dependent on the preferences of the individual and the 'complex intrinsic, normative and instrumental factors' that influence their management decision (Darragh & Emery 2018).

As indicated through this section, financial and profit-maximizing motivations are unquestionably influential in farmers' decision-making. Boehm and Burton (1997) explain that profitability is one of the most important factors influencing farmers' motivations to adopt soil conservation practices; in most cases, there must be a financial benefit for farmers to incorporate sustainable agricultural practices into their farm system. As previously discussed, the consumer-driven interest in sustainably sourced goods has had a major impact on increasing environmentally sustainable practices. These authors considered the socio-economic influencers on implementing soil conservation practices in Canada. They discovered that the increased adoption of minimum till and no-till continuous cropping systems were chosen based on economic factors as well as risk reduction and ease of implementation (Boehm & Burton, 1997). By minimizing costs on machinery and labor, farmers in this study viewed less of a risk involved and were more willing to implement conservation tillage. This resulted in greater crop diversity as well as soil conservation (Boehm & Burton, 1997).

Farmers at times may be forced to make management decisions that cause environmental degradation, like soil loss, if they can make a profit in the short-term. They may be aware of the negative consequences of their actions, and the action may not be desirable, but as previously discussed, profit is one of the driving factors of most management decisions (Mullendore et al., 2015). With a specific focus on the adoption of crop diversification, Bowman and Zilberman (2013) considered which economic factors influenced farmers' motivators for management decisions: technological capabilities; biological and geographical constraints; labor, input costs and market fluctuations; financial and credit-based capacities; social norms; policy and regulation; or the farmers' own knowledge and skills.

The authors cite a number of factors that would encourage farmers to adopt a sustainable management regime like diversified cropping. These included risk mitigation[20], geophysical limitations like limited water and nutrient supplies, mitigating pest pressures, conserving soil health, qualifying for ecosystem services or other aid, or improving overall well-being, among others (Bowman & Zilberman, 2013). Regardless,

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[20] Which will be covered in the Risk Aversion section

there are a number of factors that may not present sustainable practices as economically viable. Technological advances in plant genetics and synthetic fertilizers, herbicides and pesticides make growing continuous mono-crop systems easier, and government incentives for commodity crops also strongly discourage a transition towards sustainability. In addition, diversified cropping systems can be more labor intensive, and as agriculture shifts towards mechanization, this can be unattractive to farmers (Bowman & Zilberman, 2013). It is clear that financial and profit motivators significantly influence farmers' decision-making and can constrain farmers from implementing conservation practices.

The previous section highlights the complex nature of motivators for the implementation or continuation of conservation practices. While Mills et al. (2018) attempts to simplify farmers' motivations into separate intrinsic or extrinsic groups, Darragh & Emery (2018) suggest that farmers' objectives for environmentally conscious management regimes represent a complex network of social, cultural, personal, and financial motivators. It is true that most farmers are financially motivated to implement specific management practices, but there are many other influencers to consider, like geophysical constraints, ease of implementation, learning curves, and social norms (Boehm & Burton, 1997; Bowman & Zilberman, 2013). At this point, it is useful to consider what formulates a farmers' identity, and how this informs their farming philosophy.

The formation and expression of farmer identities

In this section, I will consider how the literature recognizes land stewardship as a central tenet to farmers' identities and how it can serve as an indicator for the adoption of conservation practices. As described in the previous section, many scientists tend to group farmers based on ideologies, the most common segregation between the Conservationists and the Productivists (Sulemana & James, 2014). While such a simplification may overlook the complex character of each farmer, a demarcation can be observed when considering the management practices and conservation behaviors of these individuals and can provide useful insights into how farmers perceive themselves (Sulemana & James, 2014). Even though farmers can be grouped based on management practices, most farmers self-identify as stewards of the land, who value natural resources, the land, landscape and nature as a central core representation of themselves (Michel-Guillou & Moser, 2006).

According to Sulemana & James (2014), identity defines who someone is, how they view themselves, and how they want to be perceived in the world; attitudes, on the other hand, are an ‘expression, belief, opinion, evaluation or preference regarding a specific person, event or activity’ (p. 51). While attitudes directly influence behavior since they affect a person’s decision perceptions, one must also account for social and self-identity and how this is positively or significantly correlated with environmental conservation behaviors. Public image as well as cohort effects have been shown to have an equal or even greater influence of farmers’ management decisions, especially in terms of environmental and natural resource conservation (Michel-Guillou & Moser, 2006). Through an analysis of three case studies, this section explores exactly how identity influences perception and subsequently behavior in terms of environmental impacts within farmer groups.

According to Aldo Leopold (1949), “the landscape of any farm is the owner’s portrait of himself” (pg. 299). This explicitly describes how farmer identity manifests itself through one’s management practices and explains that farmers’ personal identity is closely linked to their ‘farmer identity’. McGuire et al. (2015) described row crop farmers in Iowa as consisting of four different identities: the Productivist, Conservationist, Civic-minded and Naturalist[21]; they then collected results for the Iowa Farm and Rural Life Poll with 1360 selectable responses. By asking farmers what they consider to be a ‘good farmer’, the used 31 factors to inform this definition, which include: “reduces income volatility, puts long-term conservation of farm resources before short-term profits, and keeps fencerows clear of brush’”, among others (McGuire et al., 2015, p. 154). In addition, the authors proposed five agricultural policy situations to measure how the farmers would react in specific socio-ecological contexts; these include scenarios like: “Conservation compliance policy should be extended beyond soil erosion to cover other areas such as water quality and wildlife habitat” (water quality) or “More money for conservation would mean more regulations for Iowa farmers” (conservation regulation) to name a few (McGuire et al. 2015, p. 150).

The authors found typical variables associated with both the Productivist and Conservationist identities; for Productivist, farmers, they prioritized chemical and technological use, wanted the highest yield per acre, and believed fields should be clean with no surface residue. Conservationists, on the other hand, prioritized the protection of natural resources, minimizing soil erosion and runoff, maintaining organic matter, and being mindful of their impact on local waterways (McGuire et al., 2015). Interestingly,

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[21] I will only consider the Productivist and Conservationist since they were the two largest groups reported in the study.

the Conservationist and Productivist perspectives aligned on four of the policy models proposed, including: ‘water quality’, ‘highly erodible land’, ‘coupled drainage-wetlands’, and ‘wildlife, parks and trails’. This suggests that even though both groups identify with various management practices, their ‘socio-ecological’ approaches were quite similar. Since these perspectives align, the authors posit that it may be possible to align the management practices of the Productivist farmer more towards that of the Conservationist, and that future research and policy should orient itself towards this pursuit (McGuire et al., 2015).

Michel-Guillou & Moser (2006) conducted a survey of over 200 farmers in the Picardie region of Northern France in October of 2002. First, the authors categorized farmers based on their adherence and non-adherence to pro-environmental practices like: organic certification, preserving water quality, reducing chemical inputs and adopting voluntary environmental practices as established by the government (Michel-Guillou & Moser, 2006). In so doing, the farmers were split into two groups: those adopting more traditional, Productivist practices and those that practiced environmental conservation. The authors then focused on the “relationship between farming practices and representations farmers have towards the natural environment, their attitudes towards pro-environmental practices, and their beliefs towards water resources” (Michel-Guillou & Moser, 2006, p. 230).

Using a Likert Scale, the participants were asked to rank their justification for voluntary water conservation practices as a way to improve their public image, increase revenue, preserve the natural environment or as a method that only presents challenges. In addition, they were also asked to create a hierarchical word association as a means to articulate social structure as a representation of the environment. Finally, they were asked to rank how they valued water quality, how exposed they felt to degraded water, and what was their personal capacity for action in terms of water quality preservation; additionally, the authors also evaluated how personally responsible farmers felt for water pollution compared to both household and industrial responsibility (Michel-Guillou & Moser, 2006).

The authors identified 124 farmers committed to pro-environmental action and 81 farmers that did not practice what the authors defined as ‘pro-environmental behavior’. Interestingly, both groups of farmers identified the same word association as their central core representation, with Water, Respect, Land, Landscape, and Nature the five most frequently identified words within the participating group (Michel-Guillou & Moser, 2006). While this suggests that the influence of ideological factors is difficult to determine a farmers’ inclination towards environmental conservation, it also implies that farmers are largely aware of their surroundings and value the protection and enhancement of their land as a central tenet of their identity (Michel-Guillou & Moser 2006).

Both groups also believed that environmental action has the capacity to improve their public image and can also restore the environment. Interestingly, both groups choose environmental conservation practices because they value their public image and seek social approval over environmental protection. In addition, both groups recognized few longstanding constraints or financial benefit from its implementation. In terms of personal responsibility, both groups also felt less responsible for water pollution, and put more blame on households and industry than on the agricultural sector (Michel-Guillou & Moser, 2006).

While both groups identified issues of water quality in the region, farmers that practice environmental and natural resource conservation felt more involved and capable of managing issues of water pollution. Therefore, one's perceived ability to improve degraded water is correlated to their implementation of pro-environmental management regimes (Michel-Guillou & Moser, 2006). The authors suggest that this can be linked to ideology, since ego-centric motivations like improved public image were more influential than the need to protect the environment; however, this valuation of social importance and personal identity has "made farmers aware of the seriousness of environmental problems, allowing them to thus examine the impact of their practices and of their possibility for action" (Michel-Guillou & Moser, 2006, p. 234). Even so, the fact that both groups of farmers share central core values of respect and protection of their local landscapes suggests that farmers do have a sense of responsibility for the land, and that land stewardship is an important part of their identity as farmers.

Through an analysis of data for over 700 Missouri farmers, Sulemana & James (2014) examined the different farmer identities, types and how these inform their attitudes towards 'ethically sensitive environmental issues'. The authors investigated three aspects of identity: 1) a comparison between Conservationist/Productivist ideologies, 2) whether general optimism or pessimism influences management decisions, and 3) farmers preference for technological advancement or more traditional practices. The farmers were then asked to rank their agreement on a Likert scale to a series of questions raising ethical issues pertaining to the application of pesticides in windy conditions (Windy Ethic), the disposal of pesticides containers illegally (Disposing Ethic) and applying herbicides that have been observed in local well water sources (Herbicide

Ethic). Sulemana & James (2014) sought to perceive how a farmer's personal characteristics when faced with specific situations affect their ethical attitudes towards the environment in an attempt to see whether or not how one's identity influences their ethical attitudes and behaviors towards specific environmental issues.

The authors found that over half of the respondents considered all three scenarios to be unethical, with 75% of the respondents believing that the Herbicide Ethic was immoral (Sulemana & James, 2014). The farmer type that positively correlated with having attitudes that each environmental scenario was unethical identified as Conservationists, were pessimistic in their overall outlook, and favored technological advancement. On the other hand, Productivists, optimists and those favoring more traditional agricultural practices were found to believe the three scenarios were less unethical, although these findings were not statistically significant (Sulemana & James, 2014). In addition, the authors found that of all three identity types described, the Productivist/Conservationist distinction was the most representative of unethical feelings, with over half of the Conservationists identifying all three questions as unethical and less than 1/3 of the participants agreeing that all three were unethical (Sulemana & James, 2014).

Another study discovered four divergent perspectives of farmers in Austria concerning their motivations for environmentally sustainable behavior. Through a Q methodological approach, a method used to study a group of people's viewpoints on specific issues, Walder and Kantelhardt (2018) interviewed thirty farmers and classified them into four distinct groups. The largest group, making up 31% of the variation of their sample, had a strong feeling of responsibility towards the environment and the ‘common good’, and was willing to sacrifice income for its preservation. These farmers believe that the modern agricultural system is to blame for causing environmental degradation. Made up of 11% of the variation, the second group believed that implementing conservation practices is context-dependent, and that extenuating circumstances are highly influential to the adoption of these practices. They blamed bureaucracy and poor policy-enactment for environmental degradation as well as market and consumer-driven choices. The third group (10% of the variation) was financially driven; they understood the benefits of environmental protection and were willing to implement modern technology into traditional practices like chemical use. They viewed environmental degradation as a result of individual management decision but saw positive change in modern agriculture. The final group made up 8% of the variation and believed that three components increase on-farm environmental sustainability; changing consumer consumption, increasing communication and establishing better policy for the promotion of agri-environmental schemes are the best ways to ensure its continued growth (Walder & Kantelhardt, 2018).

It is clear that a complex interplay of different factors influences farmers’ management decisions and their inclination to adopt conservation practices. While some argue that categorizing farmers into distinct groups over-simplifies a number of complex factors influencing their identities, others argue that it serves as a useful tool to understand the motivations of different management practices (Sulemana & James, 2014; Mills et al., 2018). All of the studies within this section identify differences based on management practices. Some have identified differences between Productivists and Conservationists based on ethical valuation (Sulemana & James, 2014) and that some farmers were motivated to implement conservation practices based on financial drivers (Walder & Kantelhardt 2018). Social cohort effects proved to be highly influential in the implementation of environmental conserving practices, which is a clear link to one's identity (Michel-Guillou & Moser, 2006). Regardless of their categorization, all farmers shared a sense of responsibility and respect for the land, suggesting that land stewardship is a key tenet of the overall farmer identity (Michel-Guillou & Moser, 2006; McGuire et al. 2015; Walder & Kantelhardt, 2018).

Defining and valuing soil health

While most farmers consider themselves to be stewards of the land, this does not inherently translate to implementing sustainable management practices. There are a number of extenuating circumstances, which will be discussed in the following section that may inhibit a farmer's capacity to practice sustainable soil management. Nevertheless, as an effective means to determine the connection between farming philosophy and farmer identity, Lobry de Bruyn & Abbey (2002) investigated how farmers in New South Wales, Australia defined and described soil health. The authors asked farmers to define soil health, explain how they identified healthy and unhealthy soil, what tools they used to measure soil health, and how they utilized outside resources to better understand the concept of soil health and its relationship to their farm. The authors argue that through a value orientation of soil health, scientists, agronomists and farmers can better understand what motivates end users, how their local knowledge informs their soil health knowledge, and how this information can be used to improve overall natural resource management (Lobry de Bruyn & Abbey, 2002).

The authors conducted in-depth and informal interviews with 75 farmers that followed 14 questions as a means to gain “thick descriptions” of how farmers define, determine and identify soil health (Lobry de Bruyn & Abbey, 2002). The authors first identified how farmers valued sustainability based on a hierarchy of objectives: over half of the participants favored sustainability for increased income, while the second most influential motivator for implementing sustainable practices was to improve their physical environment. This suggests that farmers implement sustainable management practices to increase their income and have a minimal effect on their local physical environment. This aligns with the idea that while receiving income is typically the most important factor for farmers, they hope to impact their local physical environment as little as possible (Michel-Guillou & Moser, 2006; Darragh & Emery, 2018; Mills et al. 2018).

When defining soil health, most farmers throughout New South Wales emphasized soil productivity, and explained that healthy soil had sufficient amounts of limiting nutrients like nitrogen (Lobry de Bruyn & Abbey, 2002). Even though this was the most common response, farmers used a multitude of definitions including the idea that soil was “…a living thing. It’s not just a bit of dirt”. Healthy soils, for the most part, equated to healthy crops for these individuals; most used qualitative descriptions, while only a few used quantifiable concepts like organic matter content or microbial activity (Lobry de Bruyn & Abbey, 2002). By using simple adjectives like “good” frequently, many of these responses may seem overly simplistic. Regardless, the authors argue that these responses provide insight into how and why farmers define soil health, with their primary justification being to determine crop limitations (Lobry de Bruyn & Abbey, 2003).

According to the authors, farmers rely on an average of four features to judge the status of soil health. While variation among districts was identified, the most consistent indicators were plant growth as well as how the soil felt; 100% of farmers interviewed mentioned these factors multiple times (Lobry de Bruyn & Abbey, 2002). In terms of soil feel, 50% of farmers used the term friable to describe good quality soils. On the other hand, and unhealthy soils were described as chunky, powdery, glazed, and hard-packed. In addition, an average of 78% of farmers across different districts identified organic matter as a prominent indicator of soil health. Many suggested a strong relationship between soil structure and organic matter content (Lobry de Bruyn & Abbey, 2002). The authors point out that for both healthy and unhealthy soils, farmers largely utilized visual indicators, suggesting that through experience and observation, they are able to better understand what management practices affect soil health over time.

For this cohort of farmers, soil monitoring was viewed as a continuous process where observations were conducted in conjunction to the performance of other tasks, like cultivation, driving around, checking for weeds, collecting soil tests, or maintaining farm infrastructure like building a fence (Lobry de Bruyn & Abbey, 2002). This is an important point for researchers and agronomists, since most farmers prefer to observe soil health while performing other tasks, and not as a chore executed in isolation. Of all forms of measurement, 67% of farmers conducted soil tests, while 52% utilized visual crop and soil inspections to measure health for both. While organic matter was used as an indicator of soil health, the living or dead biomass accumulated aboveground was the favored indicator, while few if any identified root biomass or humus as a measurement of soil health (Lobry de Bruyn & Abbey 2023). This again suggests that easily identifiable visual indicators are favored by farmers as opposed to sample collection or other formal soil analyses.

As an experience-based and observation-oriented cohort, farmers utilize seemingly simplistic means to identify soil health. The authors found that most do not use the term “soil health” in normal conversation but are constantly evaluating and checking the quality of their soil in conjunction with other daily tasks. By evaluating how farmers define, determine and monitor soil health, Lobry de Bruyn & Abbey (2002) posit that scientists and agronomists can create soil health checklists or other effective monitoring tools customized to easily adapt to the current practices employed by farmers to measure soil health. The authors point out that these checklists are “a means to a beginning, not an end”, suggesting that more research is necessary into how farmers utilize these tools, and which measurements are most effective (Lobry de Bruyn & Abbey 2002). Nevertheless, identifying how farmers understand and observe soil health can help farmers, scientists and agronomists work harmoniously towards implementing sustainable management practices.

Throughout this section, soil and agricultural scientists have attempted to define the best means to understand how farming philosophy informs a farmer’s identity. While some choose to segregate farmers into either the Conservationist or Productivist camp, many recognize that what unifies farmers is their identity as land stewards (Michel-Guillou & Moser, 2006; Sulemana & James, 2014; Darragh & Emery, 2018; Mills et al., 2018) As addressed by Lobry de Bruyn & Abbey (2002), farmers wish to implement sustainable management practices to improve their income and mitigate negative effects on their physical environment. While it is true that most farmers consider themselves to be stewards of the land, there are a number of other factors that significantly impact their management decisions, like aversion to risk, regardless of the philosophy or identity upheld by these individuals.

Risk management and aversion

Within farming, there are not only financial risks, like fluctuations in demand and price, but also biological and geophysical constraints that can be hard to predict and even more difficult to adapt to. Common risks cited by farmers include: drought, disease and pest infestations, personal health and safety, yield risks, unstable markets and institutions, as well as unpredictable weather and natural disasters (Sulewski & Kloczko-Gajewska, 2014). Understanding how farmers perceive, prepare for, adapt to and manage risk can be an indicator of their adoption of soil conservation management practices. If farmers perceive adopting new management practices as risky, under what conditions are they most likely to change to a more sustainable method? The following section considers a number of risks and the likelihood that farmers will adopt environmentally conscious management practices with or without the incidence of such risks.

According to Boehm & Burton (1997), in order for farmers to adopt soil-conserving practices, there must be a financial benefit to some degree, whether perceived in the short-term or long-term. Farmers' willingness to implement new methods is also highly dependent on their feelings of risk; if they are in a more comfortable financial situation, they are more likely to implement a new practice (like minimum or no tillage, for example). As reported by Doran (2002) of an Australian farmer, "It's hard to be green when you're in the red". It is important that soil conservation practices not impose on the profitability of the farmer; Boehm & Burton (1997) considered Canadian grain farmers and their likelihood of adopting minimum and no till practices. The authors found that since some conservation practices may exhaust capital and external resources (which includes labor, power, irrigation, and operating capital), farmers must initially feel financially secure before they choose to implement such practices. The availability of resources like capital, inputs and labor determined the likelihood of adopting soil-conserving practices. Individuals with fewer resources tended to use lower-input, lower-risk farming systems while farmers with ample resources were more likely to adopt soil conservation.

Through a survey of 600 Polish farmers, Sulewski & Kloczko-Gajewska (2014) addressed three points: what these farmers identified as risks, if they were similar to other farmers in their risk aversion, and if their specific level of risk aversion impacted their crop management decision-making. Of all weather-related risk factors, drought was considered to be the riskiest, with a medium level of perceived risk. Responses concerning risk aversion were highly correlated to personal health, with financial being the second largest risk factor. While the authors found that risk aversion did influence the farmers' management decisions through crop selection, what impacted their risk aversion the most were: the farmers' debt ratio, past experience with crop failures, overall soil health as well as their ability to be financially independent. To manage risk, farmers use crop insurance, off-farm employment, saving and accumulating capital, or diversifying their crop systems to adapt to market fluctuations (Sulewski & Kloczko-Gajewska, 2014).

This study shows that climate and finances are perceived by farmers as the riskiest factors in terms of financial and personal health and that one's risk aversion is closely connected to the farmers' financial stability, past experiences, and even soil quality; they choose to mitigate these risks through insurance, outside employment, and by selecting more diversified cropping systems. Bowman & Zilberman (2013) also point out that many farmers are risk averse, and that financial and biological/geophysical constraints were likely to impact management decisions. Farmers that are more risk averse or are more financially constrained are less likely to incorporate new technology or management practices into their system, but this is also influenced by knowledge of new practices and skills possessed (Bowman & Zilberman, 2013).

This section shows that farmers have a tendency to be risk averse, and that perceived or actual risks can significantly influence management decisions. Farmers perceive the implementation of new management practices and technology as risky and may be less likely to implement them if they are financially unstable or have experienced negative outcomes when adopting a new practice. Two of the biggest risks perceived by farmers are climatic, especially drought, and financial, specifically profit and market fluctuations. Farmers also know how to deal with negative outcomes, and use crop insurance, outside employment, or save capital to handle bad times when they happen (Boehm & Burton, 1997; Bowman & Zilberman, 2013; Sulewski & Kloczko-Gajewska, 2014). In terms of potential policy action, this research shows that alleviating at least financial risks for farmers may be the best way to encourage them to adopt new technologies or management practices, especially in terms of soil conservation.

Tacit Knowledge Takeaways

This section has covered a number of different ways in which farmers collect and disseminate information. In terms of demographic characteristics, it is difficult to identify a single factor as a determinant for soil health knowledge, since a number of different attributes make up an individual's personal history. While age can be used as a proxy for experience, Burton (2014) found that in many cases, younger farmers were more inclined to implement soil conservation practices. Other studies have found that one's 'sense of place' can serve as a predictor for pro-environmental management, as well; for this cohort of doers, users and interactors, experience gathered through trial-and-error, familiarity with certain farming techniques, and the development of intuition through experience is one of the most influential factors involved in the collection and transmission of farmer knowledge (Burton, 2014). In terms of education, quality (or type) seems to be more influential than quantity (the number of years); in terms of tacit knowledge, though, many farmers can be considered good farmers with little or no education (Hatch, 1992; Burton 2014). In addition, more females are becoming interested in farming, and some studies have shown that females are more inclined to implement soil-conserving practices (Sachs et al., 2016). Regardless, demographic and personal history is only one piece of the complex matrix that makes up a farmer's knowledge base.

Farmers interact with each other and the private and public sector in different capacities. These include communites of practice, networks of practice, and webs of influencers; what differentiates these groups is the level of trust and degree of intimacy within and amongst these different cohorts (Oreszczyn et al., 2010). Through an analysis of the three different groups previously described, Oreszczyn et al. (2010) found that webs of influencers were more influential on the actual implementation of new practices and drive to acquire new knowledge. Even so, social capital, which is closely linked to communities and networks of practice, holds much sway over the implementation of certain practices by farmers, and one's own identity within a specific group largely influences how they manage their land (Kizos et al., 2014).

Many researchers have attempted to define and identify different farmer identities; most of these individuals believe that segregating farmers into two separate groups provides better insight into the formation of farmer identities and can better inform their management practices and farming philosophy (Michel-Guillou & Moser, 2006; Darragh & Emery, 2018; Mills et al., 2018). While farmers may uphold different ideologies and implement different management practices, there are a number of complex factors that influence their identities and management decisions; first and foremost, farmers consider themselves to be stewards of the land, and extenuating circumstances like market demands, risk aversion, or financial stability may hold greater influence than ideological or philosophical affiliation (Boehm & Burton, 1997; Bowman & Zilberman, 2013; Kizos et al., 2014). Regardless of their philosophy or identity, understanding how farmers define, describe and measure soil health can help researchers and agronomists work alongside farmers and land managers to improve soil health on a larger scale (Lobry de Bruhn & Abbey, 2002).

In summary, farmers are complex individuals who exist in complex social and biological systems; because of this, it is difficult to create generalizations that apply to all farmer groups. Therefore, we must consider each farmer, farm system and farming community as a unique entity operating within diverse social and biological ecosystems. When studying complex agro-ecological systems, it is therefore necessary to understand both the geological and social formation of these agricultural communities. In order to thoroughly understand how Yakima County became an agricultural epicenter of Washington State, it is necessary to consider the geological and social formation of this area. In so doing, we can see what factors contributed to the social, cultural and ecological transformation of the area, and can better understand the complex interplay of factors that determine soil health throughout the Yakima Valley.

Social and geological history of Yakima

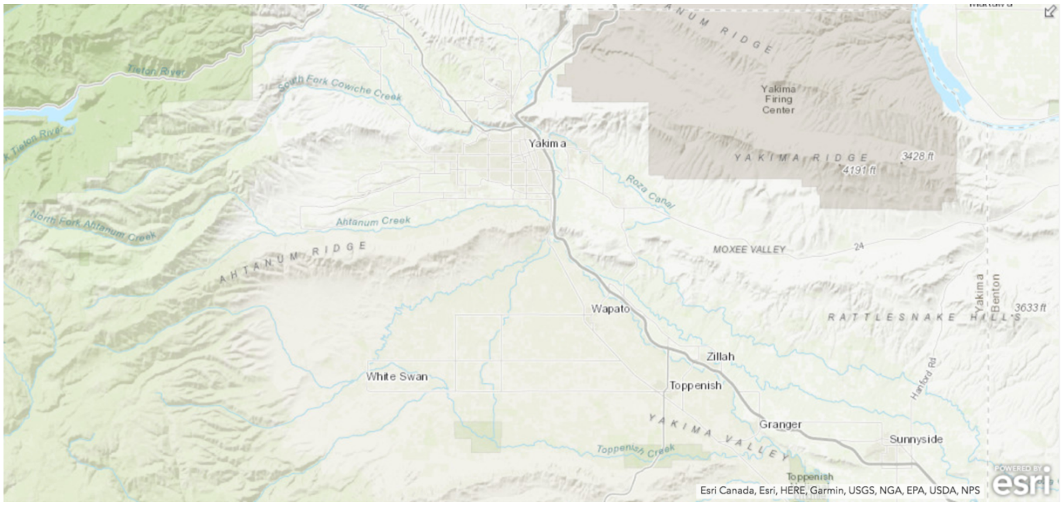

Figure 4: Map of the Yakima region, showing the numerous ridges and valleys formed over millions of years of geologic events

(http://geoduck.maps.arcgis.com/home/webmap/viewer.html?useExisting=1)

A number of unique geological and social events taking place over millions of years contributed to Yakima's place as an epicenter of agriculture. A series of lava flows and topographical folds and faults formed the unique landscape and parent material of the area beginning 17 million years ago. More recently, the Great Missoula Floods were a result of glacial and inter-glacial periods of freezing and thawing during the Pleistocene Epoch. As a result of geologic and climatic events over millions of years, the topography, soils and vegetation created the desert-steppe we see today. The social history of the area varies greatly, with its first documented inhabitants being the nomadic Yakama people that depended heavily on the Yakima River and its bounty for millennia. About 150 years ago, Euro-American settlers began populating the landscape, and the westward expansion of the United States severely imposed on the livelihood of the Yakama tribe. With further technological and agricultural development, irrigation canal projects beginning at the end of the 19th century provided ample water from the Columbia and the Yakima rivers to irrigate millions of acres of desert. These events, which will be described in further detail, shaped Yakima into the agricultural hub it is today.

Geological history

The Yakima area formed over a series of volcanic eruptions, lava flows, uplifts, folds, vaults, glaciations, floods, and stream entrenchment over the past 17 million years (Campbell, 1976). This series of geological events shaped the valley into the agricultural region it is today. Activity from the mid-Miocene era (17 million years ago) to the great Lake Missoula Flood during the Pleistocene era (13,000 years ago) and subsequent volcanic eruptions has shaped a uniquely fertile soil. A brief description of the geological history of the area will follow, citing the major events that formed the area.

Lava flows, folds and faults

Geologic records show that prior to 17 million years ago, Yakima was a flat plain with no ridges and valleys; the Cascade Range had not yet formed, nor had the Columbia or Yakima Rivers carved the area (Campbell, 1976). At this time, though, tectonic movement of the North American Plate across the Juan de Fuca Plate instigated a series of lava flows to the east that accumulated across Yakima (TOTLE Workshop, 2007). These flows created the Yakima Basalt, a series of three distinct events that formed the underlying bedrock of the area. Reaching 1,000 meters deep but not continuously, the Yakima Basalt has been broken up by layers of gravel, sand, silt, clay and soil. The volcanoes of the Cascade Range created the Ellensburg Formation beginning 10.5 to 12.5 million years ago, consisting mostly of volcanic pyroclastic and tuff material of both coarse and fine texture, was formed by the volcanoes of the Cascade Range beginning 10.5 to 12.5 million years ago (Campbell, 1976). During this time, the Columbia River flowed through Yakima and meandered south to present-day Harrah, preceding the rapid folds and shifts that would further shape the valley.

According to Norman et al. (2004), the formation of anticlines and synclines, ridges and valleys of material from the Yakima Basalt and Ellensburg Formation that have been folded and faulted, began at least 9 million years ago. Four different types of faults can be observed in this area: thrusting faults, which occur along the flanks of north ridges on an east-west trend; normal faults, similar to thrusting faults but with minor folding; high-angle reverse faults, which occur near ridge crests; and strike-slip faults that trend north-south and cut across ridges (Campbell, 1976). This structural movement continued at a rapid rate until 1 million years ago and pushed the path of the Columbia River to the east, around the Yakima Ridge and Horseheaven Hills. Although the path of the Columbia River shifted with the structural changes in the valley, the Yakima River maintained the same channel as it resides today, entrenching into the basalt (Campbell, 1976).

The Great Lake Missoula floods

One of the most controversial theories for the formation of Eastern Washington came from the J. Harlan Bretz, a geologist who suggested that enormous flooding of preglacial valleys took place in what is known as the Channeled Scablands (Bretz, 1928). The Scablands, "a gigantic series of deeply cut channels in erosion-resistant Columbia River basalt", covers most of the southeastern part of the state, including the Yakima Valley (Bretz, 1959, foreword). Although discounted by many early geologists because of the rapidity of the geological formation, J. Harlan Bretz defended his flood theory due to the presence of: anastomosing river channels (that inexplicably diverge and converge), rock basins, scarps in loess, butte and basin topography, cataracts, broad gravel deposits, bars, giant current ripples, backwater deposits and scablands of different ages (Bretz, 1959). Even today, many geologists uphold Bretz' theory, and some have called for the re-naming of the "Great Missoula Floods" to the "Bretz Floods" (Johnson, 2011).

During the Late Pleistocene, Glacial Lake Missoula held approximately 2,100 km^3 (about 1305 $miles^3$) of water that was at least 610 meters (2000 feet) tall; however, as the major glacier covering most of the northern hemisphere began to warm, the ice dam enclosing the glacial lake broke loose, releasing massive amounts of water across the eastern part of Washington state (Campbell, 1976). At the Walula Gap in the Pasco Basin, large volumes of water plugged up this anticline divide, which eventually widened the canyon and created a delta at the mouth of the Columbia River (Norman et al., 2004). Water traveled well into the Yakima valley, as far south as Union Gap and White Swan; evidence of the events can be seen in the formation of gravel bars and large deposits of alluvial silt at least 20 m thick in the lower valley (Campbell, 1976).

The largest flooding event is believed to have taken place 13,000 years ago, although at least 40 potential flooding events have been suggested (Waitt, 1987). Through an analysis of geomorphological and sedimentological deposits throughout present-day Montana, Idaho and Washington, Shaw et al. (2009) argues that the great Lake Missoula floods did not form the scablands alone. A sub-glacial reservoir extending over much of British Columbia and the northwestern section of the United States (referred to as the Cordilleran Ice sheet) can explain the geomorphological evidence suggesting that 50 times the amount of water (100,000 km^3 or over 620,000 $miles^3$) of the Missoula floods covered the Columbia Basin. Much of the sedimentary deposits across the scablands differ from those within the Great Lake Missoula; in addition, the authors argue that drainage patterns from the North and great erosion downstream from the Columbia River and Grand Coulee could be explained by flow from the Cordilleran ice sheet. The authors propose very few flooding events influenced the formation of the area over a geological history (Shaw et al. 2009).

The Columbia River Basin

The geology of the Columbia River Basin formed unique soils within the Yakima Valley. Underlain by a thick layer of Basalt, the weathering of this bedrock has made various nutrients available for plant growth. The meandering of the Columbia and Yakima rivers deposited sand, silt and clay at different locations throughout the area, and also contributed to the weathering of the basalt layers. Fine silt sediment from the Glacial Missoula floods accumulated in bars and can be observed south of the Ahtanum ridge. Loess from the strong southwestern winds picked up fine materials and deposited them in a thin layer (less than 3 m). Ash from the high level of volcanic activity has also accumulated in the area. Worster (1985) describes how the Columbia River changed the landscape of the Columbia River Basin, influencing the ability for humans to farm the land.

> “The main stem of the Columbia charges down from the Canadian Rockies into the United States, now running north, now south, then west, then south again, struggling to find its way through the Cascades, finally turning westward toward the sea. In the Pleistocene, a massive block of ice forced the river up and out of its twisty canyons, compelling it to carve a new path for itself—the Grand Coulee, a detour fifty miles long and as much as a thousand feet deep—until it could regain its established course. When the ice melted, the river reverted to the old way, leaving the Coulee a dry, abandoned trench. Falling away from that ancient, disused gash in the earth was an immense stretch of eminently arable land, sagebrushy and cloudless, a land standing in a rain shadow, but a land that might, so local boosters believed, be transformed into an ‘inland empire of agriculture, the Great Columbia Plain” (Worster, pg. 270).

Topography

The Yakima Fold Belt is a series of ridges and wide-reaching valleys that stretch east of the Cascade Range (Norman et al., 2004). The Umtanum ridge to the northeast of the valley, divides Kittitas and Yakima counties within the Columbia River Basin. The Columbia River borders this ridge to the east, while the Yakima River winds to the west. The City of Yakima sits in the Ahtanum Valley, bordered to the South by the Rattlesnake Hills and the Ahtanum Ridge. The two ridges are divided by a gap formed by the Yakima River. South of the Ahtanum Ridge is the Yakima Valley, the northern part of the Yakima Indian Reservation, which is bordered to the south by the Toppenish Ridge (Weberling et al., 2001).

Climate

Characteristic of southeastern Washington, the Yakima Valley is continental semiarid: clear hot days and cool nights are typical in the summer, with wet, cloudy and cold winters. Average temperatures in the winter reach 0 Degrees C (32 degrees F), and an average temperature of 20 degrees C (69 degrees F) during the summer, with many days well over 37 degrees C (100 degrees F) (US Climate Data, 2018).

Due to varying topography and proximity to the Cascades, precipitation and weather can vary substantially (Foxworthy, 1962). Mean annual precipitation from 1970-2000 along the Cascade Crest (which feeds into the Yakima Basin) was between 203 and 356 cm (80 to 140 inches), while at the basin's outlet, average annual precipitation was below 25 cm (10 inches) (Vano et al., 2010). Although heavy rainfall occurs high above the valley floor along the Cascade Crest, the Rainshadow effect creates a dessert climate to the east of the mountains (Washington Native Plant Society, 2018). Rain is common in the winter but ceases in the summer; while rapid vegetation growth occurs in the springtime, it nearly ceases in the dry, hot summer. Because of this, it is essential that soils in this area store water in the winter and can supply ample quantities during the dry summers (Daubenmire, 1988).

Vegetation

The Yakima Valley is part of the Shrub-Steppe ecosystem which covers 6 million hectares of central-eastern Washington and north-central Oregon (Daubenmire, 1988). The undisturbed *Artemesia tridentate-Agropyron spicatum* ecosystem consists of perennial grasses and patches of over-story shrubs (Dobler et al., 1996). *Artemisia tridentata* (sagebrush) is the predominant over-story shrub of this area, and *Agropyron spicatum* (bluebunch wheatgrass) is the primary grass; due to the openness of both the sagebrush and the wheatgrass, enough light reaches the understory so that other vegetative layers may develop (Daubenmire, 1988). Even in the driest parts of the Washington steppe, no undisturbed land is left bare. A cryptogamic layer of lichens and moss covers any vegetation-less soil, but due to its fragility, can be easily disturbed by grazing animals or other traffic (Daubenmire, 1988).

From desert steppe to agricultural epicenter

Due to the dry, hot summers in the Yakima area, one would assume that agricultural production would not be possible; however, with the areas proximity to the cascades and abundance of water flowing down to the valleys, ample sunshine, and the white man's propensity to convert marginal lands to agriculture, many settlers foresaw the agricultural abundance that would grace this land. It is therefore necessary to understand the relationship between humans and land in Yakima, and how that has transformed over the last two hundred years.

Social history

Yakima has experienced a complete geographical transformation due to the encroachment and development of white settlers in the area over the past 200 years. Before settlers descended upon Yakima, the Yakama tribe inhabited the area practicing a subsistence lifestyle of hunting, gathering and fishing (Wester, 1999). In 1855, the Yakama signed a treaty with the US establishing the Yakama reservation, a 1.25-million-acre property along the Yakima River. As more and more white settlers populated the sagebrush and the government manifested its vision of an agricultural West, the Yakama tribe was forced into the Dawes Act of 1887 with the hopes that Indians would adopt 'the Bible and the plow' and choose a more 'civilized' lifestyle (Wester, 1999). Simultaneously, the railroad companies and businessmen hungry to continue the agricultural development of the area established plans to bring the abundant water from the Cascade Mountains to the Yakima desert. From 1890 to the 1930s, nearly 500,000 acres of land was brought under irrigation with the help of the railroads and private businesses, with the largest contributor the federal Bureau of Reclamation (Dick, 1993).

The culmination of cultural changes over the past few hundred years shaped Yakima into the agricultural mecca it is today.

The Yakama People: semi-nomadic to allotted aliens

The Yakama[22] people consist of 14 distinct bands of semi-nomadic people that have inhabited the Yakima Valley for at least 12,000 years (Wester, 1999; Zeister-Vralsted, 1999). According to the tribe, "tribal people comprising the Yakama Nation have lived in this area since the beginning of time. They used the entire land base, from the lowlands around the Columbia River to the snow-peaked Cascade Mountains. Yakama people spent the coldest months in winter villages generally located on the valley floor… Villages were located on or near waterways, in places where a variety of resources could be obtained…" (Healy, n.d.). They migrated in springtime, following fresh edible vegetation consisting of camas, bitterroot and berries; these individuals also hunted the abundant wildlife, including deer, elk, sharp-tailed grouse, and the salmon that returned to the Columbia and Yakima rivers (Zeister-Vralsted, 1999). All of this food would be accumulated during the warm months to be kept and preserved during the wintertime, when Indians would return to the river valleys for warmth, wood and water (Healy, n.d.).

Beginning at the turn of the 19th century, Euro-Americans attempted to inhabit the Yakima Valley; they saw great potential for agriculture but were met with challenges with the harsh desert climate. As more settlers sought land in Yakima, the US government forced the reservations into a treaty delineating their lands; the treaty of 1855

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[22] The Yakama Nation renamed themselves in the 1990s to more closely represent the proper pronunciation of the word (Healy). In this section, Yakama refers to the tribe, while Yakima refers to the city, river and county.

was an exchange of 10 million acres for $200,000 and 1.25 million acres of land to the Yakama. A major statute of the treaty was that the Indian subsistence way of living be maintained; however, even though they were guaranteed access to fish and other water-dependent resources, they were not guaranteed water itself. This issue surfaces later. Also included in the treaty, provisions were provided to teach the tribe about the 'Euro-American' culture, and legislation also granted settlers the ability to inhabit the reservation to "lay the foundation of a farming society" (Wester, 1999).

R.H. Lansdale, an Office of Indian Affairs (OIA) agent for the Yakama tribe believed that,

> "with a fixed home, and with an individual right in the soil from which the [Yakama] will be instructed to derive their subsistence, they will be stimulated to… create an adaptation to civilized pursuits never to be acquired while the nomadic character is retained… [Yakama must be] fixed to the soil, as such domestication must always underlie any permanent progress in civilization" (Wester, 1999).

With this hope, the Dawes Act of 1889 came to fruition. This granted each tribal member an 'allotment' on the reservation of up to 160 acres per head of household. Though not explicitly communicated, the OIA classified land as a means to determine who was best fit to manage the land, whether they would hold it in trust for the tribe, lease it to raise tribal revenue or sell it to white settlers under the pretenses that they were better suited to farm the land than the Indians themselves (Wester, 1999, p. 208).

Many Indians were hesitant at first, and at least 1/10th were referred to as 'Wild Yakamas' because of their refusal to acknowledge validity of the Dawes Act because they believed that "the earth was their mother and her bosom should not be scarred with section lines and subdivisions" (Wester, 1999, p. 210). At first, the draw for the Dawes Act was minimal, since the cost of conversion to agricultural land was high, agricultural production was not an immediate guarantee, and most would have to practice their historic hunting-fishing-gathering in the interim; however, by 1898, the white encroachment forced many to change their minds. According to White Swan, the Yakama Chief from 1868-1910, “You see at Yakima and Goldendale there is a city over there at both sides and the whites is pushing us on each side… They are hurting us on both sides” (Wester, 1999, p. 211). While the initial hope of the Dawes Act was to encourage Indians to adopt an “American” way of life, many unforeseen problems arose.

Few allotted Indians thrived financially by adopting a neo-colonial agrarian lifestyle. Those that acquired land near the valley floor had better soil fertility, and those that had access to capital for tools and seeds as well as water access were the lucky ones. Even if individuals had direct access to water, large irrigation reclamation projects diverted water into canals; while the government attempted to define water rights for the natives, a ‘free-for-all of water speculation’ resulted in the drying of streams due to over-excessive use (Wester, 1999). Congress finally granted the Yakama access to water, but the tribe was limited to 147 cubic feet of water per second (cfs) while non-Indians were granted 2065 cfs, according to an advocate of the tribe, Lucillus V. McWhorter, “It takes to careful observer to right through the… Reservation… and pick out the Indian tilled lands from those of white owners and lessors. The former invariably present a withered appearance, while those of the whites show fine crops, resultant from sufficient water” (Wester, 1999, p. 214).

The Dawes Act was a failure for a number of reasons, for the exploitation of the Indian people, and the prevalence of white settlers who were willing to ‘swoop in’ and purchase or lease land. The major issue of land development concerned the issue of land development. “Because Congress could never decide whether it was more important for

Indians to learn farming or for Indian land to be farmed—irrespective of who wielded the plow—federal laws alternately raised and lowered maximum term lengths for allotment leases" (Wester, 1999, p. 217). The problem with leased land, as stated clearly by Paul Sears (1935), was that those that lease land will care for it less than the land they own themselves. This gave rise to land deterioration and negatively impacted the tribe since lessees were more interested in turning profits by maximizing crop production as opposed to improving lands. Much of this leased land was over-irrigated, resulting in salinization and over-grazed (Wester, 1999).

It is clear that injustices were committed to the Yakama Indians in the name of 'Manifest Destiny'. With the sale of Yakama land at the turn of the century at $10 per acre, many tribes people were outraged. As described by Yakama Louis Mann in a letter to Indian Commission Robert Valentine in 1909:

> "There are many poor Indians who have went to work and sold their…land through Sup[erin]t[endant] or ag[en]t hand and this day many are suffering hard ship or starvation[.] Why[?] Because one ten dollars monthly payment is…very small. I know no one on this earth would go to work sell his lands and get his payment that way and make his business go right[.]… You law makers there you need not want Indians to starve" (Wester, 1999, p. 218).

The OIA did not recognize these injustices but viewed the sale of Yakama land to white settlers as progress in the right direction. The sale of Yakama land was considered a 'law of necessity', a harsh introduction into the capitalist system rapidly overtaking the United States (Wester, 1999).

In less than a century, the Yakama were transformed from semi-nomadic tribespeople benefiting from the bounty of their native resources to essentially aliens that were largely stripped of their land rights. In the name of progress and westward expansion, the US government and white settlement encroached so heavily on their way of life that it was completely transformed. While the cultural setting shifted so drastically, the vegetation and geography itself also changed. What was once a desert steppe in many areas quickly transformed to an irrigated agriculture hub. The establishment of extensive and intricate irrigation permitted the transformation of sagebrush to crops.

Irrigation and the age of agriculture

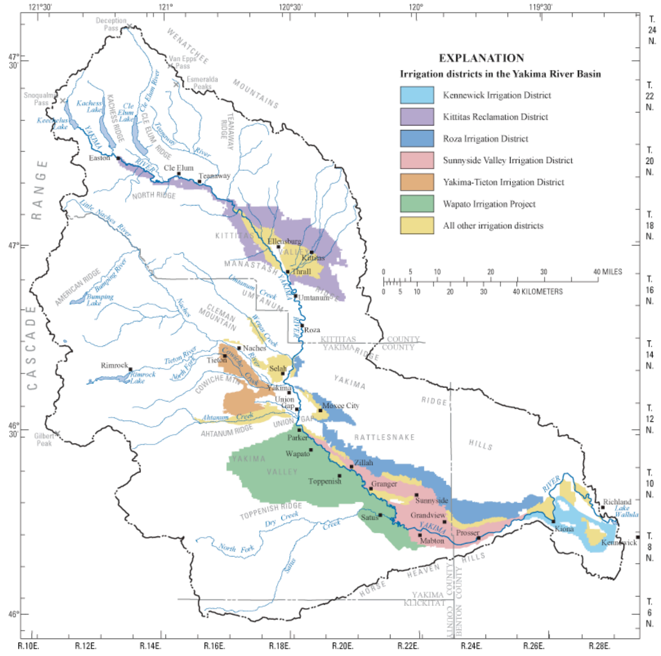

Figure 5: Map of the surface-water irrigation districts, Yakima River Basin

(U.S. Geological Survey)

With ample water resources flowing down from the Cascade Mountains to the vast dry desert of the Columbia River Basin, many with an inclination toward agricultural development viewed this area as an ideal location for the establishment of a large irrigation system. In half a century, the area east of the Cascades adopted a new aesthetic, from sage and bunchgrass grew water-loving hay and alfalfa, and lush tree fruits soon dotted the horizon. The mighty Columbia, and one of its largest tributaries, the Yakima River, supplied this conversion as dams, diversions and canals soon funneled the thawed snow from the Cascades throughout the desert. In the name of progress, human engineering and intervention further shaped the valley into an agricultural epicenter.

Prior to irrigation, settlers could not see the lush landscape that Yakima would once become; many described it as “nothing but hot winds, and dust and sagebrush” or even “a bunchgrass waste” (Zeister-Vralsted, 1999). But the Euro-American’s insistence to create a garden in the West was greater than what limitations the landscape presented. As declared by FDR much later in 1934:

> “You have acreage capable of supporting a much larger population than you now have. And we believe that by proceeding with these great projects it will not only develop the well-being of the far West and the Coast, but will also give an opportunity to many individuals and families back in the older, settled parts of the nation to come out here and distribute some of the burdens which fall on them more heavily than fall on the West… You shall have the opportunity of still going West” (Worster, 1985, p. 270).

As the railroads continued the race westward, the idea of irrigation appealed to the railroads and local businesses as a means to increase profit. With the formation of the Yakima Canal and Land Company in 1889 under Walter M. Granger, construction on the largest canal in the area, the Sunnyside canal, was under way (Dick, 1993). A number of successive companies formed with the goal to create two canals: one in Kittitas county, and an extensive and intricate irrigation system at the Yakima headwaters, with the main line as the Sunnyside canal. As explained by a local newspaper in 1893, “two years ago if a man had settled on a piece of that and he would have been advised to [a local mental institution]. Water makes the difference”. (Zeister-Vrlasted, 1999, pg. 391).

While work began on the Sunnyside canal in 1891, the Depression of 1893 halted plans, and the ‘flow of potential settlers’ was also stunted (Dick, 1993). While other private sector attempts were made, the over-appropriation of the Yakima River with halted development plans intrigued the federal Bureau of Reclamation. In 1904 and 1905, government-funded surveys by Reclamation engineers of the Yakima and Tieton regions decided that the the large projects were feasible, were cost effective, and would provide the most benefit to farmers and settlers in the area; as of December 12, 1905, the Yakima Project was underway (Dick, 1993).

From 1905 to 1957, over 464,000 acres of land came under irrigation with the completion of the Yakima Reclamation Project; a total of six divisions were completed in that time frame, including the Sunnyside division, the Tieton division, the Kittitas division, the Roza division, the Storage division and the Kennewick division (Dick, 1993). With the completion of the Sunnyside division in 1907 over 103,600 acres of land became irrigable and seven irrigation districts (Grandview, Outlook, Prosser, Snipes Mountain, Benton and Sunnyside Valley) were all granted access to water. The Tieton division, completed in 1910, granted 27,271 acres of irrigable land in two districts (the Canyon and Valley units) from the Tieton River in the Tieton Canyon (Dick, 1993).

The creation of the Storage Division, an extensive system of lakes and reservoirs that collected floodwaters during the spring and fall (when rainfall was highest) and prevented the excess withdrawal of water during the drier summers. Six storage reservoirs were created beginning that the Yakima headwaters fed from the Cascades to the west. With a total of 1,070,700 acre-feet of water these reservoirs include: Bumping Lake Reservoir, Lake Kachess, Lake Keechelus, Clear Creek Reservoir, Rimrock Lake and Lake Cle Ellum (Dick, 1993). With the diversion of the Yakima River with the Easton diversion dam, and the completion of the main canal in 1931, the Kittitas division at the base of the Cascades range brought irrigation to 59,582 acres. By 1939, the Roza division diverted water from the Yakima River into the northern section of the Yakima River Valley and supplied 72,511 acres of land with water (Dick, 1993).

As a result of the creation of an intricate and extensive irrigation system, crop profitability grew exponentially over the course of half a century. As of 1914, there were 2,200 farms and 9,100 farmers that used water from the Reclamation projects; these farmers began growing orchard fruit, hay, alfalfa and potatoes, and their crop values reached $3,331,355, with $1,855,650 from apples alone. By 1976, once all major Reclamation projects were completed, the gross annual value of crops in the Yakima Project area totaled $239,923,746, with more than half in tree fruit (Dick, 1993). It is evident that the goal of agricultural development was realized by the middle of the 20th century, since crop profitability skyrocketed as a result of converting the desert environment to a lush, irrigated landscape.

Contemporary Yakima

As of the USDA's 2012 census of agriculture, 1,780,498 acres are under cultivation in Yakima County. The market value of crops sold reached $1,645,510,000 with a 37% increase from 2007, and the top five crops are: apples, forage land, corn for silage, grapes, and wheat for grain. According to the USDA 2012 Census, slightly more than half (52%) of operators farm as their primary occupation. In addition, the majority of operators (79.2%) were white; the second largest group was of Spanish, Hispanic or of Latino origin (17.4%); less than 0.02 percent is of Native American descent.

Over the course of 200 years, the complete social, cultural, and ecological landscape of the Yakima Valley has changed drastically. What was once a desert landscape covered in sagebrush and bunchgrass, inhabited by tribes that subsisted on the abundant natural resources in a semi-nomadic lifestyle now resembles most of rural America. With massive areas of land segments delineated by fences and hedgerows, fruit trees, hop vines, and vast swaths of pasture cover the landscape today. With contemporary modernization, the once-small cities are now encroaching on the established farmland, increasing the cost of land and decreasing the amount of farmable land available. This shows that humans play a pivotal role in landscape change; the responsibility of maintaining ecological and environmental sustainability therefore belongs to those responsible for land, and subsequently soil management into the future.

Chapter 3: Methods

In order to have a fully informed understanding of the soil health knowledge of the participants in the study, I collected both quantitative and qualitative data. Semi-structured interviews were held first, and farmers were then asked to identify a field of high fertility and a field of low fertility on their land. I used GIS to randomly generate 10 samples: five from the high fertility site and five from the low fertility site. I extracted 10 soil samples per farmer using two different soil cores: with a mass of approximately 107 cm^3 and one with a mass of 105 cm^3. I air-dried the samples in a lab-grade oven until the samples stopped losing weight. Once the samples dried completely, I ran them through a 2mm sieve to remove large debris, organic matter, and rocks. I weighed the items over 2mm in size, noted their make-up, and stored the dry soil samples for later use. I then used a mortar and pestle to homogenize my samples to and measured total carbon and total nitrogen using a Perkin Elmer 2400 CHN analyzer. Through descriptive analysis and a multiple linear regression categorical analysis, I analyzed both interview and soil sampling results. Combining interviews with on-site soil sampling allowed me to have a more comprehensive understanding of the farmers and land managers' soil health knowledge.

Interviews

Sampling method

I conducted a basic google search of "farmers in Yakima county", with a few iterations on the search terms used. The search yielded 45 results: 38 listings included both an address and a phone number, and seven others listed only an address. All 45 searched farms with a listed address received a postcard in the mail explaining the nature of the project, describing the person conducting the study, and describing the timeframe in which the study would be carried out. I called the farmers and farming operations without an address, or that were sought later in the study, and provided the same information listed on the postcard. Of the 45 farmers with a listed address, only one farmer responded to the postcard directly. A total of 8 farmers or land managers chose to participate in the study based on this outreach method. Potential bias could occur using this method because I limited my sample size to farmers with a phone number and/or an address listed on-line. I mitigated this potential bias through the snowball sampling method.

The snowball sampling method (Goodman, 1961) was employed to recruit participants for this study. I asked most participants during the interview process to recommend other farmers or land managers to participate; of the twelve participants, only two recommended other individuals and provided contact information for those individuals. One individual provided contact information for at least 12 additional farmers or land managers. This farmer invited me to the farm café in the town of Harrah, Washington, where many local farmers, distributors and equipment dealers commune on a daily basis. Of these 12 participant recommendations, at least 5 were introduced via the farm café; of the 5, however, only 3 participated; in total, I amassed 7 participants using the snowball sampling method.

Potential bias surfaced within this sampling method; this is due to the fact that one participant recommended almost half of my sample size. These individuals have all known each other for decades, and many of their families have been closely related for generations. It is possible that because of their close familial and social association, they possess similar values and farming philosophies. In order to investigate the potential bias present within on-farm research studies, Luschei et al. (2009), compared the survey results of 187 randomly-selected farmers with 18 farmers recommended by local farm extension workers. Based on their results, 80% of the questions concerning weed control behaviors and attitudes between the two groups were indistinguishable. This study substantiates the usefulness of convenience sampling within on-farm research (Luschei et al., 2009).

Interview method

In total, I completed 15 semi-structured interviews with 9 additional follow-up field interviews in Yakima County. According to Huntington (1997), the semi-structured interview is typical for collecting both traditional and ecological knowledge. Through the semi-structured interview process, I was able to ask the same questions of all 15 participants but allowed the conversation to flow naturally. These interviews were held in-person (at the farm office, in conference rooms, in the farmers' trucks), and rarely over the phone. I recorded these interviews with an audio-recorder or my phone and took notes simultaneously.

Over 2/3 of the semi-structured interviews continued to the field. Using the same recording methods, we drove around to different sites, and discussed management practices *en situ*. Many farmers showed me their management equipment and their processing facilities to provide a greater representation of the extent of their farming knowledge. Conversations were more informal in this context, and farmers were able to express their soil health knowledge explicitly. Using both semi-structured and field interviews helped build rapport with the farmers and land managers, giving way to a more thorough interview process (Knapp & Fernandez-Gimenez, 2009).

Questions

Questions in the semi-structured interviews were categorized to address various aspects of soil health knowledge possessed by farmers and land managers (see Table 2)[23].

Number	Question	Category
1	What is your name, age, birthplace and occupation?	Demographic
2	How did you get into farming?	History
3	What is your farming history?	History
4	What is the geological history of the area?	History
5	What formal education have you completed?	Education
6	If you completed post-secondary education, what degree did you acquire?	Education

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[23] For a more in-depth discussion of the reasoning behind question selection, please see the Literature Review.

7	What is your definition of an agricultural community?	Community
8	Are you closely linked with other farmers or land managers? How?	Community
9	What does soil health mean to you?	Farming Identity
10	Can you describe your farming practices over a given period of time?	Farming Philosophy
11	What practices improve soil quality?	Farming Philosophy
12	What practices degrade soil quality?	Farming Philosophy
13	What do you look for on your land to determine the quality of your soil?	Farming Philosophy
14	What risks are involved with improving the soil?	Risk Aversion
15	What risks are involved with degrading the soil?	Risk Aversion
16	If money, labor or other factors were not an objective, how would you manage your land?	Risk Aversion

Table 2: Questions and categories for semi-structured interviews

Once all interviews were recorded and transcribed, I transferred all responses into an excel spreadsheet and coded them into 45 different categories; in so doing, I was able to find similarities, patterns and trends amongst the participants.

Soil fertility analysis

The second part of my thesis involved the quantitative analysis of 150 soil samples collected between November 2017 and March 2018. As part of the interview process, participants were asked to identify two fields, one they considered to be highly fertile and the other having low fertility. The question was left open-ended, allowing the farmers and land managers to interpret 'soil fertility' on their own; however, if the participant was unsure of how to define fertility, I indicated high or low organic matter content. Of the fifteen farmers interviewed, all but three drove me to the specific sites; the other three gave me verbal directions to the sites' locations.

Collecting surveys using GIS

Prior to meeting with the farmers, I assembled a survey on ArcGIS Online that aided in the spatial analysis of the fields. I used the Survey123 application and collected data at each vertex of the identified field. The survey indicated the farm name or farmer, which polygon was being created (high or low fertility), the vertex of the polygon, and the date of collection. The farmer or land manager usually drove to the high or low fertility site, and would either drive, or walk with me to different points in the field. At each vertex, I would stop, enter the survey information, and upload it to ArcGIS online for later review. Once all points for a specific polygon were created, we would move on to the next field.

Once I returned to Evergreen, I uploaded all points collected from my trip to Yakima. Either through ArcGIS Online or by using the ArcMap application, I adjusted points to create even shapes, and then created a polygon. Within the newly created polygon, I selected the 'random point generator' application within ArcMap. I specified the constraints, and 5 randomly generated points appeared in each of the polygons. I saved the survey points, the polygons, and the random points to a new map and published them to the Collector application on ArcGIS Online. The Collector App allowed me to use my phone's GPS to locate the random points within the specified fields. Based on the GPS device within the iPhone 7, the accuracy of my random point sampling is within 5 to 10 feet.

Soil sampling

Before collecting soil samples, I noted the temperature and climatic conditions of the location under observation. Depending on the sampling method used, results of soil sampling can vary greatly based on specific climatic conditions. In particular, physical properties, like bulking density, fluctuate with variable rates of rainfall and temperature. Mora & Lazaro (2014) found bulk density to be lower during summer months, and to vary greatly with rainfall. Bulk Density measures the weight (mass) of the soil by a specified volume and provides useful information to determine a soil's physical properties (Hossain et al., 2015). In addition, bulk density is strongly correlated with organic carbon content and is frequently used as a pre-requisite measurement for SOC (Grigal et al., 1989). According to Sollins and Gregg (2017), increased organic matter content results in decreased bulk density, due to the increase in volume, but the decrease in mass; however, not all fractions of organic matter are the same. Light fraction organic matter with a lower bulk density (<1.7 g/cm^3) consists of freshly decaying plant and animal material, while heavy fraction organic matter (>1.7 g/cm^3) has decomposed over a longer period of time and resembles soil minerals (Song et al., 2012). I collected 150 bulk density samples using two plastic PVC pipe 5 cm in length by 5 cm in diameter for a total of 107 and 105 g/cm^3. Once the general location of the random sample point was found, I selected a flat spot within the crop row; if a random sample point was to be collected in-between rows or in an alley, I selected the closest point within the row under cultivation.

To measure the effects of different types of soil disturbance, like tillage or other management practices, surface bulk density has proven to be a useful tool (Osunbitan et al., 2005). I collected samples in the top 10 cm; as surface depth increases, the light fractions of soil decreases. Although light fraction SOM makes up a small portion of total soil organic carbon (SOC), it has high turnover rates and fast mobility, meaning that it is easily altered by management practices, climate and soil texture (Song et al., 2012). Due to this high mineralization potential, I believe that nutrients are more readily available in this portion of the soil; therefore, I chose to measure the light fraction organic matter for the purposes of my study (Song et al., 2012). In addition, most biological activity, which includes the mineralization of N and decomposition of C among other nutrients, into forms that are usable by plants, occurs in this area known as the Rhizosphere (Lehmann & Kleber, 2015). The high decomposition rates and availability of light fraction SOM justify my selection of sampling in the top 10 cm of soil.

Because soil is technically anything smaller than 2 mm in size (Brady & Weil, 2010) and high levels of organic matter alter bulk density results (Sollins & Gregg, 2017), I cleared the top 2 to 3 layers of residue. One farm applied compost a month in advance, but because of the cold temperatures (which inhibited organic matter mineralization), I was able to remove the visible residue before sampling. By removing surface residues and compost, I could collect samples from the surface of the A horizon, which contains mineral particles, humus and organic matter. Once the ground was cleared of residue, I placed the PVC pipe on a near-flat spot. With a rubber-headed mallet and a wooden block, I was able to pound the PVC pipe into the soil (Hossain et al., 2015). Based on soil texture, organic matter content, saturation level, temperature, and physical structure, some samples were extremely difficult to pound into the soil while others packed easily (Mora & Lazaro, 2014).

Similar challenges arose during the extraction process based on the characteristics listed above. One sample was so densely packed, I needed assistance from the farmer (the site was also where their cattle frequently roamed, a clear sign of compaction (Castellano & Valone 2007) to transfer it to a Ziploc bag. The samples were extracted using a hand trowel. To collect an intact bulk density sample, all soil within the fixed volume was transferred to the Ziploc bag for measurement. To prevent incorporating soil not collected using the PVC pipe, I pulled apart peds that were extracted with the sample and wiped the outside of the sample with a piece of cheese cloth or a paper towel. I made sure the sample was flush on both sides and removed any organic material that protruded from the edge of the pipe. The sample was then pushed into a Ziploc bag labeled with the specific field and random sampling point. In total, I collected 150 soil samples using the bulk density sampling method described above. In order to prevent the mineralization of nutrients or organic material, I stored samples at a temperature between 1.7 and 4.4 degrees C (35 and 40 degrees F) (Moinet et al., 2018).

Oven-drying

Based on the Burt (2009) air-drying soils is standard procedure for most soil analyses. Drying soils at a temperature between 30 and 35 degrees C (the air-dried method) is ideal because of the optimum moisture content achieved, the relatively constant weight maintained, and the low biological activity that occurs during storage. Storing samples once they are air-dried is also a pre-requisite to carbon and nitrogen analyses (Burt, 2009). Samples were dried using a lab-grade drying oven. Depending on the texture, level of saturation, as well as type and degree of vegetative cover of the soil sample, the drying time lasted between 3 to 7 days (Amani et al., 2017). All samples were then returned to their original Ziploc bag for further analysis.

Prior to drying, the samples were weighed twice: first inside of a pre-weighed Ziploc bag, and then in a pre-weighed ceramic or Pyrex vessel. After drying, the samples were weighed again. As mentioned earlier, soil is technically any mineral, humus or organic material smaller than 2mm in size; because of this, samples must be run through a 2mm sieve to extract all mineral soils. Once the samples were sieved, both the soil and the larger objects were weighed separately. I noted what objects were larger than the 2 mm sieve (such as rocks, organic material, insects, crop residue, etc.).

With the weight of the sample before and after air-drying, I calculated bulk density. To calculate bulk density, the two equations below must be used:

Soil bulk density (g/cm^3) = weight of dry soil sample/volume of core

Volume of core = π(3.1416)r^2 x h

R = radius of core; h = height of core

Volume of soil cores: 105 cm^3 and 107 cm^3

The measurements were recorded and the samples were returned to their original storage containers for further analysis.

Carbon and nitrogen analysis

To better understand the availability of nutrients to plants, farmers and land managers frequently monitor their carbon to nitrogen (C:N) ratio. Both carbon and nitrogen are essential elements for plant growth; carbon supplies carbohydrates, lipids, and other sources of energy, while nitrogen provides proteins and other compounds that enhance plant growth (Perkin-Elmer, 2010) The more nitrogen that's available within an amendment, the more rapidly it will decompose. For example, poultry manure has a very high content of nitrogen, an average C:N ratio of 8:1 (Weerayutsil et al. 2016), while straw has a much higher Carbon content, rendering a C:N ratio of 80:1. The optimum ratio that soil microbes require to stay alive healthy is 24:1 (NRCS, 2011). Therefore, amendments should be added in appropriate proportions to meet this requirement. Both carbon and nitrogen are essential components of SOM and can be added to the soil in various forms. Because they are so necessary for plant and microbial health, I measured both elements using and CHN analyzer.

Before CHN analysis, samples were homogenized using a mortar and pestle to break up any remaining aggregates or organic matter. To further prepare samples for CHN analysis, they were weighed using the Perkin Elmer scale. Samples were measured into a small tin vessel at weights ranging from 1.7 to 2.3 mg. The Perkin Elmer 2400 CHN Analyzer measured C and N amounts in each soil sample. Using the Dumas method of combustion, soil particles are combusted in the presence of oxygen and are converted into simple molecules like CO_2, and N; once these elements are simplified, the gases are separated using chromatographic methods (PerkinElmer, 2010). The chemical analysis of C and N were output to database software, which automatically calculates the percentages of C and N per sample.

Interview and soil data integration

In order to identify what demographic or cultural factors influence a farmers' soil health knowledge and whether or not this influences overall soil health, it was necessary to synthesize my interview results with my soil sample analyses. First, a distribution graph compared the values of all three measurement techniques (bulk density, % carbon and % nitrogen) to test whether or not they were accurate measurements for organic matter content. Through a paired t-test, comparisons between high fertility and low fertility sites were conducted to identify significant differences between the three indicators measured: the mean of BD, %C and %N. Next, basic demographic characteristics of farmers that ‘accurately’ identified high and low fertility fields based on the given parameters were analyzed. In addition, comparisons between all three variables were conducted concerning the type of crop grown in the sampled field.

As a preliminary step, I conducted a Multiple Regression Analysis (MRA). This method of data analysis was used to find causal relationships between the soil health indicators measured and the 8 categories of interview responses (demographic, history, education, community involvement, farming philosophy, farming identity, and risk aversion). I ran MRA comparing categorical variables with multiple responses (age, crop type, types of certification, etc.) with continuous variables (Bulk Density, %C and %N) in order to find preliminary correlations. All six soil sampling variables (High Fertility and Low Fertility BD, %C and %N) were compared to the 39 coded responses to interview questions using a binary system for categorical analysis. 0s and 1s indicated presence or absence of the variable for up for up to 10 different variables per category, depending on the question.

The fields that yielded significant correlations from the MRA (crop type (management practice), certifications (farming philosophy), work with private consultants (management practice), connections (community involvement), and dream farm description (risk aversion)) were further analyzed using an analysis of variance between no more than two variables. For crop type, for example, the crops with the best indicators of soil health (low BD, High %C and %N) were compared against the other crop varieties in a two-way t-test. Using a similar method eco-labels like Global GAP, Salmon Safe and Organic were combined and compared with farms that did not have such certifications to see if more information could be interpreted from the significant correlations. Finally, to test my hypothesis, that older farmers born into farming families that were also well connected to their communities had better soil health knowledge, and subsequently better soil health, I used ANOVA to compare interview responses with soil health indicators measured.

Methods summary

Integrating both qualitative and quantitative analyses provides a more in-depth understanding of the social, cultural and ecological information within a given area. Through interview analysis, I developed an understanding of the basic demographic, history, education, farming philosophy and identity, and aversion to risk of the participants in the study. Using this method, I could better understand what their soil health knowledge was, and where that knowledge originates. On the other hand, conducting soil analysis to measure bulk density, percent carbon and percent nitrogen provides information on the amount of organic matter in the soil and the overall health of the soil at a depth to 7 cm. By comparing these two results, we can see if any social factors contribute to an individual's soil health knowledge, and how well this knowledge compares to established indicators of soil health. This can provide insight for research and farmer outreach, illuminating how farmers gather and transmit information, what information is well-known, who are the most informed, and what areas require more exploration and emphasis from public and private institutions.

Chapter 4: Results

The interviews, conducted between April 2017 and February 2018, yielded interesting results; although many discrepancies were observed concerning farmers' demographic information, education, community involvement and local historical understanding, the overall farming philosophies and risk aversion were quite similar. It has been observed that the tacit knowledge possessed by farmers is not easily communicable from one actor to another; knowledge is largely transferred through teaching, experience and in-the-field observation (Hoffman et al., 2007; Jensen et al., 2007). Therefore, I must clarify that these responses cannot express the entirety of the participants' knowledge and understanding of farming, but they are intended to give a general idea of what information can be transferred in a short semi-structured interview.

The following section summarizes the results found within the seven categories (Demographic information, Historical Understanding, Education, Community Involvement, Farming Identity/Philosophy and Risk Aversion). The Demographic section analyzes how the farmers interviewed compare to USDA Census data for the Yakima region. Their education and type will be addressed, as well as how farmers perceive this impacts their soil health knowledge. Participants discuss different trusted sources of information, from more intimate Communities and Networks of Practice to larger public and private institutions known as Webs of Influencers (Oreszczyn et al,. 2010). The Conservationist-Productivist dichotomy will be expressed in detail, and the diversity of farmers responses will indicate that this simple partitioning does not accurately represent farmer identities; in addition, farmers understanding of the impacts of specific management practices on soil health, as well as their knowledge of established indicators of soil health, will be discussed. Finally, an analysis of farmers' perceived risks with management practices will be considered, as well as an explanation of how fluctuating markets greatly impact farmers management decisions. This section highlights that farmers view themselves largely as stewards of the land, and that each farmer, farm system and farm community should be valued as a unique entity operating within a complex ecosystemic network.

Interview results

Demographic information

Compared to the 2012 US Census data of farmers in the Yakima Valley, the results are somewhat representative of the total population of Yakima farmers (USDA NASS, 2012). The average age of farmers in the area is 58.7, which is similar to the findings of my study. 8 were born or raised in the valley, and 7 were born elsewhere (California, Oregon, Florida, Montana, Mexico and New Zealand). 80% of the respondents were male, totaling 12 individuals, and 3 participants were female. All but one participant grew up on a farm of some sort, but variation can be observed in the generations of family farmers. 9 participants discussed farming for at least 3 generations, 4 have farmed for at least 2, and one participant was the first in her family to farm, and for over ten years. In addition, 3 farmers or land managers interviewed were not principal owners.

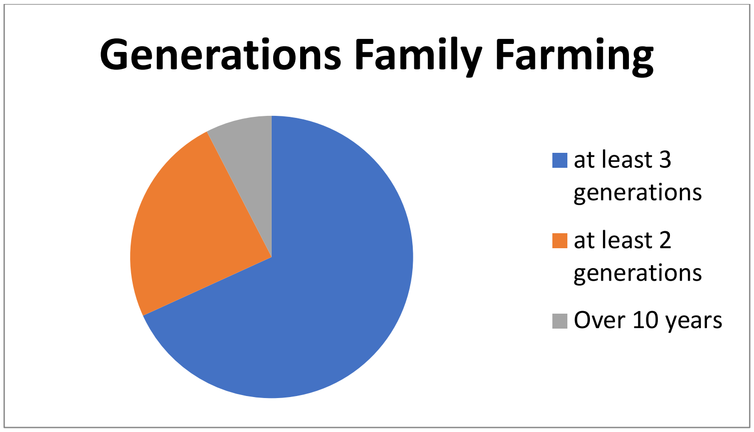


Figure 6: Pie chart of participants' family farming history

For the 3143 principal operators in Yakima, 317 were female (representing 10% of the population); in my study, 20% of the population were female, which was slightly higher than the county average. There was very little racial or ethnic diversity within my sample, with one farmer of Latino descent and one Japanese-American. This was somewhat representative of the total population, with 0.8% of Asian descent; however, 17.4% of the total population of farm operators were of Latino or Hispanic descent, compared to less than 7% in my study. Other ethnicities and races not considered in my study include: American Indian or Alaska Native (1.7%), Black/African American (0.2%), and Native Hawaiian/Pacific Islander (0.15%) (USDA NASS, 2012)

Age, education and experience

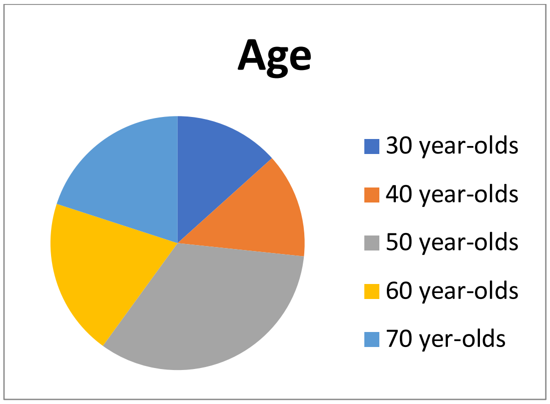


Figure 7: Pie chart of participants' age distribution

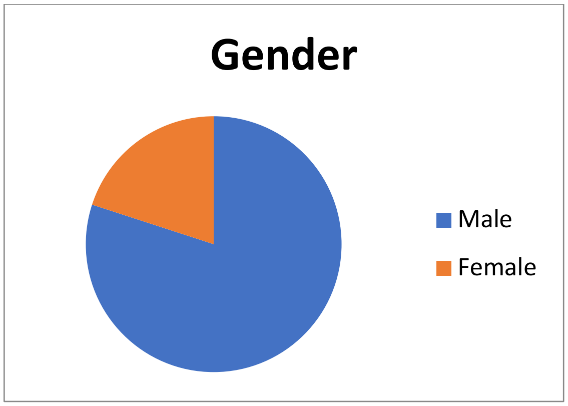


Figure 8: Pie chart of participants gender distribution

As previously discussed, Burton (2014) explains that isolating individual demographic factors like age, education and experience does not provide useful insight into what influences farmers' implementation of agri-environmental or conservation practices. Instead, the author explains that a complex interplay of factors, in particular, age, education and experience, provide more information into farmers' management decisions. For example, age in relation to education can explain the 'cohort effect', where age serves as a direct representation of experience. In addition, education and experience are related, since both are bound by social capital within their respective farmer groups (Burton, 2014). Although this approach is useful and provides a more well-rounded understanding of the complex factors that make up a farmer, I have considered these factors for the most part in isolation.

Education and ways of learning

The educational background of each farmer ranges from the completion of a master's degree to less than an elementary school education. 3 participants have completed, or are in the process of completing, post-graduate degrees; 6 participants have attained undergraduate degrees. 5 have completed some form of post-secondary school, and only one participant has no college education.

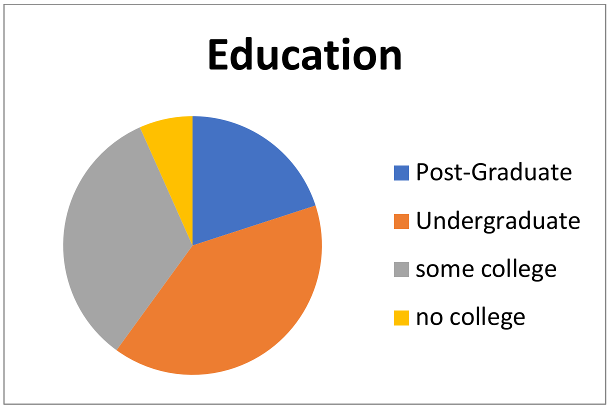


Figure 9: Pie chart of participants' type of post-secondary education

Of the 14 participants, less than half (43%) studied an agriculture-related field. The areas of study include: crop science (2), general agriculture (1), agricultural economy (1), agricultural engineering (1), sustainable food systems (1) and ranch management (1). The non-agriculture fields include: business management (2), environmental studies and geology (1), environmental policy (1), construction (1), hydraulic and mechanical engineering (1) and Slavic languages (1).

Due to the wide range of educational pursuits, it was necessary to figure out other ways that the farmers and land managers gained knowledge. One participant believed leaving the industry for a while was one of the best decisions he made: "Then I decided to take business, I thought I'd probably farm, and so, actually getting away from the agricultural climate… So my education was part of it. But a bigger part was just getting away from agriculture. And not being in that same rut." Over half (53%) of farmers described methods of experimentation and analysis, either by experimenting with new crop varieties, management practices and techniques, or even creating replicated trials with controls. A few others also use outside resources like the internet (2) and books (2).

As previously discussed, experience plays a huge role in the knowledge acquisition of farmers. All of the 15 participants described some form of trial-and-error used in their farming practices.

"I learned more just from the experience than what I did in college"; at least two participants shared this perspective. Within this experience-based knowledge, 1 farmer explained that his observation of natural systems highly influenced his farming mentality, while another explained that his experience in the university setting formed the basis of how he farmed. "…you know us guys that have been doing it for years and years, we just automatically do our thing"

It is of value to consider the role that 'intuition', 'instinct' and 'feeling' play in farmers' day-to-day actions. As previously discussed, 'intuition' is the automatic response to a series of events based on previous experience with similar situations (Burton, 2014; Nuthall & Old, 2018). At least three farmers specifically described the important role that 'feelings' and 'instinct' play in their farming practices. "… if you've farmed and watched the soil and watched your plants and learned about them, it's kinda like I can do all the analysis and do all the book work and all the extension stuff, but I can nail it quicker with my gut, and actually come out better. It's part of growing things."

Spirituality, and the role of God within agriculture and soil health was also discussed explicitly by 4 participants. One farmer explained that soil degradation was a sin, and that farmers are nothing more than stewards of the lord's earth, and her goal is to leave it in better shape than she found it. One agronomist for a hop grower defined soil health and its relationship to God: “To me, it’s a very complex biological system and I think it was designed by God… And soil health would be if it was operating how God had it in mind.” In addition, one farmer explained that his Buddhist upbringing plays a major role in his decision to farm organically.

Another commonly-discussed method for gaining knowledge was to speak to knowledgeable members of the community, specifically within certain crop producer groups. Less than half (43%) explained that much of their knowledge came from their fathers, grandfathers, and other knowledgeable farmers. “My father is still very involved, and so you know, just learning a lot through him. As many giants and other people I can glean information from” (JS). This quote suggests that many farmers gain information from more family members or other older, experienced farmers in the area. This belief agrees with Iniesta-Arandia et al. (2014), who found that the knowledge acquisition of local ecosystems within farmer groups is greatly influenced by the family in which they were raised. “…things my dad did, my grandfather did, but also I watch my neighbors… because different people do a lot of different things. Because they’re not growing the same crops, they’re still farmers” (LI). This farmer expresses different ways of gathering experience and knowledge, and also suggests that farmers work with each other, as family members, neighbors, or members within a community, to create and disseminate information. The role of trust within farmer groups will be discussed in the next section.

Sense of place and connection to the land

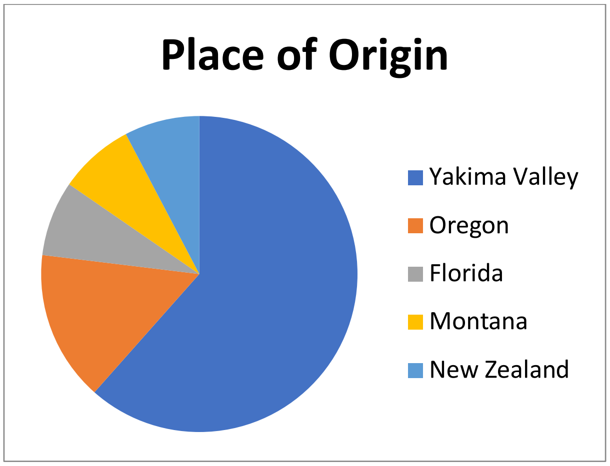


Figure 10: Pie chart of participants' place of origin

As expressed by Mullendore et al. (2015) Sense of Place theory is an expression of an individual's dependence on their land, and how this existentially-based relationship informs an individual's sense of identity. In order to address this point, I asked farmers to identify their place of origin; in addition, I asked farmers to explain the geological or social history of the area as a way for them to express their connection with the history of the land itself. Over half of the participants were born or raised in the Yakima Valley; one third of the sample size inhabited the area for at least three generations, with many farming families dating back to the turn of the 20th century. "We've been farming this particular piece since 1935 when my dad bought it from his father. So, it's been in the family for close to 100 years. I'm not sure the exact date my grandfather purchased it, but. I think our family came to this area in about the mid-1880s."

Almost all of the farmers born into farming families in the Yakima Valley expressed extreme interest in the geological history of the area. While others not born in the valley were also knowledgeable of the area's geological history, it is possible that their deep connection to the land (as expressed by the Sense of Place theory) combined with an interest in the geological formation taking place over millions of years throughout Yakim,a may have encouraged their interest. One farmer studied geology in college and was able to inform me of the actual geological processes the created the soils of the area. "For our specific area of the hill where we farm, it's actually really cool because it used to be flat. [There was] a river that went through it and there was North-South compression, and so, actually, on top of Snipes Mountain, you can see all the river gravels, you can see which direction the river was flowing." In addition to the geological processes responsible for the formation of the soils of the area, many farmers described in detail the social processes that influenced the agricultural development of the Yakima Valley.

Social history

Some farmers, particularly those whose families have farmed in the area for at least three generations, described the social history of the area. One farmer explained that his family was helped establish the hop and apple marketing orders in the area. Another farmer, a Japanese-American, described in detail the immigration of his grandparents to the region, and how they contributed to the agricultural development of the area.

> "…[A]nd so my grandfather was recruited to come from Taiwan because he had a degree from the imperial agriculture college… The ag department recruited him to come here and teach Japanese immigrants on the [Yakama] reservation to farm, and he came in [19]07. And I think the Japanese immigrants are credited with breaking over 20,000 acres of ground of sagebrush on this reservation. So, this area is called 'the bench'. ..This irrigation canal that goes behind us is the 'Wilbur Ditch'; was dug by Dave Wilbur, or his father I can't remember. He's a tribal member, but he was my grandfather's neighbor… So my grandfather came to the bench. And this was like the best dirt on the [reservation], because its on the bench, while everything down [the slope] is full of rocks… the term [my grandmother] used was 'Yama no Tegumi'. 'Gumi' means people, Yama is hill: 'The people on the hill'. And so, I think they probably bragged that they were the big farmers. The guys down on the lower hill areas typically had smaller farms."

Within the socio-cultural description of Yakima's history, this farmer explains his ancestors' understanding of the soil quality in the area. Another third generation Yakima farmer described the process of “nob-knocking”, where farmers cleared remnants of geological history to improve the agricultural capacity of the land. “…when the farms were made, there may have been a little ‘nob-knocking to even the general slope. And as you take the original topsoil and move it to another spot, what happens to that spot with no topsoil? You probably have less organic matter. And it takes years and years to recover from that.” These interesting historical accounts of the influences of human settlement helps inform the farmer and other interested parties of the soil types, textures, and quality of the region.

Trusted networks: From communities and networks of practice to webs of influencers

As previously discussed, farmers depend on a variety informational sources regarding new and existing farming practices. Expanding from more intimate communities of practice, more loosely-connected networks of practice and somewhat restricted webs of influencers, farmers rely heavily on the communities and influencers that they work with regularly (Oreszczyn et al., 2010). According to one study, farmers more closely resemble Networks of Practice due to their wide distribution of multiple smaller stakeholder. The authors also suggest that few farmers rely on members of their communities of practice for knowledge acquisition, even if they are tightly bound (Oreszczyn et al. 2010). Of all farmer networks, the Webs of Influencers, specifically trusted individuals within larger private and public institutions, hold the most sway over the implementation of new technologies and practices (Oreszczyn et al. 2010).

The following section considers how different group interactions described previously influence the practices and motivations of participants within my study. I will first explain how farmers defined their agricultural communities, and how connected they felt to others within their social groups. The different networks of practice and webs of influencers will be described next, and I will explain how my results compare to other studies.

Communities of practice

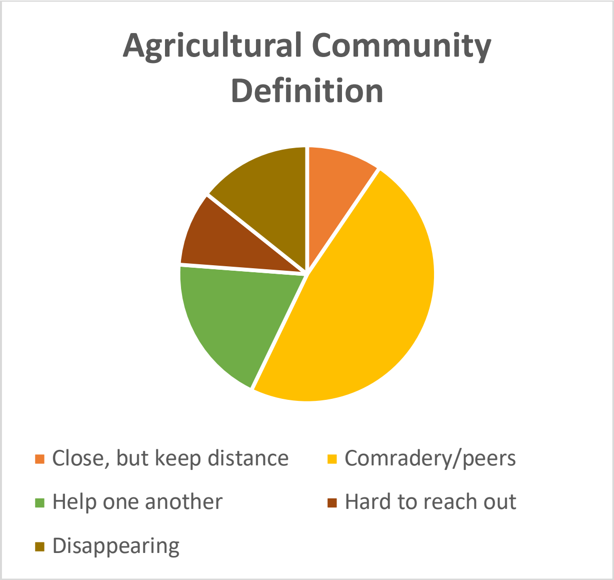


Figure 11: Pie chart of participants' definition of an agricultural community

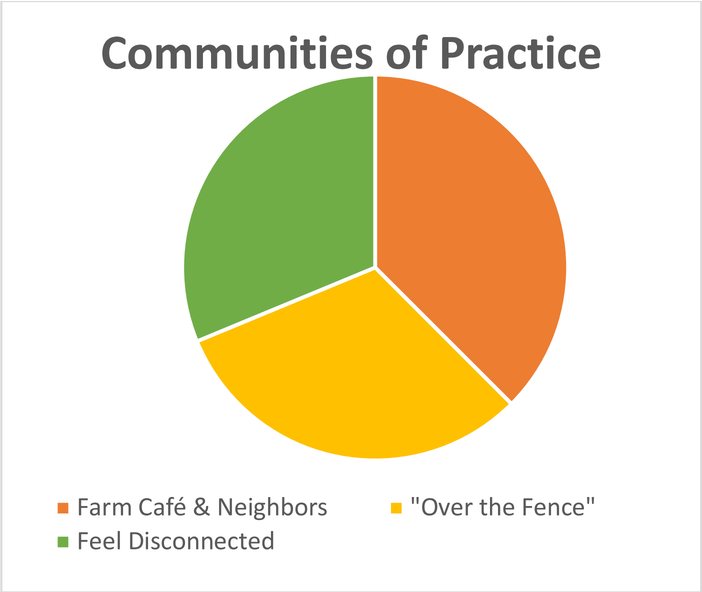


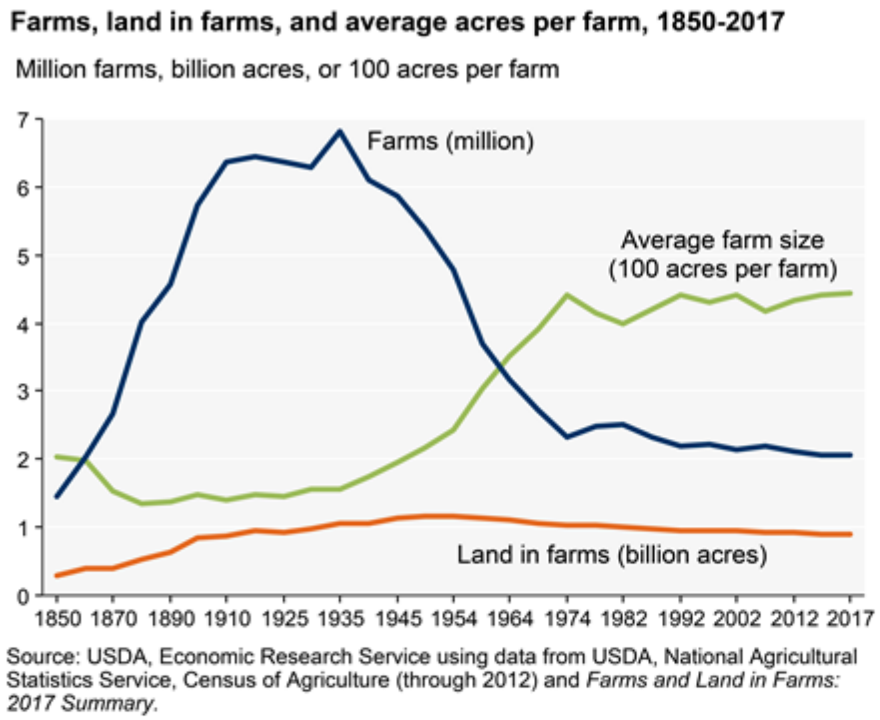
Figure 12: Pie chart of how participants' connect with each other

Differing perspectives arose within the participants' involvement and understanding of agricultural communities. The majority (2/3) of the farmers and land managers explained that they relied on other farmers and neighbors and described a sense of comradery within agricultural communities. As elucidated by one farmer, "…we tend to view ourselves not as competitors but on equal footing. Usually we're quite open about sharing information… It's really pleasant to have coffee with fellow growers and become friends over time." Two farmers explained that farmers keep close connections with their neighbors but recommend maintaining a maintaining an individual identity. "It's vitally important, but you can't let it dictate you. You have to think outside the box. The biggest asset of the agricultural community is also the biggest problem. So, if you just start doing, just copying what everyone else is doing…that's the problem."

Four farmers provided examples of how they receive help and support from others in their agricultural communities. "[In Harrah], really old farms… you're 70 to 100-year-old farms out here. And a lot of its because we take care of each other. I'm not over it. My neighbors sabotaging the operation and I'm helping him. You know, if you need equipment, you just come over and borrow my equipment. I'm not renting it to you." The specific examples described involved of droughts and fires, and the support that they received during hard times. "When our barn burned down, we had all of our neighbors bring us hay to feed our cattle. We had our church give us a $5 thousand-dollar donation. It's the mentality of your neighbors and friends that all pull together to help you in times of need".

Not everybody has developed strong connections, though. At least two farmers felt a lack of meaningful relationships, either due to their far proximity to other farmers, or their short time living in the area. As clarified by one farmer, "there's farmers that just know everybody. It's just like people. Some people are just outgoing, some people are more introverted." (JS). This information supports Hatch (1992) who suggests that the less frequently farmers interact with other farmers, the less likely they are to achieve social capital; they therefore are not considered to be ‘good farmers’.

In addition, at least three farmers explained that the agricultural community model is falling to the way-side, in favor of bigger and fewer farms. “…fewer and fewer people are going to be working on farms, and fewer and fewer people are going to be living in rural areas.” (AS). As expressed in Graph 1 the number of family farms have decreased drastically over the past 75 years, while the size of the farms has increased significantly. Interestingly, the amount of land under cultivation has stayed the same.



Farms, land in farms, and average acres per farm, 1850-2017

Million farms, billion acres, or 100 acres per farm

Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Census of Agriculture (through 2012) and *Farms and Land in Farms: 2017 Summary*.

Figure 13: Graph depicting how farms, farmland and average farm size have changed over the past 150 years

(Dmitri et al., 2005)

In regard to communities of practice. Six farmers described regular attendance at some local gathering place like a farm café. Of these 6 farmers, 5 of these individuals have attended the same farm café for decades on a daily basis. There are some (1/3) that rely on direct relationships with their neighbors, or “over the fence” interactions as some put it. Even so, at least 5 explained that they lacked meaningful relationship, either with neighbors or growers of the same crop, and wished they had more connections.

According to Hatch (1992) social standing and involvement within agricultural communities influences how farmers are perceived by members of their community as ‘Good Farmers’. If farmers are within close proximity to each other, they observe and compare their land quality and practices to each other. Over half compared their land and practices to their neighbors. They described prominent people in the community, what has and hasn’t worked for their neighbors, and the status of their ground. When describing different tillage practices, one farmer compares his methods with his neighbors: “Now Lon plows ‘em and he has a reason for it. He’s raising vegetables and he doesn’t want any trash (residue) on top, so they way to get rid of it is to plow it under. With our mint root, it thrives with loose soil right on top with organic matter. And this helps to hold moisture so. Neither way is wrong, it’s just not the best practice for some purpose.”

Networks of practice and webs of influencers

My next step in identifying areas of knowledge transmission and collection concerns the webs of influencers, or the various organizations, governmental, university and private resources utilized by the farmers and land managers within this study (Oreszczyn et al., 2010). All 15 farmers described some sort of assistance or connection with an outside organization: 1/3 are members of marketing orders, at least 4 attend crop-specific conferences, 2/3 use university extension and outreach and 1/3 work with NRCS. Other groups include Tilth Producers of Washington, a non-profit based out of Seattle that creates connections between organic producers throughout the state, and the South Yakima

Conservation District, which connects growers with private, governmental and university specialists on natural resource conservation in the Yakima Valley. In addition, at least 6 farmers described relationships with local chemical companies or private agricultural consulting firms as a point of reference for soil health management.

Networks of practice are more loosely-bound groups or organizations that connect a variety of stakeholders with similar interests or live within a given region (Oreszczyn et al., 2010). The networks of practice described by participants were: marketing orders, conservation districts, crop or management-specific conferences and trade shows, or other organizations. According to the USDA, marketing orders connect producers within fruit, vegetable and specialty crops so they may "leverage their own funds to design and execute programs that they would not be able to do as individuals" (USDA, 2018). While some studies have found that marketing orders have not stabilized crop prices, others suggest that specialized crops may show some economic benefit from their participation in marketing orders (Jesse & Johnson, 1981; Williams et al., 2008). As discussed in the social history section of this paper, apple and hop marketing orders played a major role in the development of agriculture in the Yakima area. Some of the farmers and farms represented in this study founded these marketing orders, like Hop Growers of America, Sage Marketing, Olympic Fruit Company, and Bluebird, Inc.

Crop-specific and agricultural trade shows were also mentioned as places of learning for some growers. For those in the valley that grow specialty crops, or are not in close proximity to other farmers, these events offer means to meet with producers that may face the same issues. Valuable insight can be gained that may not always be easy to figure out by oneself. One farmer, who attends the annual Washington Association of Wine

Grape Growers annual meeting says that: “there’s always researchers giving presentations, and some of them are pretty good. I really latch on to farmers that are really doing stuff practically. This is what we’re doing and its working”.

Oreszczyn et al. (2010) identified Webs of Influencers as the most influential source of information on farmer practices. Interestingly, Stuart et al. (2018) found that farmers valued fertilizer recommendations from private sector chemical companies or agricultural consultants over public-sector recommendations; in addition, these same farmers expressed more trust in individuals as opposed to specific public or private operations themselves. Luloff et al. (2012) found that farmers were more likely to implement new technology, like conservation tillage, if a trusted tractor supplier, like John Deere, offered implements that farmers could use.

Although at least 10 farmers described connections with local extension, the majority interact with them on a limited basis. 4 farmers work with them strictly through on-farm experimentation and analysis. For instance, one hop grower is currently working with OSU to identify the relationship between mildew and the application of nitrogen fertilizers. Additionally, the Mint Industry Research Council works with WSU to conduct experiments on optimal growth in conjunction with chemical use, pesticides, herbicides and efficient harvesting processes. Some of the participants believe that University and Extension isn’t fit for their operation. “I think that’s more for smaller farms or guys that got a couple acres or people that move to this area and don’t know anything about it”. These findings are supported by Luloff et al. (2012), who found that many farmers consider university and extension to be unreliable sources of information due to conflicting regulations, inconsistent agendas, insufficient technical assistance and lack of funding.

On the other hand, at least three farmers cited close relationships with university extension offices; one farmer is closely connected with university and extension specialists because his agricultural experience largely originates in the university setting. "I am very tightly linked with university specialists. And I do that because I know the system… I'm in contact with the people at WSU and OSU, but in the past, I've used extension a lot and I used any written publications that they have as a starter place". As suggested by Luloff et al. (2018), these individuals may have close and trusted relationships with specific individuals within the public sector or may have worked within these organizations previously and have an insider's understanding of how they work.

The United States Department of Agriculture's (USDA) Natural Resource Conservation Service (NRCS) works to "help people help the land" (NRCS). Interestingly, less than half of the participants worked with NRCS at all; and more than half of these individuals that work with NRCS do so on a limited basis. 4 of the farmers and land managers I spoke to used funding from the NRCS Environmental Quality Incentives Program which provides funding to farmers who implement voluntary conservation practices (NRCS). ¾ of the farmers utilizing EQIP funds developed a drip irrigation system, while the other participants used the money to install hoop houses. Other incentives provided to farmers include the implementation of cover crops, improving forest stands, and prescribed grazing for livestock operations (NRCS).

Curiously, some studies found that farmers are considered to be suspicious of government involvement in their operations (Oreszczyn et al., 2010; Greiner & Gregg, 2011). While the question of trust in governmental programs was not specifically addressed in the format of the interview, one participant believed that other farmers were apprehensive to working with government officials because they were unfamiliar with how the system worked. Although more than half of the farmers had no or limited work with government agencies, this does not suggest that all farmers lack trust in governmental intervention because of a lack of understanding of how the system works. Similarly to Hijbeek et al. (2018) and Greiner & Gregg (2011), I would suggest that these farmers feel that current policy doesn't satisfy their needs and that their needs are not well-understood by policymakers.

Over half of the individuals cited issues with labor, and how increased minimum wages hurt their bottom line. One farmer discussed in great detail current legislative appeals and that because they were not created by farmers, they could not effectively serve farmers.

> "I think that there are pending things like that, I'm sure you've heard of the regulation that was in the senate last week, two weeks ago. And they wanted us farmers to provide 4 days notification before we spray. That's impossible, if there's a rain event, we need to go now. We can't go, 'oh four days from now there will be a rain event… there's some things we have to do right when they happen and that are weather dependent. You don't know four days ahead of time if there's going to be a wind. It did not pass, it was shot down. So that kind of stuff is ridiculous, and if they want to buy food out of the US, that's what they're going to do because we can't farm that way. Nobody can" (CD).

This quote suggests a disconnect or lack of understanding of farmers' needs by policymakers.

Other groups that farmers work with are private companies, like chemical distributors and agricultural advisors. Although almost half did not describe such relationships, at least 40% spoke in detail about their connections with fertilizer and pesticide distributors, while 4 people discussed having assistance and advising from private local consulting firms. Of the 6 that described relationships with chemical companies, two use a local dealer like

Husch & Husch, a fertilizer company out of Harrah that was founded in 1935, while the other 4 work with large national corporations like GS Long, Wilbur-Ellis and Simplot.

The services utilized by the participants from these companies varied, as well. 3 of the farmers have soil samples analyzed and receive fertilizer, pesticide and herbicide input recommendations. On the other hand, some farmers may purchase chemicals from larger distributors, but would not take input recommendations from them directly. "…we work with chemical companies, to a point. We would work with them to say what pesticide vs. another and as far as compliance things and regulation. But as far as what to apply, when to apply it, we don't usually… I don't get any commission based on the amount of chemicals we apply". Another farmer explained that even with organic inputs, the game is still the same. "My point is that I learned that people that are in the industry that are promoting the chemical use or whatever, it doesn't matter if its organic or conventional, they're promoting products and that's what they sell, and that becomes the norm and the industry standard, and that's not correct".

While some farmers expressed trust in their chemical representatives, others chose not to trust fertilizer recommendations coming from these sources, with an understanding that chemical dealers are salespeople that must make a profit themselves. Luloff et al. (2012) and Stuart et al. (2018) suggest that farmers trust specific individuals in chemical companies that they've worked with over a long time and on a regular basis. Many of the farmers articulated a similar sense of enduring trust with these individuals, especially with the local fertilizer company Husch & Husch. Many farmers who live in the farm town of Harrah grew up with the individuals that represent Husch & Husch and trust their recommendations. "My grandfather's buddy, Pete Husch, was one of the first guys to get into the fertilizer business. And my grandfather used to go with Pete Husch to Mukilteo and work in the lumber mills in the winter. And they were buddies, they went to the Yakima river and fished". Results from these interviews support the belief that farmers may have some trust in larger institutions but develop a more particularized trust with specific individuals.

In summary, the farmers interviewed connect with other groups through the Communities of Practice, Networks of Practice and Webs of Influencers described by Oreszczyn et al. (2010). While many farmers described intimate interactions within their Communities of Practice, some felt disconnected with other farmer due to a number of reasons; this can be explained by the value of social capital, and one's frequency of interaction and proximity to given agricultural communities. Many farmers also participate in Networks of Practice but receive much of their information from the larger Webs of Influencers (Oreszczyn et al. 2010, Luloff et al. 2012, Stuart et al. 2018). While farmers worked with both public and private institutions to gather information concerning soil health and land management, trust in both types of the over-arching institutions themselves was limited; many expressed trust in specific individuals, confirming the findings of both Luloff et al. (2012) and Stuart et al. (2018). While social capital has been discussed, the next section analyzes how farmers form specific identities, and how these identities inform their farming philosophy.

Farmer identity & farming philosophy

Farmers' identity informs their soil health knowledge and impacts their farming philosophy and subsequent management practices (Lobry de Bruyn & Abbey, 2002). The results from this study show that all farmers view themselves as stewards of the land and express this ethic through different farming practices. Because every farmer, farm system and farm community is unique, there is no prescriptive on-size-fits-all formula to sustainable land stewardship. Three issues illustrate this complexity: 1) the presence of weeds, 2) the amount of trash (crop residue) left on the fields, and 3) perceptions on organic agricultural and the implementation of these practices. Farmers' identity influences their definitions of soil health, including physical, chemical and biological processes. I will then consider what crops farmers choose to grow, how they perceive and execute specific sustainable management practices, and will provide insight into how the implementation of these practices as informed by their farming philosophy.

Weeds: Beneficial or a nuisance?

Weed pressures are a common stress for any farmer. My results show that farming identity informs management philosophy and can be represented in how farmers perceive and treat weeds on their land. According to Burton (2014), education, age, and cohort effects can influence one's impressions of weeds. According to the author, some studies have shown that older farmers view weeds as a nuisance and believe that clean fields are in keeping with good agriculture. On the other hand, younger farmers with higher education have been found to implement more conservation-minded practices and recognize the benefits that weeds and crop residue can have for their soil (Burton 2014). Some would argue that this point represents the Productivist/Conservationist ideologies (Carolan 2005). In my study, farmers expressed different perspectives on the value of weeds depending on the needs of their operation.

Two participants clearly defined weeds as unwanted plants; however, one of them is a staunch believer in organic agriculture, while the other has a more nutrient-focused perspective; the organic farmer is younger than the nutrient-focused farmer and has a master's degree in environmental science and policy. The first farmer currently grows alfalfa and hay for organic dairies and has been informed by the dairies that purchase her hay: "I want the salad bar. That's what makes my cows happy". As a certified organic producer, she frequently compares her perspective to 'conventional' growers and believes that conventional dairies, on the other hand, prefer a monoculture, not a biodiverse platter.

The second farmer grows mint, which requires additional processing and distillation to extract the essential oil; therefore, any trace amounts of weeds is undesirable, and may result in a lost profit. "Now you notice you don't see any weeds in our field. Weeds also have an oil in them. Different weeds have them, some have an oil some don't. But usually, they'll impart a flavor to the oil that you don't want. So, we try to keep our fields clean". Although the two farmers have the same basic definition of weeds, one's customers prefers their presence while the other will lose profit if there are weeds in his crop. Burton's (2014) findings concerning age and education as indicators of can be supported by these findings; however, this one factor does not justify the ideological divide between Conservationists and Productivists, since extrinsic factors like purchaser and market preferences also influence this perspective and initiatives to deal with weeds.

Another farmer uses the presence of weeds to indicate poor quality soil. As another mint grower, his profits also depend on having as few weeds as possible. While this farmer must also combat weeds with the heavy use of herbicides to turn a profit, his use of weeds as an indicator of poor soil health is supported by other farmers who view weeds as beneficial to soil health. One farmer explains that the presence of weeds is fundamental to nutrient cycling in the soil and believe that they do improve soil health.

> "… when you have bare ground, nature wants to fill it with something. So its weeds or its what the farmer doesn't want… Now we've been trained to think in agriculture, farmers that weeds are bad and they're stealing your water and your nutrients. And they are taking nutrients and water, but I think they can be managed. And I think that we've got excess nutrients and water than we can allow the weeds to use, and I see them as a nutrient cycling aspect of the system. So they're capturing nutrients and if we then mow it or at some point till it back into the ground, we are facilitating that nutrient cycling…"

Essentially, weeds are able to take up nutrients and water from the soil, but if weeds are re-incorporated, nutrients can be made more available for crops in the future. Instead of planting cover crops in-between his rows, another farmer allows weeds to propagate in his alley ways. Similar to the practices previously explained, he describes some weeds as 'diggers' that pull nutrients from lower soil horizons and brings them up to be used by the plants under cultivation. Regardless, some weeds are still undesirable plants in certain crops, and farmers must take the steps necessary to prevent them from showing up in their fields.

Although some of the farmers preferred clean fields, four explained that biodiversity in the fields was essential for soil and plant health. In addition, two agreed that monocultures are clean and easy but are not how nature intended it. "I think its complex and there's lots of things growing basically in community or harmony… I think plants are designed to live in community. And when we do monocultures, its convenient and its how we've learned how to do it, and it looks clean, but I don' really think its how God designed it". Two farmers, both under the age of 50, believe the monoculture mentality is a relic of the past, and is on its way out of farming trends. This suggests that Burton (2014)'s findings indicating younger farmers as being more environmentally-conscious is in agreement with their perspectives.

All eight of the orchard, grape and blueberry growers maintained clean rows, but allowed cover crops or weeds to grow in the alleys. One pear grower explains that clean rows alleviate pest and water problems. She explains that mowing or tilling in between rows, though, will encourage pests to move up the tree. “As soon as you mow down, where are the bugs going to go? Up in the tree. So, you give the bugs a little space to live, and then no problem.” Two of these farmers discuss the damaging effects of herbicide use and opt for machine and hand cultivation or weed cloth to prevent the presence of weeds in their rows. “…A lot of our vineyards, we don’t use any herbicide on them. We choose to mechanically cultivate rather than use roundup and some other things just because we believe it’s harder on the biology of the soil and other impacts.”.

Participants in this study have differing perceptions of weeds in relation to their crops. While most would agree that they can serve as indicators of soil health, the farmers in this study manage them differently based on the type of crops grown; some believe that their presence is beneficial while others must use heavy herbicides to eliminate as many weeds as possible. While some of Burton’s (2014) findings were supported by responses in the study, the farmers perspectives concerning weeds could not be simplified to basic ideological discrepancies. Other constraints, particularly with maintaining crop health and quality influenced how farmers treated their weeds.

Organic practices

The differences between organic and conventional agriculture are possibly most pronounced by the presence of weeds. Three farmers explain that the easiest way to discern a conventional field and an organic field are the number of weeds you can find. “So, you can look at an organic field and you can say, ‘hmm… there’s weeds down the hill'. If you look at a conventional field, there's no weeds." Due to USDA Organic regulations, synthetic-based herbicides are not allowed in organic agriculture (NOP, 2016); therefore, most farmers cultivate (pull weeds) mechanically or by hand. "…we just pull a lot of weeds by hand. That's why organic is so expensive (so labor intensive) it just kills us". Many organic farmers cite labor as an issue; because synthetic herbicides are not allowed, labor is typically their largest expense (Sustainable Clark, 2016)

One farmer explained that organic farming is more challenging since pesticides or herbicides are prohibited. "And with organic agriculture, we're so much more proactive than with conventional. You can make an orchard look like a park. And you can mow and spray and mow and spray. But in organic, no. It's the same as conventional, and it's a totally different paradigm. When people ask me, should we become an organic farmer? If yes, then, what kind of, what do you want to do? Do you want to think through all of these processes, right?". Of the 15 farmers interviewed, 8 have at least some certified organic land. Another interesting finding is that all three of the female farmers interviewed are currently certified organic or have been certified in the past. This supports the conclusions of Sachs et al. (2016) who suggest that female farmers are more likely to become certified organic than their male counterparts.

Interestingly, most of these farmers with certified organic land described at least some amount of dissatisfaction with the rules and regulations. Although one farmer was generally in agreement with the NOP standards, he believed they valued education over experience: "…and I struggle with the organic people because they only trust degrees, and I'd be broke if I totally followed that". Two hop growers believed that organic certification has taken more of a political edge and isn't always in the farmer's favor.

> "As a consumer, I love it. As a farmer, I don't really like it. And partly it's because it becomes more bureaucracy than genuine sustainability. Like for instance… I can have two products, one of them will be OMRI (a registered organic product), and the concentration of it is like 10% let's say. I'll have another product, same ingredients, same company, same process. The concentration is 40%. It's not OMRI. That makes no sense… It's more sustainable for me to take the 40% concentration because I'm going to dilute it anyway. Then I have less material getting shipped, on and on down the road...Certified organic, its more, much more consumer-driven than producer driven. And they think, basically it's like these guys feel like they're on trial when the inspectors are here. And the inspectors, I've seen them, they're like hipsters from Seattle[24]."

This same disconnect, or perceived lack of understanding between certifier and farmer, has driven others away from organic certification. Of the 7 other farmers that have no certified organic land, almost all of them believe organic certification is not fit for their operation. Two farmers indicated slight interest in organic certification but believed that the small size of their operation and the effort, time, and paperwork involved with certification was too demanding for the needs of their farm. "We haven't chosen to become certified organic because I don't know. It's like everything we do, we have to do it on our own. We're a small farm, so I don't have a department here that somebody here is just gonna go do this. Somebody's gonna be me." In addition, the low demand for certain organic crops, paired with the effort involved with growing both conventional and organic varieties was too expensive and time consuming for them to handle. "You've got 10 sprayers lined up to go spray orchards, five of them are for your organic guys, five of them are for conventional, and one guy hops on the wrong tractor and loads up the wrong thing…" As expressed by Hijbeek et al. (2018) and Greiner & Gregg (2011), these farmers feel that current policy and government regulation in regard to organic certification doesn't appreciate the needs or constraints of their operation.

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[24] For More information on market influence, see the *Market demands* sections, p. 142 and p. 277

Based on principle or personal values, also defined as identity, some other farmers would never grow organic agriculture.

> "I probably can speak for a number of my friends on this, they think the same thing I do. If the public wants to buy organically produced fruits and vegetables at a higher price, then it's great for us. When our wives go shopping, they quite often avoid the organic stuff… We see the quality of the crop, the fruits and vegetables that comes off the stuff produced with non-organic farming, and its high quality, no blemishes, its great stuff… Organics are okay for the city people, we don't want it".

This farmer is over the age of 50 and was raised in the area; in following sections, I will explore how this demographic compares to others, especially in regard to organic agriculture. Another farmer, born and raised in the Yakima area and also over the age of 51, states agrees with the previous farmer. "I think you'd be hard-pressed to find a farmer that'll tell you that organic fruit or vegetables are healthier."

Burton's (2014) conclusions concerning age and environmental practices are somewhat in agreement with the statements of these two farmers; however, one must look at the implementation of management practices, not just ideology, to understand farmers feelings towards conservation agriculture. Even though many of these farmers oppose certified organic products, all seven of them incorporate at least some organic practices into their operation, whether its applying compost or manure, using cover crops, or applying what many would call 'softer' chemicals.

Not every farmer that I spoke to had issues with organic agriculture. At least two of them were strong believers in the organic movement. One farmer knew that when she purchased her farm, it would be certified organic. Her interest in agriculture began after motherhood, and she became concerned with where her food came from. Another organic farmer, finds the challenge of farming organically rewarding: "It's really fun. We feel more comfortable with what employees are exposed to. My parents switched to organic because they didn't want my sister and I in the orchard with conventional spray".

In sum, the divergent views on the presence or absence of weeds, or organic vs. conventional agriculture are apparent in this group. While some authors believe these divergent perspectives can be easily broken down into Conservationist and Productivist ideologies, the previous section shows that the issue is more complex, and that each farmer deals with different constraints that are frequently overlooked when partitioning these two groups. As will be addressed in the following section, even if they hold staunch opinions on one side or the other, all fifteen farmers are in some way farming with soil health in mind.

Soil Health Knowledge: Understanding established indicators of soil health

Using the term 'health' establishes that soils are living, and under proper conditions, the living organisms that make up this system are taken care of as well. All participants defined soil health, identified what improves and degrades soil quality, and describe practices the farmers themselves use to manager their crops and their land (Lobry de Bruyn & Abbey, 2002). Although not addressed as formal questions, soil physical, chemical and biological properties described by the farmers and land managers were recorded. They also described specific management techniques they and other farmers use to improve and degrade the soil.

Defining soil health

Asking farmers to define soil health provided insight into the farmers' sense of identity and could be used to better understand how their identity informs their farming philosophy and impacts their management choices. In addition, this question informs what farmers considered to be healthy, or even optimal for their growing operation, and helped to inform whether or not these farmers understood the important role that soil plays in agriculture (Lobry de Bruyn & Abbey, 2002). Some farmers described specific properties or characteristics while others recognized its importance to their farm's health.

Over half of the participants stated explicitly that soil health is the foundation of their farm. "Well, it's the life of everything. Water and a little sunshine. If you don't have those things, you don't have a farm". Five recognized that the economic and environmental sustainability of their farm was connected to health of their soil. "The thought process of improving soil health to your advantage, and good production can flow from that, which is our belief. Then that's truly sustainable". Another farmer explained that humanity depended on healthy soil. Upon asking her to define soil health, this was her response: "Production, my livelihood, soil health is everything. If you don't have healthy soil, then you don't have a farm. You have no food. If you don't keep it in good health, its not going to sustain us".

Eight of the farmers defined soil health using biological characteristics or described it as a living organism. Many of the participants explained that soil organisms must be healthy in order to achieve optimum soil health. "I think of it more as a living soil, so to me, if my soil is living, its working for me. So I don't think of my plants as mining as much as I think of my soil as living and providing nutrients… Soil health is the most important thing in farming". This farmer suggests that if one views soil as a living complex system, issues like nutrient availability for plants and workability will follow naturally.

Four farmers used metaphors or comparisons between their soil and human health. “Oh, it means a lot because it helps, like us. If you’re not healthy, you can’t work. Soil is the same thing. I mean, I go look at the plants and you know something’s wrong. You have to find out what the problem is, because you know the yields you’re supposed to get. Because if that plant doesn’t look healthy enough, soil’s the whole thing”. I found that this comparison between human and soil health from one of the most educated and least educated participants in the study. Although one completed her master’s degree and the other quit school before he received an elementary education, they both shared the belief that maintaining soil health is as indispensable as maintaining human health.

While many of these farmers would be considered Conservationists by the previously cited authors, they understand that soil health is an integral part of the economy of their farm, and without it, their yields would diminish. Darragh & Emery (2018) found that farmers mentioned financial incentives in their study as an influential factor to the implementation of environmentally-conscious management regimes, but other factors conveyed include: topographical constraints, learning curves, the ease of implementation, and social norms (Boehm & Burton, 1997; Bowman & Zilberman, 2013). In addition, one of the farmers previously cited is not certified organic and uses the recommendations of agricultural consultants and chemical companies to supply nutrients to his soil; according to McGuire et al.’s definition (2015), this farmer would be considered a Productivist. Regardless, he still describes his soil as a living system, and understands that soil health guarantees plant and crop health.

Familiarity with established indicators of soil health

Other farmers broke soil health and/or quality down into specific characteristics. Four farmers explained that healthy soil contained all of the nutrients necessary for plant production. One farmer uses soil analyses to tell him how healthy his soil is. "…we rely on people like Agri-Management and Husch & Husch [agronomists and chemical companies] to point out that your soil needs that for a particular crop. A healthy soil I would say is a well-balanced soil in all of the elements that the crop in question needs". Another farmer also explained that healthy soil provides adequate nutrients for the crop under cultivation. "To me, its huge. It's probably the most important thing we look at every year… because we've gotta make sure we have the right nutrients in the soil so that for the crops that we have we can get the most out of it".

Workable soil, or soil that needs minimal management, was also defined as healthy. "So, a healthy soil for me would be I can go grow a crop in it, and I don't have to babysit it… easy to manage, predictable yields of my crops, manageable weed and pest control. It's like being a coach and having a team of players that go out and exercise and eat well and you know, they have a good frame of mind. Those players are the ones that are easy to coach". If a soil works to the advantage of the farmer, then many of those farmers would describe it as healthy.

While all three farmers worked with chemical and agricultural consulting firms for assistance on soil and nutrient analysis on their farms, they emphasized the role played by their own experience, and also how closely they worked with other farmers in their community in the creation and dissemination of soil health knowledge.

I asked farmers to define soil health and I received a plethora of responses; the majority of participants recognized that soil health was the foundation of their farming system, and some understood that they could not sustain their farm or their environment without it. Others highlighted the importance of having adequate nutrients for crop health as well as soil that was easily workable and dependable, like a good team. Over half expressed that soil is a living biological system and made comparisons between human and soil health. Although the farmers and land managers interviewed for this study do not define soil health in the same way, most of them (if not all), understand that it is an important component to their farming operation. The following sections consider what farmers know about established indicators of soil health (physical, chemical and biological properties); while they were not explicitly asked to describe their understanding of these properties, it is still useful to understand what points came up for each farmer, and which indicators were more well-known than others.

Physical properties

In one form or another, most farmers discussed specific aspects of the soil's physical properties. 2/3 of the interviewed farmers described soil structure, whether in regard to soil aggregation, or as an indicator for soil health. For the most part, many farmers identified physical characteristics when they were asked to define soil health. "In my opinion, healthier soil will have better organic matter levels, and it'll be aerated soils rather than compacted, and my ideal soil will be easily friable… you have to have something that's crumbly." Tilth and friability were identified by four farmers; in addition, the importance of soil structure in relation to pore space was discussed by three farmers. As explained by Dexter (2004b), soils with good friability and tilth retain water well, have ample air and water pore space, and maintain good structure. Many farmers interviewed were aware that these principles indicated good soil physical quality.

1/3 of the participants discussed the soil's water retaining ability and its permeability. Some apply gypsum and lime to increase their soil's permeability; others add organic matter or minimize soil disturbance to allow encourage water penetration and prevent nutrient leaching. Two farmers irrigate their soil at variable rates, based on deeper soil horizons that may be hardened or have a caliche layer. "The further east you go, it gets a little worse… it's what we call, it's cemented, it's a caliche layer, its impermeable, water does not got through it… You've gotta really mind your water, and that's why we use drip irrigation". Another farmer closer to the Yakima River has sandier soil, which struggles to retain water. She explains that her plants are happier with overhead sprinklers or would prefer a soil texture that holds onto water better, like a silt loam. These two farmers express their knowledge of their soil's texture, and even the geological forming processes that have taken place in their area to create the soil that they farm.

Disturbing the soil structure through intensive tillage was also discussed; at least 6 farmers explained that disturbance impacts soil physical properties. "I think almost everyone, all my neighbors that till in their organic matter, its 90% wasted… they need to have it on top so that it can begin the process of healing the soil, of bringing it to life…the perfect concept is: build the soil from the top instead of trying to incorporate everything."[25]. While intensive tillage oxidizes crop residues rapidly for uptake by soil microbes, the continued disturbance of the soil structure has been shown to increase wind and water erosion, deplete organic matter, and reduce the structural integrity of the soil (Bot &

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[25] The concept of soil as a living organism will be discussed in more detail in the Biological Properties section, p. 242.

Benites, 2005). Most farmers interviewed were aware of the negative impacts of intensive tillage.

Crop type largely determines tillage intensity, frequency and duration. This point was addressed by the previously quoted farmer who grows blueberries, a perennial crop which requires no incorporation of crop residue or preparation of a seed bed for easier planting. Of all of the farmers with row or annual crops (corn, wheat, hops, or vegetables), they practice minimum tillage.

> "…you've still gotta till because if you're going to plant it there, you don't want all the material plugging up your cultivation equipment or your planting equipment. So you have to be relatively clean, but we shred it first, and then we incorporate it, the disk only works about 6-inches. So, we have these blades in the front that peel it back, and then two sets of blades that throw the dirt back. So, it's like you're moving the shovel one way and you're moving it back the other way".

As opposed to the traditional moldboard plow, which extends a blade deep into the soil to expose nutrients, while incorporating surface residues, disking works at the rhizosphere, or the top 6-inches, where most crop roots reach. Although surface structure is disrupted using this technique, the lower soil horizons are left intact (Faidutti & Zhang, 2003).

Over half of the farmers addressed compaction, the process of over-tillage or working the ground at the wrong time. Compaction limits the amount that air, water and roots can penetrate the soil, and is therefore antagonistic to crop production (Bot & Benites, 2005). "Soil compaction is a big thing in hops, you want it nice and loose, so you can move water through it and get nutrients down. Give them somewhere to grow at the same time". As previously discussed, compaction is more of an issue in row and annual crops, since bare soil is exposed to heavy machinery, sometimes during rainfall (which further increases the risk of compaction). Livestock operations must also take steps to minimize compaction, since their 'crop' usually weighs 1,000 lbs. and if managed improperly, can increase soil exposure, compaction and erosion (Briske et al., 2017). The one livestock operation in this study mitigates compaction through grazing rotation, aeration, and moving cattle off of sensitive areas during rainfall. "Degrading your soil would be just letting the animals eat it down to the ground, and stomp it, and muck it…"

Surprisingly, only three farmers described specific management practices they've incorporated to mitigate soil erosion. The only vineyard in the study grows some grapes on steep slopes; because of this, he sprays a softer herbicide to handle weed pressures. On all of his low-grade land, he prefers hand or machine cultivation, but passing heavy machinery on steep slopes increases the risk of erosion; therefore, he sprays an herbicide instead, which actually preserves the structure of his soil. An interesting point to be made is that if this farmer was certified organic, he could not spray an herbicide to mitigate the weed pressures; even though he has made a point to manage his land with the integrity of his soil structure in mind, he would not comply with organic regulations, and would be forced to cultivate with machinery, or spend extra money on labor to pull weeds by hand. This is an example of how some governmental rules and restrictions cannot incorporate the needs of each unique farmer, farm system and farm community (Greiner & Gregg, 2011; Hijbeek et al., 2018)

Nevertheless, other farmers are aware of wind and water erosion on their soil, and plant crops and incorporate irrigation practices that minimize their erosion risks. "…erosion would be a problem, but where this used to be mostly rill irrigated, most everything is sprinkler irrigated, which cuts the weight of the erosion problem with the water process… Wind erosion, we have some problems on the field directly ahead of me with wind erosion. When that's in Dill in the spring, the soil is worked for a fine seed bed.

And if you're right at planting time, just before or after, you get a lot of soil from the high winds. And there's nothing we can do about that. I prefer to keep that field in something other than Dill."

In summary, at least 2/3 of the farmers and land managers interviewed discuss soil physical characteristics in some manner. Many were aware that good structure usually indicates a healthier soil, and use words like 'tilth' and 'friability' to describe a workable soil. Pore space, and the ability of soil to move and retain water were also discussed. Some farmers emphasized minimizing soil disturbance; for any farmers or land managers with row or annual crops, minimum tillage was incorporated into their system. More than half of the farmers mentioned compaction and performed management strategies to mitigate this issue. Surprisingly, only three farmers explicitly referred to erosion; regardless, many farmers incorporated management practices like permanent ground cover and minimum tillage, which minimizes this risk.

Compared to chemical and biological indicators of soil health, the participants in my study had a better understanding of physical characteristics. As previously discussed, farmers are experience-based learners; they create an understanding of their land through years, decades and generations of trial-and-error (Sumane et al., 2017; Jensen et al,. 2007; Okali et al., 1994). Changes in physical quality are visible with the naked eye and can be observed over time. While changes in chemical and biological characteristics can be observed over time, as well, observing causal relationships between tillage and erosion, or driving heavy machinery over wet soil and observing compaction and crusting require less understanding and education from farmers (McGarry, de Souza Mello Bicalho & dos Guimarães Peixoto 2016). While farmers' understanding of biological and chemical characteristics will be considered further in this section, the simple and direct effects of management that impacts soil structure may explain why the farmers interviewed in this study expressed greater understanding of soil physical quality than the other two indicators.

Biological properties

The role that soil biology play in improving soil quality has largely been ignored until recently due to the prominence of research on soil chemistry and nutrient application (Doran & Zeiss, 2000; Barrios, 2007; Lehman et al., 2015). Because of this, I assumed that only a few farmers would discuss soil biology at all; surprisingly, over 2/3 of the participants interviewed described living soil organisms in some capacity. Many explained that they focus their farming practices around improving soil biology, and almost half believe it plays a major role in soil health. "So, we're always looking to kind of build the ecosystem, the biology and just have certain minerals…we're more, I guess, biological farming. We try to remain towards the nutrition, the biology, the soil health…" This particular farmer prefers to machine cultivate on most of his property instead of using "RoundUp" (Glyphosate) as an herbicide, because he believes its "…harder on the biology…"

Many other farmers recognized that applying any chemicals, albeit synthetic or naturally derived, would negatively impact the soil biology. "I think of it more as a living soil, so to me, if my soil is living, its working for me. So, I don't think of my plants as mining as much as I think of my soil as living and providing nutrients…I believe that most farmers are farming dead soil… Dead soil is when you completely remove the structure, you have no care for the life, those things that are living in the soil, and you simply throw in chemicals, whether you're organic or conventional…" This farmer is certified organic but believes that both organic and conventional farmers kill their soil biology; he also believes that its possible to ‘feed your soil’ using conventional practices. Another organic farmer, however, believes that conventional growers “ignore the microcosm of community in the soil” and that as an organic farmer, she knows that she has a good macro- and microbiological community in her soil.

A farm manager for a large-scale hop operation that has both certified organic and conventional crops prioritizes the enhancement of microbial activity. They’ve found that their organic fields are out-producing their conventional fields, even though the nutrient levels from leaf tissue tests show little difference between the two farming types. “…we grow some organic crops to where our organic hops are out-producing our conventional ones. Now, by a lot of conventional tests that we use with petiole leaf sampling, they should not be…” They believe that because they do not apply synthetic chemicals on these fields, the soil organisms are able to work symbiotically with their crops.

A blueberry grower in the area argues that many other blueberry farmers over-emphasize pH and believe that an acidic environment will produce better blueberries; he believes that having healthy soil biology will create high quality blueberries, not just an acidic soil environment. “And I don’t look at the pH nearly as much because it’s actually, it’s the organic matter in the soil and it’s the living soil. You can overcome so much with that, I’m not saying that pH doesn’t matter, to get these kinds or those kinds of microbes alive, and the fungi and this… I’m not disagreeing with that. But all I’m saying is I’m amazed at how much can be overcome by getting your biological right for your area. I will have a pH of about 6.5 [a fairly neutral pH], and I’m producing the same as people that are getting their stuff at 5.2 [an acidic pH], they’re just artificially throwing what’s needed there. I get the soil to be living soil, I have it at 6.5-6.8, it should be producing blueberries almost, and it does".

Soils contain a dense and complex system of macro- and microorganisms that carry out a number of different functions (Lehman et al., 2015). Within my sample, the two most commonly described soil microorganisms were microbes and mycorrhizae. Of the 15 participants, almost half discussed the role that microbes play in soil biological health. Three participants explained that microbes play an important role in the breakdown of organic matter for nutrient availability; one farmer described the symbiotic relationship of nitrogen-fixing bacteria. "What happens is if you, especially when you get biodiversity as well, because every plant has a slightly different sugar compound, and the microbial bacteria feed on that, it's a symbiotic relationship. So, because the plant can't absorb nutrients until it's been through a process that the microbial bacteria facilitate. So the plants and the microbes work in conjunction with each other". In addition, this farmer recognized that pH plays a role in microbial health, and states that the higher the acidity, the fewer microbes that can tolerate the environment.

Mycorrhizal fungi were addressed by four farmers, but most of them discussed it in very little detail. One farmer explained that she uses mycorrhizal fungi as a biological indicator of soil health; however, few farmers explained how mycorrhizae function to improve overall soil health. I spoke with another fertility manager for a conventional large-scale hop operation who believes that soil biology is essential to the health and well-being of any operation. As a newcomer to the operation, he believes the farm isn't doing enough to support soil organisms.

"…that's why I'm trying to do cover cropping, like I think we're not getting the benefit out of the mycorrhizal fungi out of the soil because of the way we irrigate and fertilize and also

> because we till. So, I think the soil would be better if we left it alone more, and didn't over-irrigate it, and managed it so that those biological systems, especially the bacteria and the fungi, and all the little insects that are in the soil, including earthworms, could do what I think they're designed to do. But it all has to fit into a production system and so I don't know how, I don't know what the ideal picture is going to look like and how fast. It won't be fast at all, moving in that direction, but I think we're making some progress".

Twelve participants use cover crops in some capacity on their operation. As previously discussed, cover crops utilize biological nutrient cycling by encouraging Beneficial Nitrogen Fixers (BNF) to transform nitrogen from the atmosphere into a plant-usable form that can be re-incorporated into the soil bank for uptake by subsequent crops (Barrios, 2007). As previously discussed, plant biodiversity, albeit with cover crops or weeds, also improves overall soil microbial health (Nogueira et al., 2016). Four farmers described biodiversity in some capacity, but only one explained how it improves soil health. "…incorporating biodiversity out there, our feeling is that if we do it right, well we know it's going to augment our operation… the biggest thing is enhancing microbial activity in the soil".

Another way to increase microbial activity in the soil is to apply inoculants. These amendments contain a few species of soil microbes that work to improve nutrient and water uptake by plants; however, some inoculants are better suited for specific plants and environments, so one must be conscious that they are applying the proper inoculant for their operation (Gaskin et al. 2013). At least two farmers explained that they use inoculants to supplement their soil biology.

Although some farmers may not have addressed specific biological indicators, five explained that their management practices feed the soil, thus implying that the soil is living. Although one farmer did not describe specific biological indicators (microbes, mycorrhizae, etc.), he justified his practices as feeding the soil. While research into the biological make-up of soils is increasing, few farmers have been taught or are experienced in identifying biological indicators of soil health. There are many factors that explain this disconnect, like the complexity of soil biological systems, and the minimal understanding of soil ecology by both scientists and land managers (Costanza et al., 1997; Lehman et al. 2015).

Through their intuitive and experience-based awareness of the complex biological system that is their land, farmers have an understanding that there are living components to their soil; however, the hegemonic dominance of the traditional scientific mode of learning has encouraged some farmers to doubt their own experience-based intuitive knowledge in favor of information coming from reputable sources (Kloppenburg et al. 1991). Since much of the research in the latter half of the 20th century was centered on soil chemical and physical characteristics, and farmers have exhibited an over-reliance on information coming from academic sources, their understanding and experience identifying biological indicators may be less than that of their physical and chemical understanding.

Regardless, most of the farmers interviewed have at least a basic understanding of the role played by soil microorganisms in soil and crop health. Many of these farmers are taking the necessary steps to create an environment that soil macro and micro-organisms find suitable. Many more are coming to realize the positive benefits they will receive from the living soil biology. Many of the farm owners that discussed soil biology were able to manage it to the best of their ability; however, the two hop growers described previously felt constrained by market and owner demands. It is well known, though, that managing soil biology has not been the focus of management practices over the past half century. Since humans are just now realizing the important role played by soil organisms, not just nutrients, we still have much to learn (Doran & Zeiss, 2000; Barros, 2007; Lehman et al. 2015). In addition, a shift has begun where we not only prioritize soil nutrient quantities, but also abundance of soil microbial activity. Soil Quality indicators that monitor biology are now being used regularly; hopefully, we will pay as much attention to soil microbes as we are mindful of soil chemical properties in the near future.

Chemical properties

Initially, I assumed farmers would have the greatest knowledge of chemical properties, like the types of nutrients available and required by plants, soil acidity and alkalinity, and chemical processes taking place below and aboveground. Many farmers were aware of nutrient requirements and deficiencies in their plants; almost all used crop indicators to identify nutrient deficiencies in their soil. In addition, most had an understanding of soil pH, and the effects of the highly alkaline soils common in the area. Interestingly, most did not describe specific nutrient processes taking place, like the nitrogen of phosphorus cycles or the soil's Cation Exchange Capacity (CEC)[26]. This is a point that must be explored further by soil conservationists and agricultural consultants; are farmers aware of the chemical processes taking place in their soil?

When discussing soil fertility, nutrient availability and chemical properties are largely described by farmers. There are 15 soil macro- and micronutrients required by most plants; nitrogen, phosphorus and potassium (NPK), 'the big 3' usually are needed in the largest quantities in plants; therefore, they have historically been favored when managing soil fertility than other macro and micro-nutrients (Brady & Weil, 2010). A

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[26] For more information, see *Chemical Indicators* section, p. 69

farmer who farms mint and annual row crops conventionally recognizes that many of his friends are not applying micronutrients in large enough quantities.

> "Most of us understand the NPK relationship quite well, but you get into some of the minor crop chemicals [micronutrients] like copper and manganese and some of those, you can be deficient in those. On our seed crops, we usually apply zinc [another micronutrient] which seems to help the seed crops (grains, I believe?) but we rely on people like agri-management and Husch & Husch (chemical and ag consultants) to point out that your soil needs that for a particular crop. A healthy soil I would say is a well-balanced soil in all of the elements that the crop in question needs".

As previously discussed, many farmers rely on agricultural and chemical consultants to analyze the nutrient content of their soil. These consultants advise farmers on the optimum chemicals to apply at the ideal time for proper nutrient management.

Almost all farmers discussed nutrient availability in some capacity, while at least 13 participants described some form of chemical processes or reactions; they referred to the availability of nutrients with specific chemical fertilizers and explained that nutrients can become 'locked up'. While only one farmer addressed the soil's cation exchange capacity (CEC), at least four referred to nutrients becoming locked up based on the presence or absence of nutrients. Although this does not refer directly to a soil's CEC, it indicates that farmers have a basic understanding that excess nutrients can not only waste money, but it can also prevent the availability and uptake of other nutrients by plants. In addition, five farmers explicitly described biochemical processes, or that through planting, like cover crops or crop rotation, one can add or remove nutrients from the soil.

One of the most frequently discussed talking points was soil pH. Yakima soils typically have a higher calcium content. To better understand a problem field, one farmer dug multiple eight-foot holes to see what was happening belowground; she encountered this alkalinity head-on.

> "…we found all of these layers of sand and clay. Different layers around the block, caliche layers, hard pans. We were trying to break it up. This vinegar is being used to dissolve (the caliche layer) to see if it will break. Its been in there for 2 weeks. We have high pH so high vinegar, so it will help the caliche. So that was a thing, and now what we're going to do. We're going to change the pH a little bit, so we will rip both ways, before we did that, we took a sonar over the field, so they send us all these maps but no key".

Twelve farmers described how soil pH impacts their crops and the availability of nutrients, also implying a basic understanding of the soil's CEC.

Most farmers interviewed had a basic understanding of chemical processes taking place; I would argue that individuals with a more in-depth and extensive understanding of soil chemistry either studied the information on their own or learned about it through an agriculture-specific post-secondary education. While farmers were not asked explicitly to provide their understanding of soil chemical properties, the information gathered suggests that many of these processes are not intuitive; in general, most farmers without an agricultural or environmental educational background have less of an awareness of nutrient loss through leaching, or ammonification, which is not visible with the naked eye.

Due to the expert to non-expert relay of information from scientists to farmers, many land managers trust that recommendations from extension agents, soil conservationists, and agricultural consultants would already address issues that may come up. Because of this, it is possible that farmers may believe that they do not have to worry about such issues as nutrient loss through leaching and ammonification themselves because they're paying a specialist to identify these problems for them. As discussed previously, problems arise in this scenario, since the history of soil and agricultural research has prioritized making generalizable, universal recommendations to all farmers and farm systems; however, as referenced throughout this thesis, each farmer, farm system, and farm community is a unique ecosystem in themselves. Therefore, more research into farmers' actual understanding of soil chemical properties is necessary to understand what farmers know, and how scientists, agronomists and consultants can better inform the individuals responsible for farming and managing the environment.

Organic Matter

Organic Matter plays a huge role in overall soil health; high quantities of organic matter are usually indicative of healthy soil, based on biological, chemical and physical indicators (Bot & Benites, 2005). In addition, organic matter can act as a point of coalescence for both soil scientists and farmers; it's easy to identify, intuitive, and one of the best indicators of soil health (de Souza Mello Bicalho & dos Guimaraes Peixoto, 2016). All farmers interviewed identified SOM as an important indicator of soil health "[Organic matter] improves the tilth and the friability of the soil. We like to keep high organic matter… I like in general to keep as high organic matter levels as we can get because I don't think there's danger on this type of soil of getting too much organic matter with your practices".

As will be discussed later, farmers use a number of indicators to determine the quality of their soil. Twelve of the farmers and land managers interviewed for this study indicated that they use organic matter as an indicator of soil health. In addition, all fifteen farmers incorporate management practices that reduce the breakdown of organic matter in order to add more to their soil. "One of the first things we look at is organic matter, that's why we're putting compost in, to improve that. That's why in the hops, we're planting triticale as a cover crop to produce green manure, and we mow it off and disk it in… The other thing I'd add is organic matter helps you a lot with water [retention] in your soil. That definitely plays a role in that as well".

There are a number of management techniques used by farmers to improve soil organic matter levels; I've considered the four most commonly discussed techniques described by farmers that add organic matter to the soil. These include: incorporating cover crops into the system; applying either manure, compost, or biosolids; minimizing disturbance of the soil structure (minimum or no-till); farming perennial crops; and crop rotation (Janzen et al., 2005; Dixon & Garrity 2014, Nunes et al. 2018, Karlen & Obrycki 2018). As explained by one farmer, who incorporates all of these practices into his operation:

> "…we've pretty much greatly reduced, almost eliminated plowing, and with the shredders and things like that, we try to leave as much residue as possible. I wish I could leave more, but that's part of the reason why we bring a lot of compost in. And that's what we're trying to make up for. And then with the compost, we're trying to put that microbial inoculation back into the soil. The one thing I think we could do more of and I need to figure out a system that fits our operation is cover cropping, because if we cover crop, then you'll actually increase that microbial activity in the biosphere, in the rhizosphere".

According to De Baets et al. (2011), leaving soil exposed without coverage as fallow ground or for other purposes has been shown to reduce overall soil quality; it also has been shown to increase the breakdown of organic material, leaving fewer nutrients available for future crop production. Cover cropping has become a popular practice in the past few decades and offers a much more beneficial alternative to fallow land. Cover crops not only maintain soil coverage, but many legumes (alfalfa, clover, beans, etc.) encourage nitrogen fixation from the atmosphere, in addition to assisting the plants in the absorption of other soil nutrients. Cover crops have also been shown to retain soil moisture, which is essential in a desert climate like Yakima (Mitchell et al., 2017). They support a healthy soil biological system and can serve as a green manure and can be used to increase soil organic matter levels (De Baets et al., 2011).

Thirteen participants in this study use some form of cover crops in their operation. For the perennial growers with large row spacing, like hops and orchard fruit (apples, pears, grapes, and blueberries), cover crops are planted in-between rows to minimize compaction from heavy traffic and machinery, in addition to improving organic matter levels and overall soil health. “What benefits us is having that cover crop, holding the soil in place, having that root turnover. So, I think a perennial cover crop, you have that root turnover… it’s gonna be key…”. This individual is one of the three fertility managers or R&D specialists of the hop industry. All three of these individuals are researching cover cropping systems and are incorporating them into their systems. “…well, [the corporation’s board] are letting me do cover cropping because they think its probably a better way, you know, if we can learn how to do it so that it doesn’t depress our yields, and maybe in fact helps improve our yields. Or just gives us some benefits like a little bit less dust or maybe it does improve soil health. They buy into that, and are supportive of it, they’re not antagonistic, they’d like it to go that way”. What must be noted is that these individuals work for large operations and are not the farmers themselves; through quantitative analysis they must prove to the owners or other investors that practices like cover cropping increase yield in some capacity. “We developed a biodiverse cover crop that we put down. How do I measure the success of that? It may show up in yield now, it may not show up in yield now.”.

As explained by a pear grower, cover crops serve a multitude of benefits to perennial crop systems: “In orchards, just orchard grass mix. In the grapes, we’ve done some radishes to help break up soil further down, deep rooting cover crop, I know we’ve done that in the past, especially in areas of the soil that are more hard-packed, compacted.

Fertility issues that we've got. So yeah, we look at those beneficial cover crops that maybe will help the soil break things up and making it more efficient and accessing water and higher yields, things like that". Many farmers plant cover crops in-between rows of their orchards and perennial systems to prevent compaction, increase soil nutrients and retain water (Ernst et al., 2018).

As discussed previously, biodiversity is necessary to provide ample nutrient sources for soil biology and crops (Barrios, 2007). It has been shown that having a more diverse cover crop mix creates a healthier soil environment; many farmers understand this concept and attempt to include a diverse array of cover crop species to provide a variety of nutrients. "…we plant grass between our trees. It's a special grass mix, and I like to use a little bit of clover for N… so there's bluegrass, rye grass, usually your grasses that don't grow so fast. We just mow it down. But this one block… I had it in pasture. And now, I didn't seed it or nothing, I just kept mowing, and I've got grass". Many farmers utilized special diverse cover crop mixes, while some just plant one or two cover crop varieties to satisfy specific needs. "…in the hops, we're planting triticale as a cover crop to produce green manure, and we mow it off and disk it in". Some farmers use no seed mix, but allow the previously-planted hay grass and weed seeds to provide cover in their alleyways. A perfect example is the wine grape grower located on the hills of the Ahtanum ridge that allows natural weeds and grasses to grow between his crops. This farmer describes specific weeds as 'diggers' that pull up nutrients from the subsoil that can be mowed down and used for the following crop.

Although it has been shown that increasing biodiversity with plant coverage improves soil physical, chemical and biological properties (Barrios, 2007), having any sort of ground coverage will greatly reduce a farmer's risk of wind and water erosion, compaction, and nutrient loss. In addition, cover crops can add nutrients, increase water retention, and increase organic matter (De Baets et al., 2011).

Although planting cover crops is ideal, some farmers find it too risky to waste productive land with a cover crop, largely because it does not increase profits (Boehm & Burton, 1997). Therefore, other amendments high in organic matter are applied to the soil. All fifteen of the farmers interviewed apply compost, green and animal manure, biosolids, or a combination of the three, and all of them believe they improve their soil health.

Manure, compost and biosolids

Manure, compost, and biosolids are ideal soil amendments because they have a low C:N ratio, (meaning they can decompose quickly), making nutrients rapidly available to soil microorganisms and crops. For the most part, manure, compost and biosolids are cheap and readily available, since most dairies and livestock operations have excess waste that by law must not accumulate in excess (D'Hose et al., 2014; Farrell & Jones, 2009; Zou et al., 2017). Many farmers grow perennial crops that produce large amounts of waste, specifically hops and mint. Compost is also an important source of nutrients for many organic and sustainable growers; because they can't use synthetic chemicals to apply nutrients to their soil, composted residues have been shown to be high in many macro and micro-nutrients (Annunziata & Vecchio, 2016). Although somewhat controversial, biosolids, a by-product of the wastewater treatment process, have been shown to increase organic matter levels as well as improve overall soil health.

Composting processes crop and animal residues in a moist, warm, and well-aerated environment; one author found that the application of compost on a variety of crops increased plant-available N, P and K, aggregate stability, microbial biomass and biodiversity, and decreased bulk density (D'Hose et al., 2014). Some farmers apply old crop residues that have been processed in some way, while others apply composted manure. Many farmers explained that there was an ample supply of composted materials to be applied to their soil. "Years ago, we used to make our own [compost], and we just figured we could just get it so much cheaper. Maybe it's not quite the quality, but you could get truckloads coming in. We prefer to get it from dairies because they use a lot more carbon-base. They have a lot of straw and stuff in their mix". One annual row crop farmer makes his own compost from crop residues, but also uses manure from a local feed lot. "The asparagus butts are going into that truck, and we haul them out to the compost pile… it goes back to the dirt, and we'll compost 'em about 30 turns, so we actually bring the manure in the winter time, because that's when the dairies want us to get rid of it, and then what we'll do is we'll turn it and we'll try to dry it". As an organic and conventional grower, he has found that compost is beneficial for both conventional and organic crops. "…we were initially only using compost on the organic, but we have enough compost now to apply it to the conventional. And so, the majority of our conventional fields now have compost".

One of the cash crops in the area is mint; most of the mint growers interviewed have on-site mint distilleries where oil is extracted at high heat and under large amounts of water pressure. This process is beneficial for the growers, since they have ample supplies of excess organic matter to apply to their soil. In its partially processed and broken-down state, nutrients in mint slugs are more readily available for uptake by the next year's crop. One farmer commented on his neighboring mint farmer's abundance of organic matter:

"And the reason I'm so envious [of my neighboring mint farmer] is because they cook that mint, the only thing they're taking off is 200 lbs. of oil off every acre. Everything else comes back to the soil… all that organic matter goes back into his field. I mean, they spray the crap out of this stuff, but his soil just is beautiful because he has all that organic matter". Another mint farmer applies mint slugs in areas of high alkalinity. "The only place I use mint slugs would be for soil that has too much salt and we can't keep it wet. So, you put the mint slugs on, you keep the moisture. And by keeping the moisture, it gets rid of your salts".

A few farmers apply large quantities of composted and raw manure and believe it improves their soil quality in a number of ways.

> "I had a hay field for 12 years. And I put all this manure, in fact, and you can ask anybody…How many people have put this much manure with straw and everything on top of a hay field? Some crazy people. And I've done it. People have seen me and are like, 'are you crazy? What the hell are you thinking?' I think I was, I was thinking wrong when I did it… And that hay, from being almost tired, done growing… that hay grew really strong. It was really good hay after that. I went 12 years on that stuff.".

The only livestock grower interviewed for this study believes that applying manure is the best option for her operation, even if synthetic fertilizers are easier. "A lot of times, it's cheaper to go with just a pellet, but I look at the soil differently. I would rather go with an organic manure. I have it do to, I have it to spread, I can compost it. That is the best way, to put natural to natural".

Of all fifteen growers, only one farming operation applies biosolids to their property. This farm also collects them from 30 different wastewater treatment facilities and applies them to 200,000 acres across Washington. Biosolids are still an extremely controversial issue, and much of the general public is apprehensive of its widespread use (Barclay 2013). Only one other farmer considered applying biosolids at all but was met with widespread opposition. “7 or 8 years ago, we looked at the possibility, along with the compost to incorporate municipal sludge, and there was a community meeting, there were a lot of very unhappy people… one of the Roy owners stood up and said, ‘Okay, we’re done here, we’re not doing this.’”. Even though this same farmer recognized the misperceptions of the public concerning biosolids, they still chose not to use it. The one farmer that applies biosolids to their ground recognizes the public misperceptions, but believes that the overall benefits outweigh the risks, especially with the current EPA rules and regulations in place. “there’s always a public perception and people not fully understanding. I think it just takes educating and being honest and upfront and communicating with people when they have questions about biosolids. But as far as farmers being happy with the product and growing really good crops and higher yields and better soil fertility, and OM and balancing pH and everything else, it’s been really beneficial to us and also other farmers”.

One farmer found that despite what the general public believes, applying compost, manure, or other residues is not necessary if one’s soil health is optimal. “…the best way I can explain it to you is, if you think about taking a bonfire and throwing all of your material on it at once, it just burns up and its gone. In our soil, the way the buffer is, I’m not saying I understand it completely. The mint slugs, the compost, the manure, when you worked it into the ground, it was gone. You could not see any residue… I can’t tell you exactly what it did, but like I said, it’s like a bonfire…” Based on the unique fine texture of this farmer’s soil, he’s observed different outcomes than one may expect from confirmed scientific findings. He even claims that he can use fewer inputs than other farmers because he’s “feeding the soil instead of feeding the plant”.

In summary, all fifteen farmers apply some organic matter to their soil, either in raw or composted form. Some purchase manure and compost from local feed lots or municipalities, while others have excess residues which they can apply to their fields. One farmer is a huge proponent of biosolids, a controversial amendment that, when properly treated and monitored, can supply ample nutrients to crops and can also be used as a means to minimize the amount of waste going into landfills (King County Wastewater Treatment Division, 2016). The application of composted organic material is just one facet of methods utilized by farmers to increase SOM.

Perennial crops

One of the best ways to maintain soil structure, add organic matter, and consequently improve overall soil health is to grow perennial crops. With many perennial crops, the soil column is left intact; a complex network of roots serves to maintain the structure, in addition to adding organic matter from crop residue (Ernst et al., 2016). Fortunately for the soil and farmers of the Yakima Valley, many of the cash crops in the area are perennial crops. These include: apples, hops, grapes, blueberries, mint, alfalfa and hay; while they are all perennial, they have different management requirements, and therefore impact the soil differently.

All fifteen farmers grow at least one perennial crop; the different management practices performed on each crop influence the organic matter accumulation, and overall soil health, in a variety of ways. For apple, pear, cherry, grape orchards and hops, cover crops and grass mixes typically occupy the alleyways, while a weed strip is maintained directly beneath the plant's canopy. This practice limits pest habitat and prevents weeds and other plants from stealing nutrients and water from the crops (Vossen & Ingals, 2002).

While organic matter is maintained deeper in the soil column and in the alleyways, organic matter at the surface, directly beneath the trees is limited due to the surface tillage and application of herbicides. For blueberries, however, a weed fabric is applied, preventing the accumulation weed growth and also retaining water and organic matter (Miller, 2015). Different management practices, which influence the amount of organic matter present, and are also indicative of healthier soils.

Minimum and no-till practices

Maintaining soil structure and preventing disturbance has been shown to improve overall soil health (Nunes et al., 2018). While perennial crops induce much less soil disturbance, many annual row crops like wheat or corn require more intensive cultivation in order to incorporate residues from the previous years' crop. One of the most hotly contested issues concerning agricultural techniques are the benefits associated with minimum or no-tillage practices. Historically, farmers have utilized the moldboard plow, an instrument that played a major role in the development of the United States. The moldboard plow rips the ground from below, and organic matter and nutrient-rich top soil is brought up to the surface, exposing nutrients to the environment for mineralization and increasing their availability for future crops (Faidutti & Zhang, 2003). Such an intensive tool was necessary for converting virgin prairie grassland throughout the United States into farmable land, since it broke up the dense masses of native root vegetation and disrupted total soil structure and was common practice until the second half of the 20th century, when scientists became aware of the relationship between intensive tillage and soil erosion (Lal 2007).

Conservation or minimum-tillage practices became more normalized, where farmers would not rip the ground deeply to turn the soil but would instead turn under annual crops and residues using a disk at a shallower depth. Even though conservation tillage reduces the risk of wind and water erosion, there are still many scientists and farmers that would argue this practice is still detrimental to soil structure and biology (Reicosky, 2015). No-tillage keeps residue in place with virtually no disturbance of the soil surface whatsoever. Seeds and nutrients (including manure) are injected into the soil, and the residue is left *en situ* as a nutrient source and to maintain soil structure (Lal, 2007).

Different crops have different tillage requirements, in addition to different management practices. Although many farmers are aware that intensive tillage increases erosion potential, they may have to use a deeper implement to turn up residue, break up the soil structure, and prepare a seedbed for the following year's crop. Of the farmers interviewed, many discussed their preferences for using a variety of implements for different tasks and compare their tillage requirements with other farmers.

> "Are you familiar with a ripper disk? [It] cuts and turns the soil, then the shanks behind rip deeper into the ground. And then the rear disks turn it again. It's used for sizing, cutting residue into manageable chunks… on your right you'll see a big disk. That's for sizing and mixing only it doesn't go deeply like the ripper disk. The old method is plowing, a typical plow. People are getting away from moldboard plowing [because] we're getting a better seed bed out of mixing it and leaving the trash [residue] on top. Now Lon plows 'em and he has a reason for it. He's raising vegetables and he doesn't want any trash on top, so the way to get rid of it is to plow it under. With our mint root, it thrives with loose soil right on top with organic matter. And this helps to hold moisture. Neither way is wrong, it's just not the best practice for some purpose".

A farmer that grows vegetable crops utilizes minimum tillage but explains that tillage is necessary for his organic crops, since they machine cultivate to get rid of weeds.

> "And so, you've still gotta till because if you're gonna plant in there, you don't want all the material plugging up your cultivation equipment or your planting equipment. So, you have to be relatively clean, but we shred it first, and then we incorporate it. The disk only works

about 6 inches. So, we have these blades in the front that peel it back, and then two sets of blades that throw the dirt back. So its like you're moving the shovel one way and you're moving it back the other way. And down the middle where the ditch is, that's where we have these ripper shanks, and try to loosen up the compacted soil. So that's minimum tillage".

Another farmer that rotates between annual row crops like corn and wheat with perennial mint also favors the ripper disk since it minimizes the number of 'passes' on the soil necessary to break up the residue.

"So, we used to do a plow program behind the corn harvest. We'd disk it probably 2, maybe 3 times, we'd mow it first, then we'd disk it, knock down the stalks, then we'd go in with a plow and plow it under… So, you're doing a lot of passes with the tractor a lot of the time, a lot of equipment. So, we bought a couple new pieces of minimum till equipment… it's got paddles in the back to stir it as you go along. We'll run that and then another machine which basically has coulter blades on it, chops everything to little bits, then we'll run that ripper machine through it, and we'll let it go through the winter like that way… so we're doing probably half the tractor work now, but getting the same if not better results than the following crops because we're not pulverizing the soil".

As previously discussed, minimizing the number of passes of heavy machinery reducing the risk of compaction, erosion, and poor water permeability; and maintains soil physical quality (NRCS, 1996).

All fifteen farmers practice at least some form of minimum or no tillage; as previously described, most choose not to plow intensively in order to protect the soil structure. For farmers with perennial crops like grapes, apples, and blueberries, tillage is a very minimal process; for other perennial crops like hops, the plants require more groundwork. "[In the orchard] we prefer to have a grass cover crop, but its bare underneath the trees, what you call a weed strip, and your drive rows, grass strip in the middle… hops need to be cultivated more. Trees don't need to re-do the ground. You don't work the ground in trees. Soil compaction is a big thing in hops, you want it nice and loose, so you can move water through it and get nutrients down".

All farmers work to minimize the amount of disturbance in the soil; they are aware that making multiple passes can create compaction, preventing water and roots from penetrating the soil. In addition, excessive disturbance negatively impacts the soil biology, which was described by a few farmers. “The more you disturb the soil, the more you’re bringing things up, losing soil moisture, things like that. And some of the farmers we work with in biosolids and dryland wheat have gone to no-till just for those reasons, especially moisture, and then organic matter as well. It’s starting to catch on more here… less erosion and all that”. Most participants are aware that intensive disturbance negatively impacts soil structure, and all of them are implementing minimum or no tillage practices to help maintain it.

It has been shown that no-till agriculture for row crops like wheat require applied synthetic nutrients, since one benefit of tillage is that it aids in the mineralization of crop residues from the previous years’ crops (Malhi et al., 2001). For many organic operations that cannot apply synthetic chemicals, no-tillage does not provide enough nutrients and limits yield potential (Annunziata & Vecchio, 2016). Since each farmer and farm system is unique, it is essential that policy considers the constrains for each operation. Future research should consider which management practices lead to the most negative soil, ecosystem, and environmental impacts; questions addressing what is truly more beneficial for the health of the environment should be addressed, and policy and regulation should understand the complex circumstances and constraints each farmer and farm system encounters.

Soil degradation through management practices

Farmers were asked to provide examples of management practices that degrade soil health; by asking farmers to communicate soil degrading practices, I hoped to better understand what they knew about overall soil health and quality as well as how they compare their own practices to those that degrade the soil. Their responses inform how an individual's farming philosophy impacts their management practices (Walhutter et al., 2016). As described previously, all 15 explained that management that degrades soil organic matter will also degrade overall soil quality. "Usually when people harvest and leave no residue. That, in my opinion, is what degrades it the most, and then when you take what little residue you have and work it under the ground". This farmer believes that by eliminating as much residue as possible, and with the subsequent 'de-plowing' as he refers to it, where residue is incorporated 18 inches down, one can run the risk of losing organic matter and degrading their soil. Many other recognized that within a desert climate and with such little organic matter to begin with, one must be mindful of organic matter levels. "Here, our soil's at a different level because of our climate and the types of soils we have. We have mineral soils, and it's difficult if you have any high pH or sodium in the soil, it just consumes the organic matter. And so, it's really difficult to bring a level way up, but its important that you keep bringing some back in as much as you can…"

Two farmers explained that bare soil also degrades soil quality. As expressed in the previous paragraph, improper and intensive tillage, which contributes to rapid organic matter mineralization, was described by almost half of the participants as a means of soil degradation. "I think almost everyone, all my neighbors that till in, and most gardeners that till in their organic matter and its 90% wasted. Because what needs to be done is they need to have it on top so that it can begin the process of healing the soil, of bringing it to life". This same farmer makes an analogy of soil as skin, and how skin would appear if it was treated the same way that many farmers treat their soil: "Mostly they ignore that the soil is like an organ, like your skin. And if you did to your skin what people do to their soil, then we'd all be scarred up and it'd be a horrible thing… I just don't think people realize how much harm they're doing in soil".

Ten participants believed improper nutrient management contributes to soil degradation. Many described taking up more nutrients than what is returned to the soil as mining, which provokes future problems. "…you know, a lot of farming today is mining, you're mining your soils, right? And after a while, you know I just got, having more and more pest issues, and I've gotta spray more. Its' kinda this merry-go-round". One farmer describes this practice as raping the ground: "…we had a couple fields out here where I'm standing right now, horrible, horrible fields. They were raped, all they did was rape the ground. They didn't put anything into it. They just grew crops on it, they were unwilling to spend the money to put fertilizer down." Removing nutrients without returning them to the soil was considered degrading for at least 2/3 of the participants in this study.

On the other hand, some farmers believed that over-applying nutrients was not only economically illogical, but also contributed to land degradation. Two farmers considered the history of synthetic fertilizer use and its impacts on the environment. "Just after post-WWII, so you had the advent of oil-derived synthetic nitrogen fertilizer initially, it was looked like, 'this is a miracle'… not fully understanding the ramifications of overuse or abuse". Others describe the overuse of chemicals in general as a sure-fire method to degrade soil. "Chemicals are degrading, some are burning. You've got some chemicals that will actually stop the growth of anything. It will just burn it. There’s a multitude of sin is what I call it, that you can do to the soil and it will never come back”.

Improper irrigation management was described by 5 participants as a means of soil and land degradation. “So, the worst thing is overwatering. This to me, seems like there’s some data to back that up… not overwatering, not leaching nutrients out, and not affecting your soil aeration with your overwatering. You’re just gonna shoot yourself in the foot right there”. Others explained that furrow irrigation, the practice of applying large quantities of water to the surface in trenches between rows, leads to water erosion, and subsequent soil degradation. “…the other thing that used to degrade the soil was when we actually used to use furrow irrigation, we’d run this stuff down the row and you’d have a waste ditch, so water had silt in it, so it’d dump into the drainage ways and the drainage would dump into the river. And so now, the dirt that’s coming off of that brown water is probably the best dirt that you have, because it’s the most mobile, it’s the fluffiest dirt”.

The final practice discussed by the participants of this study is compaction; over half of the farmers interviewed believed soil compaction rapidly degraded soils. “Compaction is a very important factor and anything the chemicals do to it. And its overlooked by most farmers, they don’t consider compaction a big deal, but a permanent crop (like blueberries), it can be pretty serious because you can’t rip it up and loosen it up, and the structure of the soil has all to do with its ability to percolate water and bring oxygen in the soil which is necessary for the microbes to survive”. The only livestock operation interviewed for this study believed that improper livestock management contributed to compaction as well as exposing bare soil. “Degrading would be just letting the animals eat it down to the ground, and stomp it, and muck it, and not putting anything back into it”.

Finally, another farmer described what happens when you plow wet soil: “I can’t even express the frustration when you’re taking a plow across the ground that has a little wet on top… Well, that wet, it’s like peanut butter, and you try to drive across it, and everything is sticking, corn stalks on top and dry stuff underneath, which it just balls up. It’s a mess, I’m getting stressed thinking about it”. Most of the farmers would agree that practices that degrade soil structure negatively impact soil quality as well.

There were a number of ways described by the participants in this study to degrade soil health; all 15 farmers agreed that removing organic matter, especially in the desert climate of Yakima, would contribute to soil degradation. Other practices included: improper tillage, mismanagement of nutrients and chemicals, improper irrigation, and compaction. It is clear that these farmers prioritize appropriate and efficient soil management practices and believe that its mismanagement will have detrimental effects in the future.

Soil quality indicators

Soil scientists and agronomists have established a series of parameters that can be measured to indicate the quality of soil health; most have undergone rigorous in-the-field and laboratory testing to prove whether or not certain characteristics can be used to determine healthier soil. Farmers also have a number of indicators they use to determine the quality of their soil using methods similar to those used by scientists (Doran 2002, Knapp & Fernandez-Gimenez, 2009; Dawoe et al. 2012; Walhutter et al., 2016). Almost all of the participants use in-the-field observation on a daily basis to determine the quality of their soil. According to one of the hop farm managers, “the best fertilizer in the field is your footprints"; many of the farmers spend much of their time in the field observing their soil and crops directly.

> "I do like walking the field and seeing it every day. You really get a feel for it, hey I've got weeds coming up out here. Or why is this turning yellow, its turning a color, why is it turning a color here? I did have that in my hay field and that's because I was out walking in it, and I was out irrigating, and I'm ike, 'hey, I've got a lot of yellow showing up on this one piece, what do we got going on here?' and you put a little time in, make some phone calls and you realize, hey, you're watering too much. Oh okay, I can fix that problem real easy. I can stay home tomorrow".

One individual described patterns of infiltration and water movement as an indication of soil quality. "You can always look at water, how the irrigation is hitting it. Is it like pooling on the surface or it just looks wet, like the soil just took all that water and soaked it right in. That's the main thing… it's looking at how the water behaves and how it feels under your feet".

Almost all of the farmers and land managers interviewed send their soil samples to a lab for nutrient analysis. These include: total nutrient content of macro and micronutrients, pH, cation exchange capacity, and other laboratory-based indicator analyses. Similarly, almost all of the farmers interviewed collect tissue samples to understand plant nutrient availability at different growing times of the year. Although little can be done to augment nutrient levels for a current crop, these samples provide information on what may be lacking for the following year's crop. "…in the fall, they just took our soil analysis just recently, and that'll help us evaluate, we don't do that every year, we do that every other year. And we base our fertilizer on our analysis, we do a leaf analysis in the summer…"

All but one farmer specifically uses crop health as an indicator of soil health. "…at the end of the day, yield is how we pay bills. So, yield as a function of quality and quantity…" (Sean Benson). For this particular farming operation, they've established Key Performance Indicators (KPIs) to measure the success of most parts of the farm: "…so one of my challenges is to come up with KPI's… Fertility, how efficiently did we use our fertilizer budget? Did we, because you know there are different forms of nutrients cost different amounts of money…" Most farmers interviewed utilize multiple indicators to determine the health of their soil.

> "First and foremost, we soil test almost every field every year. So, we know what the chemistry it's in the soil and what is high enough in and what it lacks. We can also see growing pains in the crops. You can see this field lacks something, corn for example, quite readable. You can look at the leaves and say, 'well that lacks zinc or something. And also, I go by my own records which I keep from year to year. And I know what's been applied to the soil and I know what those tests are".

80% of the farmers interviewed specifically cited soil organic matter as a measure of healthy soil. Organic matter can be measured with lab analysis or in-the field observation. This is extremely important, since organic matter can be used as a bridge between soil scientists and farmers to define soil health (de Souza Mello Bicalho & dos Guimaraes Peixoto, 2016). In addition, less than half of the farmers use soil biological indicators, in addition to other physical and chemical indicators: "…so you're looking at the crop, the tree health the petioles, right? So, we do petioles twice a year for tree fruit and we do soil samples every couple years since they don't change as rapidly. What's out there? Are we having a disease infestation? What is the view? Is the soil hard and compact, or is it soft and pliable? Are there earthworms? Are there bugs? What's there?"

Technology plays an important role for some farmers and land managers: two discussed the use of drones to take aerial photographs. This practice allows farmers to observe color variations and crop health from a much larger scale. Two other farmers use Electrical Conductivity maps; a non-metallic cart drives over the soil and measures the electrical current of a given field, which can tell you the salinity or sodicity of your soil, (and essentially measures pH) (Grisso et al., n.d.). One farmer uses the NRCS' Web Soil Survey to understand the soil type and textural analysis of a given field.

Four farmers explained that they just have a feeling or intuition about a given field that is difficult to quantify or replicate in a laboratory setting. "We're not real scientists trying to measure everything. But somewhat as a feeling, an observation more. Seeing the health of your vines. Is your fruit set even? How do the vines look and respond? Is your crop good, or is it starting to languish…" Another farmer takes a completely different approach, which he attributes to his educational and agricultural background. "Personally, I'm oriented towards what I see the crop doing and what I see on the soil test. So, I don't feel the soil for moisture content, probably because I was just never trained or had a need to do it that way. I think it's a valid way. If I handled soil more, I'd probably know more… It's not how I approach it so its not how I fit it into my schedule".

There are a number of methods used by farmers to measure the quality of their soil. In-the-field observation was described specifically by almost all of the participants interviewed, along with crop indicators and soil and tissue laboratory analyses. Recent technological advancements assist a few of these farmers and land managers with aerial photography and electrical conductivity. And some suggest that their 'feelings' or intuition, things that are difficult to explicate, help them to evaluate their soil health.

Texture analysis and knowledge of geological history

Similar to indicators of soil quality, some farmers had extensive knowledge of the texture of their own soil; texture, as defined by the amount of sand, silt and clay within a particular soil, can vary drastically even within one field (Brady & Weil, 2010). Having an understanding of textural characteristics indicates that farmers are either working closely with their soil or are aware of what soil textures are ideal for certain crops and forms of agriculture. All farmers have an understanding of their soil texture in some manner or another. As previously discussed, one farmer found an entire caliche layer in her soil after an eight-foot deep soil horizon analysis.

Over half of the participants described the soil texture of their area. "The further east you go, it gets a little worse… its more caliche, hardpan layers underneath. The soil varies a lot here. I can dig down with a back-hoe 15 feet and not hit a rock. Up there, I go down two feet, I won't be so lucky… it's a caliche layer, its impermeable, water does not go through it". In addition, at least 6 farmers were well aware of the climate in which they farm, explaining that their soils naturally have low levels of organic matter.

In addition, I noted farmers' understanding of the geological history of the area to see if geological knowledge was linked to soil health knowledge; eleven of the fifteen farmers and land managers described the land's history in some capacity. Of the farmers that were aware of the geological history, over half related soil texture to the land forming processes of the area.

> "…we do have some clay in some of our western slopes… I think our classification is Warden Sandy Loam. So, as wine growers, you focus on this block and this block and the very nuances of the soil and how that carries over to the wine and their flavors and aromas that come from that. So, you're kind of tuned in to some of that. This is really a unique peninsula coming out of Uhtanum Ridge. Most of the ridgelines go kind of east-west, whereas this little peninsula juts out of that, so we've got West, East South-facing slopes and they're all different. The west is kind of shallower, a little more rocky, a little more clay. But the prevailing wind comes from Mt. Adams, and over the millions of years, its kind of blown some of the sand and silt over the ridge, so the east side is kind of a silty loam, a little deeper soils, so very different. South is kind of a blend of both… Very volcanic. We've got areas, cutouts where you just see hundreds of layers of the ash and maybe when the rivers came through. There's just a lot of deposits, a lot of sandstone outcroppings underlay a lot of this".

As previously described, the Yakima Valley was formed over millions of years of lava flows, volcanic activity, tectonic shifts, glaciations, as well as massive floods from the Great Missoula Floods (Campbell, 1981). Over half of the participants described floods of some sort, while most of these individuals cited the Missoula floods in particular. Less than half described volcanic activity, and exactly half alluded to the impact of glaciers on the soil formation of the area. One farmer disagrees entirely with what is believed to be the geological formation of the area.

> "So, my belief system is that, geologically, there was a catastrophe, and everything that I see geologically is that there was a large body of water, it broke through. There was a flood that came through and it left sediments. And those are actually fairly recent. All the evidence that I see, if you look at all the rivers that are going into the ocean, every river in the world. The sediment, the oldest sediment is only 6,000 years. There's just no evidence of a world that is older than 6 or 7 thousand years"

Of all farmers interviewed, I considered four to have extensive knowledge of the geological formation of the area.

> "I've had a minor interest in geology for years, and I've read a few books about the Missoula floods which have formed a lot of our soils in this area. So, my wife and I would take trips and we'd follow the paths of the floods of Missoula all the way up to Sand Point, Idaho, and down here, and all the way down to Portland. It's pretty interesting just the way all of our soils were formed in that. One of the things that I noticed was that the rock patches that we all have at certain levels around the soil. And for years I wondered, now why is that patch of rocks there? Did somebody farm this before I did and threw a bunch of rock in a hole? As I studied more about the Missoula floods, I learned more about the floating ice debris that came down carrying all of these rocks. And as the flood receded, it backed clear up into this valley here, as the floods receded, these icebergs became stranded usually on the slopes of the land".

Understanding the texture of one's soils shows how closely these individuals work with their land, and what tools they use to better understand their local environment. While most farmers described some sort of textural analysis, others were able to provide more in-depth information based on personal experience or education. Half of the farmers related the texture of their soils to the geological formation of the area, and eleven of these individuals described the geological formation of the area in some capacity. While some had more in-depth knowledge and understanding of the texture and geological formation of the area, most of these individuals possessed at least a basic understanding of the soil's texture and formation.

Risk aversion

Many farmers are blamed for contributing to climate change and land degradation, and some feel as though they are the scapegoat of many of the world's environmental problems (Walder & Kantelhardt, 2018). What must be considered with farming is that even if these individuals consider themselves to be stewards of the earth, their livelihood and their family's survival depends on the quality and quantity of their crops. Many are forced to choose to receive what an immediate return as opposed to maintaining long-term environmental health (Boehm & Burton, 1997). Applying synthetic nutrients is a tried and true method passed on to many of today's farmers from their parents. With a more long-term approach like organic or sustainable farming practices, the payout may not be immediate, and risk may be involved when making decisions to ensure long-term soil and environmental stability in their locality (Bowman & Zilberman, 2013).

With a particular focus on financial risk, I asked farmers to identify any risks they find with land improvement, countered with risks involved with practices that degrade their soil. Many farmers discussed the impact of fluctuating markets on their chosen practices, and they also emphasized how financial stress may limit all what they wish to accomplish on their land. In addition, I asked farmers to describe their dream farm: if money, labor or other limiting factors were not present, would they change their management practices?

These questions help to inform how this group of farmers and land managers view risk, and what measures they may take to avoid losing their livelihood.

Risks with improvement included financial, time, production and even soil health for some of the participants. 80% of the farmers interviewed believed that some financial risk was involved with improving overall soil health. “The risks are your costs. A lot of the things that we do are expensive. Yeah, we could go out and buy a whole bunch of glyphosate and do it a whole lot cheaper, for sure”. Other farmers echoed these concerns, particularly when one first adopts more sustainable practices: “Well, the first risk in improving too much too rapidly is you spend more than you can get back. Which is reality, we can’t do it unless we can afford to do it. And sometimes we don’t get to control what we get out of our product, that makes it hard”. Another farmer identified financial risks between high and low-income crops. “Another risk with improving the soil is if you see that its low in certain elements, and you have a low-income crop like wheat on it, it’s a financial risk to apply more than the wheat is going to use. Normally, you would like to apply enough to bring the soil up to ‘specs, but economic returns say you can’t do that with a crop like wheat. On a high-income crop like hops or mint, you give it whatever it needs to get production. Because that’s the name of the game”.

For farmers in hops, which has experienced a significant increase in demand due to the growing craft brewery market (Taylor, 2016), they are investing that money into their soil bank. “Improving it I guess is the cost. We’re in a hop market right now, I think the best, the very best way to spend that windfall is put that money right in the soil bank. Because I think now… every conversation I’ve had with the higher-ups, is that really makes sense is that if your soil is really good, it can help you get through those lean times.

Milk that soil a little bit and it'll be a lot more forgiving". Even with a financial risk, other farmers asserted that the benefits outweigh the risks, especially if management is on board with the decisions. "It's expensive to be so, taking the tests, but I think there's a benefit. I don't know if I could measure it, what the benefit is. If I had to sell this to a boss… that would be challenging. So if ownership is not on the page, it could look like expenses are changing drastically". Another farmer sees these risks as a necessity. "Well, I think its financial, in the long run, it's a necessity. If you start cutting corners farming, you're not gonna make it".

Closely linked to the financial risk is production; when changing one's management approach, yields may change initially or continuously. Almost half of the participants identified production as a hazard to improving soil health. "The risks are production, if you do something that hurts your production out of the industry standards. It is a real chance. When all your neighbors are using something that works, and they can make a profit at it, it's really hard to go against that industry standard and try something new". This same farmer explained that his long-term approach may not work for everybody. "I am fairly cautious with making decisions, so it does take quite a bit of time to make the changes, so there is an expense involved. We are all risk-averse to some point. I can't run the farm into the ground taking chances. Most of the changes, you know, over a 40-year period. So, it's not something that's done [quickly]". Four other farmers agree that time is a risk when adopting management practices that improve soil health.

Another farmer saw both time and money as the largest risks but maintains a long-term perspective to justify his management methods.

"To improve soil, because to affect change in the soil, for the most part, it usually takes a significant amount of time. And it can take significant amounts of money. And the benefits

> may not be immediately apparent. So, that requires the intestinal fortitude to be able to spend money that's difficult to see how its gonna pay back in the short term. But if you take a long-term, and they [the owners] want to be sustainable in the long-term. That you are investing in your soil, will pay off".

Another hop agronomist admitted that soil improvement is a positive coincidence, but typically is not a farmer's main goal. "Nobody has that as the primary goal. The prime goal is to stay profitable, and if we can improve soils without costing too much, and in the end, it will improve yield because everything is more healthy, then we can do it… but just serving the soil is no one's goal, you know? They're running farms so they have to produce things that people want to buy. That's the main goal".

Three farmers and land managers believe that if you make the wrong decisions, it could impact the health of the soil, which would impact time, productivity, and consequently, profit.

> "So sometimes you've just gotta trust that the new idea is the right idea. And so, I guess if it didn't work, and the way Grandpa used to do it was still better, you're out a whole bunch of money, and maybe the bank doesn't like you anymore… trying new things can set you back a year or two or three. I mean, you might do some damage to your soil, that could take years to recover from. Soil does heal itself to some extent, I think, but some damage can be done to it".

One farmer believed that implementing practices to improve soil health may inhibit one's ability to see small-seeded plants when planting. Another agronomist believed the greatest risk was wasting data: "The data that we put into it. And if it's not representative, if its skewed, then everything is skewed. And we're not dealing with reality".

Farmers expressed similar risks when management practices degrade soil; financial, production, and time were conveyed as potential risks of soil degradation. Few farmers described environmental impact as another risk to soil degradation. Nine farmers expressed financial risk as a consequence of soil degrading practices: "No growth, no farm, no income. And the bank takes your place and you're homeless. That's it". In addition, seven farmers described productivity risks as a consequence of soil degradation, which leads to financial risks. "The risk of not doing it is worse because if your soil isn't healthy, it isn't well cared for, you're not going to get the yields that you need to be profitable. And in the end, in reality, any business, whether its farming or whatever, it has to be profitable to continue". Even if he loses profit in the short-term, this same farmer would rather suffer that risk than what he believes to be long-term financial loss with soil degradation. "So, we can't ask whatever we want for our food, we take what we can get. So, we have to balance that, we can't ignore the things we need to do, but we have to be careful that we do them in a time-like fashion that will allow us to succeed. And we have to be willing to give up profit, at least in the short term, to maintain profitability in the long term".

Most participants expressed a combination of factors that are potential risks attributed to soil degradation, but many believed that everything suffers with poor soil management. "The biggest risk to letting it go is I mean everything suffers. Your yield suffers, you gotta spend a lot more money on fertilizers and you get a lot less out of it. Got more disease, but letting it degrade, I don't think people realize how much that costs them". Another farmer recognizes that cutting corners or not putting forth the effort hinders leads to loss of one's farm. "I don't know how you get a benefit out of it. It's like, the previous owner of this ground, he went bankrupt for a reason… I know why, because he wasn't spending any money on soil management… So, we spent the money that he didn't, and we made it better. We did the things he wasn't willing to do and made it better and now we grow awesome crops on it. If you don't take care of what you have, God goes, "I'll give it to someone that cares, its making me mad.'".

Although production and financial risks were addressed for both soil improving and soil degrading practices, there was a clear recognition of short-term versus long-term risks; many of the farmers interviewed recognized that some short-term risks were involved with soil improvement, but most recognized that the risk of losing a farm is far greater if an individual cuts corners and does not farm with soil in mind. One farmer understands this perspective but doesn't blame farmers for doing what they have to do in the short-term to maintain yields. "There's a financial risk because like I said some of those pay-offs can take quite a long time. Or can take time to manifest, and in an age where we're used to immediate solutions to problems, that can be a challenge… Now if you're under financial distress or some very strict financial criteria, then it's really difficult to take that short-term risk. It's tough on people in that situation. I don't blame them for what they're doing".

Understanding this basic principle, that farmers make management decisions in order to keep their operation afloat short-term, justifies why many may incorporate practices that do not always improve soil health (Boehm & Burton, 1997; Doran, 2002). Society must understand that farmers exist in an economic environment where they are subject to market demands and may have to cut corners to turn a profit. Misunderstandings between the general public and this reality force farmers to feel that they are under attack for 'ruining the environment' (Bowman & Zilberman, 2013). If the public were to recognize that farmers have a deep appreciation for their land and view themselves as land stewards, this stigma may change.

Market demands

Almost all farmers expressed concerns with being subjected to market demands. As described previously, farmers do not determine what prices they receive for their crop.

Many choose to grow high-value crops like hops and mint, which typically face less fluctuation in the market and are worth more money (especially hops in our current market). In addition, many farmers choose to grow organically because of the higher profits they receive (Annunziata & Vecchio, 2016). For those that grow commodity crops like wheat and corn, though, the highly saturated market may force them to make management decisions that they may not necessarily agree with (Angadjivand, 2018); but as previously addressed, it may become a matter of saving the soil or saving the farm in the short-term (Boehm & Burton, 1997).

> "If people understand what it takes to grow a crop… it's hard because you know the growers are the ones at the bottom of the barrel… We like farming so much, we do it for nothing and quite often have to, because the markets fluctuate and if you're at the top of the market, great. But the market's usually not high for very long, because the growers are the first ones to go out. Boom. They see there's a need, boom, and everybody will go out and grow it, and pretty soon there's nothing. But you certainly don't see that in the grocery store. And the processors, and the big chains, are the ones who take advantage of the growers… At one time, people used to make a living on 40 acres or less, but now, you know, I think the average growers gotta have at least 500 acres of diversified crops. And wheat growers gotta have at least 2,000 acres. It's just a lot different".

For example, one of the farmers grew organic squash for a large wholesaler on the West Coast. Like every farmer, she had a margin she needed to maintain for her farming operation and could not sell her crop for a lower price. She was in competition with larger farmers in Mexico who could grow the crops for much less and at a much larger scale than herself. Because she could not receive less income for her crop, the retailer chose to purchase squash exclusively from the larger Mexican farm. This farmer now grows hay and is taking time to re-assess her options. Even though there are many dairies in the area that require hay, she still has to compete with larger operations along the Interstate 90 corridor. This is a common issue for low-value crops like vegetables, grains and forage (Angadjivand, 2018).

Apples, one of the biggest crops of the area, is in a low market; new varieties are coming out, and the demand for these older varieties forces farmers to pull out their older varieties and plant newer ones (Chokshi, 2018). Since it takes at least three years before apple trees turn a profit, this is a time of farm closures and consolidation, where smaller farms are purchased by larger operations that can withstand the financial instability. One smaller apple farmer expressed this concern.

> "…we're trying to keep up with these new varieties. The old varieties don't bring in as much money. It's pretty expensive [to pull old trees out] and put in new ones… [Trees begin producing] in the 3rd leaf, 4th leaf [year], well not what you would call a big return but a sustainable return. When you get into 5, 6 years, it takes a while… what's happening right now is certain varieties don't have as much demand for it. There's nothing wrong with the apple, like those Jon-a-golds we took out. It's just the stores don't want them as much and they don't want to use up the shelf space for them and the demand drops off…"

Four farmers explained that their crop was in high demand, either because of their choice of crop, longevity in the market, or a combination. As previously explained, the demand for hops is much higher than some other crops in the region, due to the craft brewery boom in the past decade (Taylor, 2016). One individual is an R&D specialist and expressed that he would not have a job if the market was low in his crop. "…Research and Development, especially in agriculture… it's an up-market game… It seems that it's kind of a luxury kind of thing. It's an investment, but I think you'd get down to bare bones pretty quick". Another agronomist for a hop grower recognizes that markets fluctuate and discusses that more experienced farmers know that the market won't always stay up like it is now.

> "…the older generation, the guys in their 60s and older have seen the bottoms a couple times in their lifetime. And people always go out of business in the bottoms, and those that don't got out of business in the bottoms, and those that don't go out of business have to tighten their belts so much that it's just not fun… So now its roughly about 40 in our area. And they've all gotten bigger because they bought when the hop farmer next to them went out of business and had 300 acres or 600 acres and he couldn't make it anymore… it's a

generational thing of who's seen the low markets. And the craft brew industry has only come up in the last 15-20 years… and they're mad for hops and the price of hops, so it's been good money for the hops for the last 5, 6, 7, 8 years. So, anybody that came into it then, they think its all great. But all the old timers know it's not gonna last, it never does".

Three farmers emphasized the regulatory demands imposed upon them, and as previously discussed, quality control impositions can be a nuisance, as well.

"There's a benefit to it (Global GAP certification), for sure, but it wasn't developed by a grower by any means. So, it's a weird framework that's put onto a farm that says you must do, or you should do, or this is how you should track these things. So that's always, it's just difficult because it's a different industry that's imposing that, versus everybody has their own system in farming. In terms of how they perform different activities, so when an auditor comes in they can get a fast view within a day's period of what they want to see. It's just tedious to be honest, so it takes a lot of time. I think it's going to drive a lot of farmers out of business, or it already has, because they don't know how to comply…"

Other financial stressors impose limits on farmers' abilities, including labor and profits. Half of the farmers addressed concerns with labor, and all of the orchardists vocalized serious constraints imposed upon them by governmental mandates.

"A lot of these guys make pretty good money out here, they make more than I do. You listen to these people on TV, these guys are destitute and all that, they make pretty good money. I have some guys that are making $20 an hour. When they're pruning and picking apples and cherries, they make that much money… we've always paid over minimum, because you can't get them to work for minimum… What's driven up the price, too, is the H2A program. And those guys, every time, they have to furnish their housing and transportation and everything like that."

Many of these farmers obviously do not wish to impose on the rights of their workers, but the small to medium-sized farmers feel strapped because they have little say on how much they pay their laborers, even though their own profits do not increase.

While one vineyard-owner is trying to resist complete mechanization as long as possible, it may be something he's forced to do due to a limited work force, and to cut costs: "I can definitely see us in a few years, you know, picking our grapes mostly mechanized… We're resisting as long as we can, but we're talking more and more about it.

It's just the reality of things. You gotta be able to pay the bills and stuff". While consumer and farmer preferences may prioritize one objective, the reality of making money frequently dictates how farmers manage their land (Bowman & Zilberman, 2013).

As mentioned before, profits limit management decisions. One farmer explained that while their crop is in high demand and they are turning a significant profit, they are able to invest in their 'soil bank'. Many others recognize that farmers are forced to 'mistreat' their soil during leaner times.

> "If you're not in the black, you don't stay in business… I think every farm is concerned about soil health. Everybody that's farming the ground is concerned about it. And if they're doing things that are damaging to the soil health, it's not because they want to or they feel good about it, but they have gotten to a point where that's kind of all they know, the way they do things and they'd lit to be different but they don't know how to make it different… if they got 20 or 30% more for their goods so there was some slack in their budget, then they could experiment more and take the risk of lower yields".

In accordance with Boehm & Burton (1997), at least half of these farmers echoed these sentiments.

Many farmers also cited issues with quality assurance; this involves some optional marketing standards like Global G.A.P, Organic Certification, and other programs used to ensure food safety/traceability, environmental and biodiversity conservation, worker health and safety, and animal welfare (Global G.A.P). The incorporation of some of these practices have altered the status quo, forcing farmers to confirm to these standards with little regard to the costs required to implement these new practices. Even though some farmers did not participate in these certification standards, five farmers described instances in which quality assurance measures negatively impacted their day to day proceedings. In addition, 1/3 of the total participants believed some quality assurance measures were tough on smaller operations. When describing the demands of their hop handler, one farmer felt pressured to implement measures that he didn't believe were fit for his farm. "Anything that is asked of us, we're going to do. But I'm not going to be listed to it unless its asked of us…the less reviews we have the better. I mean, It's time consuming. We're not very big…there's only 11 of us [right now]" (Leo Loza and Jr.).

The issue of identity and ideology may come into question when farmers are faced with market demands and profit maximization. As described throughout this review, the one factor unifying almost all farmers is that they perceive themselves as stewards of the land and will take whatever measures necessary to protect their local ecosystems and environment (Sulemana & James, 2014). When faced with feeding their families and maintaining their businesses, though, many farmers will make decisions that may have negative impacts on the environment. Because of the difficult decisions farmers must make to survive, many feel they are blamed for total environmental degradation (Walder & Kantelhardt, 2018). Many farmers have addressed a short-term versus long-term perspective on farm profitability; while many believe that conserving natural resources will benefit them in the long-term, they do not blame their peers for making management decisions that keep their farm afloat for the next year. Farmers face a number of complex issues, and their motivations or aversions to implement soil conserving practices represent the complexity that is their farm system and business.

Dream farm description

There were a number of concerns voiced by the participants of this study; most of them discussed the pressures imposed on all farmers by market and consumer demands. In order to see how these farmers would manage their land without worrying about profit or survival, and to understand how risk aversion supersedes an individual's farming philosophy and farming identity, I asked them how they would farm if there were no financial or labor-related factors to consider… a dream question. Although this is an impossible scenario, and seemingly unrealistic to implement, I was curious to find out if they would farm differently if all restrictions or constraints had been removed. In particular, I wanted to know if they would farm more with the soil in mind or otherwise. Because it can be difficult to separate fantasy from reality, some farmers were confused by this question, especially concerning labor; even so, this question yielded interesting results.

Over half of the farmers would utilize more precision agriculture, or improved technology on their farm. Some wished to use sensors to measure evapotranspiration rates and crop health, while others hoped to apply nutrients on a plant-by-plant basis.

> "…I think technology is the only thing, if that wasn't the limiting factor. Because there are a lot of ways to measure water and filtration and temperature and those things, but they're in the 'unproven zone'. Like we've experimented with a few, and we're like, okay, not working. The one that we use, we only get to see weekly, which is frustrating because we want to make our decisions now. So, I think that's going to change with time, but it's really expensive".

Others foresee more data and precision in agriculture: "So the future is gonna be very very much more precision irrigation… more knowledge and data driven and precise… It's gonna be more of a scalpel than a sledgehammer. It's probably [not] gonna be like blanket solutions, but what's right for this part of the file is not what's right for where that survey tape is, and so it'll be different". In agreement with Brodt et al. (2006), the farmers in this study believe that the inclusion of precision agricultural technologies, like customized spray-systems and water and nutrient monitoring sensors will help farmers increase efficiency and minimize negative impacts on the environment.

Others would find better ways to collect and manage data over different time-scales.

"I think the obstacles now are there's a lack of knowledge in terms of quantifying different things… that's why I have a job, I'm trying to quantify different investments, so I mean there's a sense that perennial cover crops are good, reduced tillage is good, how does it affect the crop, how does it affect the bottom line, what are the long-term soil effects, on and on and on down the line. "I wish I had a guy that all he did, once a week, he went to every field, was pulling soil samples, you know… If I could take overhead pictures and log it so I can go back year after year and go, 'what do I got going different here? I did this technique and is it paying off? Can I see differences?"

Others asked for better machinery in general, in terms of increased mechanization, while two specifically would implement less mechanization. "I would actually do quite a bit of labor that would not be permanent labor, that would be young people. And they would work through the system. And much more would be hand-done. I think there's benefit to that, benefit to the people and benefit to the land… I like mechanization because it makes life simpler, I think that that is harmful to the soil, I think it's harmful to society. I think it's the biggest problem". Another farmer asked for better legislation, or regulation that was written by and for farmers.

Three farmers would farm with soil health in mind, whether it was managing based on specific soil type, or to farm like older generations.

"Definitely would be out here a lot more, getting a better picture of techniques, whether they were working or not… I wish I could break it up into 10-acre blocks where I could really narrow it down. Manage based on soil type, slopes versus the valleys versus the edges. You know, I'm out here spreading fertilizer right now going over these slopes, up on top of the bench, down into the valley, and I'm doing the same mix for all three areas, and I know they're all different. But I just don't have the time or the money to differentiate".

Another farmer would farm like his grandfather:

"I'd probably grow a lot easier crops likle alfalfa hay or something like that because, but I'd still like to keep the ground in the family, you know. And when my grandfather started farming, his 3 crops were wheat, alfalfa hay and potatoes. And so, I don't know, I'd want to go back to those three… the hay and the wheat would actually give you the opportunity to improve the soil. And in the past, you know, in the olden days, your soil was your most important asset, and I think it still is".

Five farmers would improve overall fertility and nutrients and some mentioned bringing nutrients up to proper levels for their crops. "…maybe improving the levels in all of the soil, that would be one thing. Bring them up to, instead of the bare minimum, up to the proper level of phosphate and potash". On the other hand, at least two farmers would try to use less chemicals. "If money was no factor, I would definitely remove all the chemicals, not because I'm against chemicals, but I think the chemicals make us lazy… I'd really dig into how we can do it and do it naturally. Because if there were no barriers of economics involved, then we could more rapidly discover a healthy way of doing it that would help the consumer and help the economics of agriculture, too".

Curiously enough, five farmers would not change much; one farmer said they would farm the same way, but get there faster, while others said they enjoyed what they were doing, and that they already farmed with plant and soil health as a main priority. One farmer believed it was her inherent duty to leave her soil better than she found it:

> "…my whole thought on farming is to do it organically, naturally and to the best of my ability. I was born a farmer's daughter. Genetically, I have a love for what I'm doing. And I know the responsibility that I need and have on my shoulders. And that is to make this soil better conditioned than when I got it. And whoever it goes to, because everything that's here is not mine, it belongs to the lord. And so when I die, whoever takes over this soil and works this farm will have it in better shape than I received it" (Janelle Moses).

Based on their responses, the participants in my study understand that their cohort farm to survive; if the market or economic pressures are not in their favor, they may have to make management decisions that could cost them in the short term (Boehm & Burton, 1997). Even so, most of them are farming with plant and soil health in mind, and even without the pressures imposed upon them, they hope to improve their soil for the following generations.

Interview results takeaway

Through an extensive analysis of interview data with fifteen farmers in the Yakima Valley, I was able to understand many aspects of the farmers' soil health knowledge, where that knowledge originates, and how it is compares to established indicators of soil health. Farmers interviewed come from a diverse background, but most have gathered experience from farming through their families, education, experience or a combination of the three. The communities and networks in which they operate vary, but many rely on each other for advice and help during difficult times. Their trust in the public and private sector varies, but most work with some outside organizations for advice or input on their management decisions.

In terms of identity, the results of these interviews suggest that the Productivist-Conservationist dichotomy overlooks much of the complexity that composes each farmer, farm system and farm community. All farmers, whether perceived as Productivist or Conservationist by the literature, valued soil health. Most had an understanding of ways to improve or degrade soil health; notably, all farmers prioritized the accumulation of organic matter, and understood the important role it plays in overall soil health. Education type determined the knowledge upheld by farmers concerning more complex characteristics of soil health, like soil biology and chemistry; however, the majority of farmers had a solid understanding of soil physical characteristics. This is most likely due to the visible causal relationships between management practices and soil structure.

Many of the farmers interviewed understand that soil conservation and improvement is a long-term approach to farm profitability and recognize that there may be certain short-term risks involved when enhancing soil health. Nevertheless, many farmers do not blame other farmers for implementing environmentally-degradative practices, since fluctuating markets and consumer demands make success difficult to achieve in most farming operations. Nevertheless, when imagining a dream farm scenario in which no restrictions on constraints were imposed upon them, many of the participants in this study would work to maintain their ‘soil bank’ for the future.

Soil sampling results and discussion

For both high and low fertility sites, 150 soil samples were analyzed for bulk density, percent carbon and percent nitrogen. Samples were collected from 30 different sites where 7 different crop types were grown: blueberries, grapes, hay/pasture, hops, mint, orchard, and row crops. All samples were collected in Yakima County, Washington at a depth of 5-7 cm in a semi-arid climate. I first compared the efficacy of the measurements themselves as a successful means to express organic matter content in the collected samples. In addition, high and low fertility samples were compared to see if farmers accurately described sites of high and low fertility.

It was necessary to identify any correlations between the established indicators of soil health with the seven categories of SHK defined by the fifteen participants. These included: demographic factors, education, trust in Internal and external groups, history, farming identity, farming philosophy, and risk aversion. My first step in this process was to conduct Multiple Linear Regressions (MLRs) to generate hypotheses based on potential correlations between a series of categorical variables (farmer responses) with continuous variables (soil health indicators).

Using analysis of variance (ANOVA) as well as paired t-tests, I explored the validity of my initial hypothesis, that older farmers, born in the Yakima Valley into farming families (with at least three generations of familial farming) that are well-connected to their agricultural communities (specifically through a farm café) will have higher levels of organic matter, and better soil health. I used the same method to analyze potential correlations generated through the MLR process. By combining both soil sample results and interview responses, I hope to comprehend how the SHK of farmers can be represented through specific indicators of soil health, and what factors have a greater influence over the accumulation of organic matter in agricultural soils of this region.

Distribution of selected variables

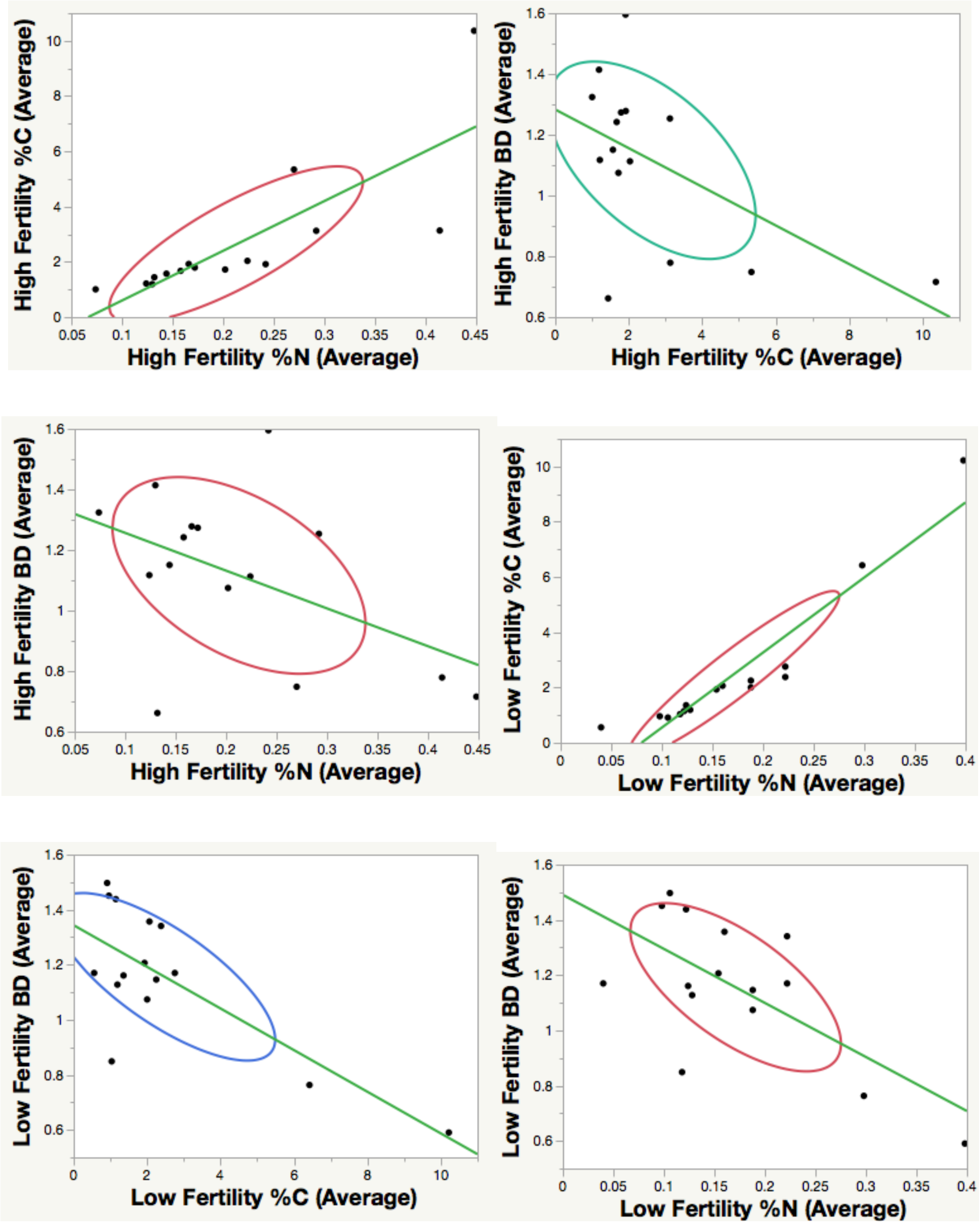

Figure 14: Correlation between BD, %N and %C for HF and LF sites

To measure soil health, I compared results of high and low fertility sites for bulk density (BD), percent carbon (%C) and percent nitrogen (%N) (Figure 14). As previously discussed, organic matter is one of the most important indicators of soil health, since both farmers and scientists are aware of the benefits of organic matter accumulation to improved soil quality (D'Hose et al., 2014; de Souza Mello Bicalho & dos Guimaraes Peixoto, 2016). In order to assess the efficacy of these samples as measurements of soil health, and specifically, as indicators of levels of organic matter, I conducted an ANOVA test to identify correlations between the SOM indicators with the fifteen high fertility (HF) and low fertility (LF) samples. Tables 6, 7, and 8 [27] indicate that all samples show correlation between HF and LF BD, %C and %N. This means that these measurements are indicative of levels of organic matter and can be used as effective measures of soil health. For example, the greater the %C in HF sites, the greater the increase of %N. Also, the greater the BD on LF sites, the lower the %C. With an R^2 value ranging from 0.23 to 0.89 and a p-value ranging from 0.03 to < 0.0001, one can say that all correlations are at least significant[28].

For bulk density, R^2 values ranged from 0.23 to 0.56 and p-values range from 0.0014 to 0.07; this indicates that bulk density is a significant indicator of soil health (Table 3). According to Kuykendall (2008), increased soil organic matter content results in lowered bulk density, which allows for increased water infiltration and retention, improved soil structural integrity, aggregate stability, as well as friability and tilth. Bulk density is an indirect measure of soil health, since a decrease in bulk density is not a direct measurement of the chemical constituents of organic matter. Because of this, other indicators had even more significant results.

The strongest correlations can be found between HF & LF %C and %N (HF %C and %N $R^2 = 0.64$and p-value = 0.0004; LF %C and %N $R^2 = 0.89$ and p-value =

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[27] See Appendix p. 321

[28] Significant correlations: R^2 value above 0.2 and p-value below 0.05; Noteworthy correlations: R^2 above 0.15 and p-0value less than 0.2

<0.0001) (Table 7). As explained by Dieckow et al. (2007), the most reliable measurement methods for soil organic matter are carbon and nitrogen and can serve as the first analytical measurement of organic matter. Specifically, carbon and nitrogen compose the various forms of organic matter, from sugars to carbohydrates, proteins and lignin (Bosatta & Agren, 1991). As direct representatives of the nutrient cycling of organic matter, it makes sense that these measurements would have the most significant indicators of increased levels of organic matter. Based on the selected indicators, it is possible to measure soil health as well as organic matter content based on bulk density, percent carbon and percent nitrogen.

Total sample descriptive analysis

Average BD, %C and %N were compared for all 150 soil samples collected. The average bulk density measurement was 1.15 g/cm^3 with a standard deviation of 0.29; the lowest being 0.47 g/cm^3 from blueberries and the highest 1.68 g/cm^3 under row crops. For %C, the average measurement was 2.72% with a standard deviation of 3.49; the lowest sample reading is 0.43% for row crops and the highest being 26.3% for blueberries. %N for the 150 soil samples taken averaged 0.19% with a standard deviation of 0.13. The lowest sample had merely 0.03%N for row crops while the highest was 0.86% N for blueberries.

Samples showed great variability between farms and farm sites; a key overall trend can be observed between crop type and soil health indicators. As described above, blueberries had the highest values for soil health while row crops were the lowest. A notable finding are the minimums and maximums found for BD, %C and %N; minimums, or indicators of poorer soil health, were observed for %C and %N in row crop systems. Blueberries, on the other hand, yielded the best soil health indicators, with higher %C and %N and lower BD than any other cropping system recorded. This is an extremely important point, and the impact of crop type on predicting high and low fertility for BD, %C and %N will be covered in detail later in this study.

High and low fertility

When asking farmers to identify sites of high fertility and low fertility (or high and low organic matter content), my results diverge from those found in similar studies. As a whole, there were no significant differences between either of the three variables: BD, %C or %N. Results are represented in the graphs below.

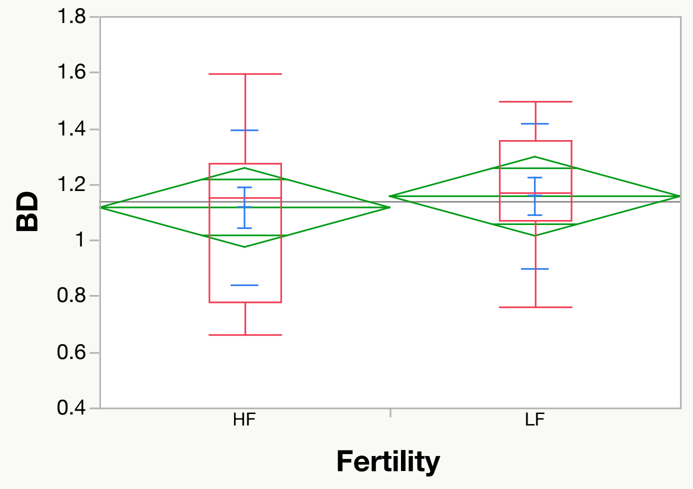

Figure 15: Paired t-test comparing HF & LF BD

As represented in the graph above, the range between minimums and maximums for BD for the high fertility and low fertility sites is roughly the same (HF min: 0.66 g/cm^3, HF max: 1.60 g/cm^3; LF min: 0.59 g/cm^3, LF max: 1.5 g/cm^3). A larger proportion of the high fertility samples were below the line of best fit and the mean for high fertility sites is slightly lower (HF M=1.11, SD=0.28; LF M=1.16, SD=0.26). While lower BD is an indication of better soil health, there was still little difference observed.

High fertility and low fertility sites showed virtually no difference in mean BD ($R^2 = 0.006$, $p = 0.34$)

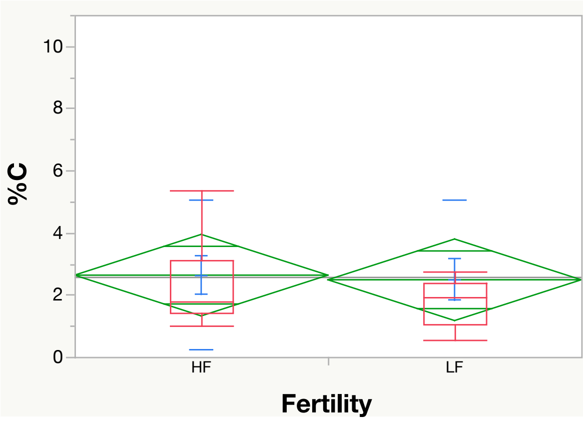

Figure 16: Paired t-test comparing HF & LF %C

Little variation exists between high and low fertility sites for %C, as well (HF min: 1 %C, HF max 10.36 %C; LF min: 0.56 %C, LF max: 10.2). A larger proportion of high fertility samples were above the line of best fit (indicating a higher %C); however, the mean for high fertility sites is only slightly higher than the mean for low fertility sites (HF M= 2.63 %C, SD=2.4; LF M=2.48 %C, SD=2.56). With an R^2 of 0.001 and a p value of 0.56, there is no significant difference between high fertility and low fertility %C values.

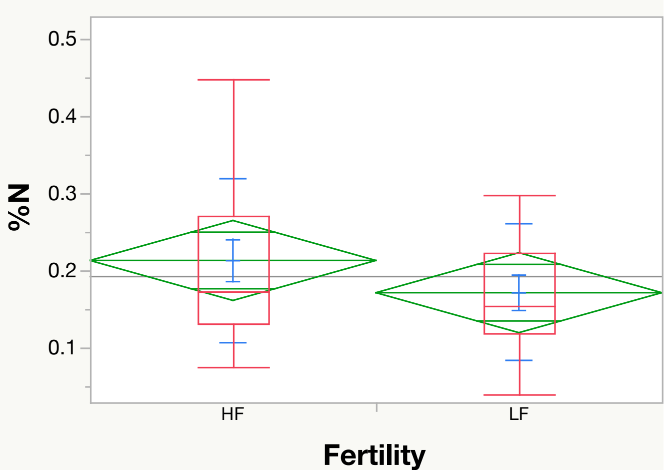

Figure 17: Paired t-test comparing HF & LF %N

While similar results were observed for the HF & LF %N, there was slightly more variation between the two than for %C and BD. The range was somewhat higher for the high fertility sites than the low fertility sites (HF min: 0.07 %N, HF max: 0.45 %N; LF min: 0.04 %N, LF max: 0.40 %N). Comparable to %C, a larger proportion of samples were above the line of best fit, but little variation can be discerned. With a slightly higher HF mean value (HF M=0.21 %N, SD=0.11; LF M=0.17, SD=0.09), an R^2 value of 0.05 and a p-value of 0.25, there is no significant difference between high fertility and low fertility sites in terms of %N.

In summary, the collective values of all three variables (BD, %C, and %N) show very little difference between high fertility and low fertility sites. There was slightly more variation found in %N than any other parameter measured; this variable was not significant or noteworthy, though, and will not be considered further in this study. It is therefore necessary to look beyond comparisons of the farmers as a whole and consider them on an individual basis.

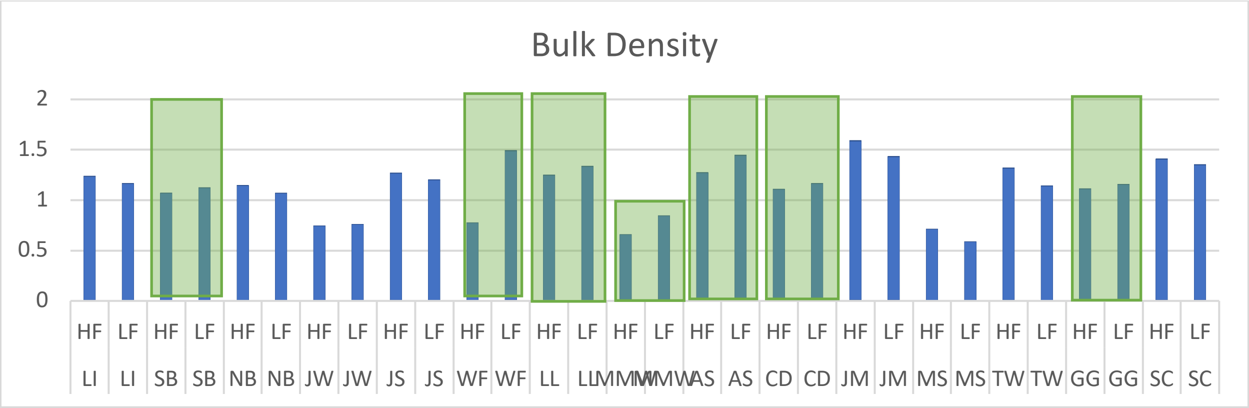

Figure 18: Average results for each farmer comparing high and low fertility sites based on Bulk Density.[29]

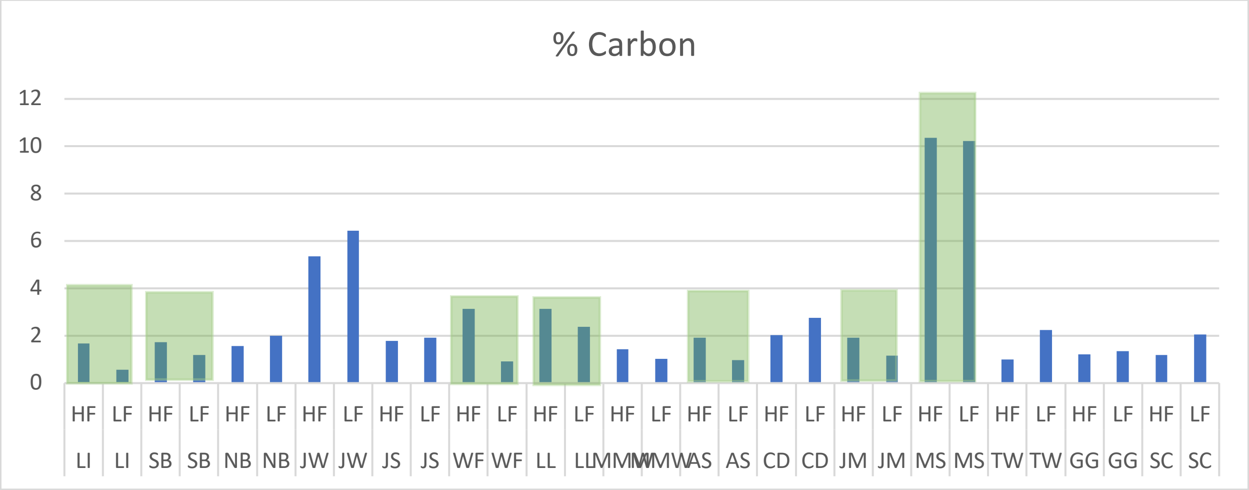

Figure 19: Average results for each farmer comparing high and low fertility sites based on percent carbon

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[29] Green indicates lower Bulk Density, or higher percent carbon and Nitrogen a sign of better soil health

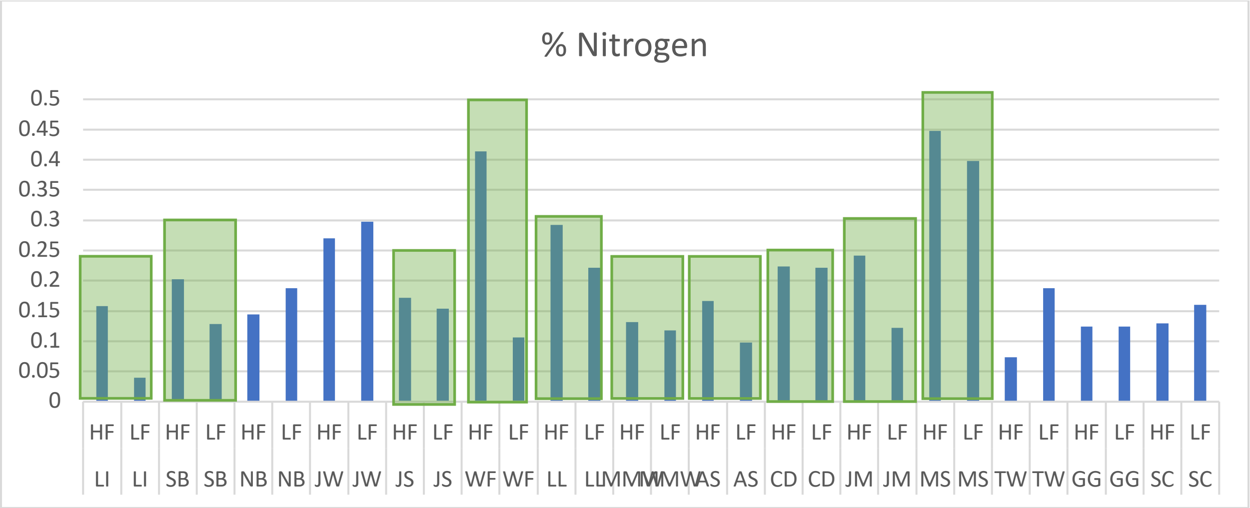

Figure 20: Average results for each farmer comparing high and low fertility sites based on percent nitrogen.

As represented in Figure 19, at least half of the participants identified HF sites has having a lower BD. Similar to BD, half of the farmers identified sites of HF with a higher %C. For %N, however, 2/3 of the participants identified HF sites with a higher %N. There were only four participants that accurately identified sites of high fertility and low fertility based on the three specified parameters: there are three hop farmers and one mint and row crop producer; only one of them was raised in Yakima. They span the entire age spectrum, with one manager in his 30s, two in their 50s, and one in his 70s; they are all male. Two growers are owners, while the other two are farm managers for large hop operations. The participants span the entire range of the educational spectrum, as well: one of them has the lowest education, having only completed elementary school, one has some college education, another completed a bachelor's degree while one of them is pursuing an MBA. The two larger hop operations are Global GAP certified, Salmon Safe, and have organic acreage; the other two have none of these.

Five participants (1/3) had accurate high and low fertility identification for at least two of the given parameters; three farmers identified sites with higher %C and %N, while the other two identified higher %N and lower BD for high fertility sites. There are: one row crop and vegetable farmer, two hay growers (one with livestock), one orchard and grape grower, and one blueberry grower. These participants also span the age spectrum, from a 30-year-old producer to a farmer in his 70s. Over half are female growers, and only two were born in Yakima; all five are farm owners. All five have at least some college education and one has a Master's in Environmental Policy. All five are currently or have been certified organic, while at least one is Global GAP certified.

Two participants identified only one accurate high fertility and low fertility comparison, while four had no correct readings. There are two orchardists, one hop manager, one mint and row crop farmer, one blueberry grower, and one viticulturist. They are between 40 and 70 years of age, and all but one was raised in Yakima. Their education spans from some college education to a master's degree, all but one is an owner, and they are all male. None of these farmers are certified organic, Global GAP, or Salmon Safe.

There may be a number of confounding factors explaining this lack of difference between high and low fertility sites, which include: miscommunication between myself and the farmer, incorrect collection of GIS data points from the field, lack of samples collected or sampling depth. In terms of miscommunication between myself in the farmer, the definition of 'high or low fertility' may not have been clearly elucidated for all participants. If prompted, I clarified a difference between high or low organic matter content; however, there are a number of definitions of fertility (Buneman et al., 2018). In addition, many farmers indicated locations where I should sample, but did not accompany me to those sites. It is possible that a mis-relay of directions or exact location of the high and low fertility sites took place.

While the GIS system I utilized to collect samples was easy, efficient, and yielded random sample locations, there were some discrepancies with the collection of data points. On a number of occasions, I noticed incorrect collection of survey points if the points were collected while I was in a vehicle (like the farmer's truck, for example). I would then re-arrange points on the map at home, while also verifying with farmers that the correct map had been collected. Even so, it is still possible that some of the sites were not accurately recorded.

In addition, the sampling depth and number of samples may not have been representative of the fields. At a depth of 0-5 cm, these samples were collected at the surface. Gelaw et al. (2014) and other studies collected samples at four sampling depths: 0-5 cm, 5-10 cm, 10-20 cm and 20-30 cm. For farmers with low fertility readings that were on average higher than their high fertility results, it is possible that amendments with high organic matter content (like compost, manure, biosolids or other crop residues) were surface-applied to their soils; the shallow sampling depth may have collected these higher-than-average OM results. Although I made a point to remove all organic matter debris and visible compost from the soil core location, it is still possible that some of these amendments were collected with the samples.

Regardless of the potential for error within these samples, it is still interesting to identify trends between groups. For those that accurately identified high fertility and low fertility sites, most were hop farmers, but only one was raised in Yakima. For those that identified two high and low fertility sites accurately, most were females whom had been certified organic at some point in their farming careers. For those that identified one or fewer accurate high and low fertility parameters, all but one was raised in Yakima, and none of them were certified organic. In addition, the age and education level spanned the entire range within each group.

While some demographic characteristics patterns can be observed in farmers that accurately identified high and low fertility sites, a more striking finding is the lack of difference between the sites themselves. As discussed, errors concerning miscommunication or other factors may have affected the results of selected parameters. On the other hand, farmers may use other indicators to determine the health of their soil. While studies have found that organic matter is a strong point of connection in terms of assessing soil health for both farmers and land managers, farmers may use other indicators to determine soil quality that are outside of the scope of this study (Doran & Safley, 1997). I suggest that further research into farmer-identified sites of high fertility and low fertility be carried out to see if organic matter is a useful indicator of soil health.

Multiple Linear Regression

A multiple linear regression (MLR) test was used for hypothesis generation and as a means to identify potential relationships between the selected dependent variables (BD, %C and %N) with the seven categories of interview data (demographic, history, community, farming philosophy, farming identity and risk aversion). Of the 39 independent variables within the seven groups, five showed some correlation. These include: types of certification (farming philosophy), whether or not farmers used a private agricultural consulting firm, (community) what their dream farm would look like (risk aversion), and what type of crop their samples were collected from (farming philosophy).

It must be noted that with such a small samples size (n=15), it is not possible to make definite statements regarding the overall fertility of the farmers based on interview results.

Sample crop type

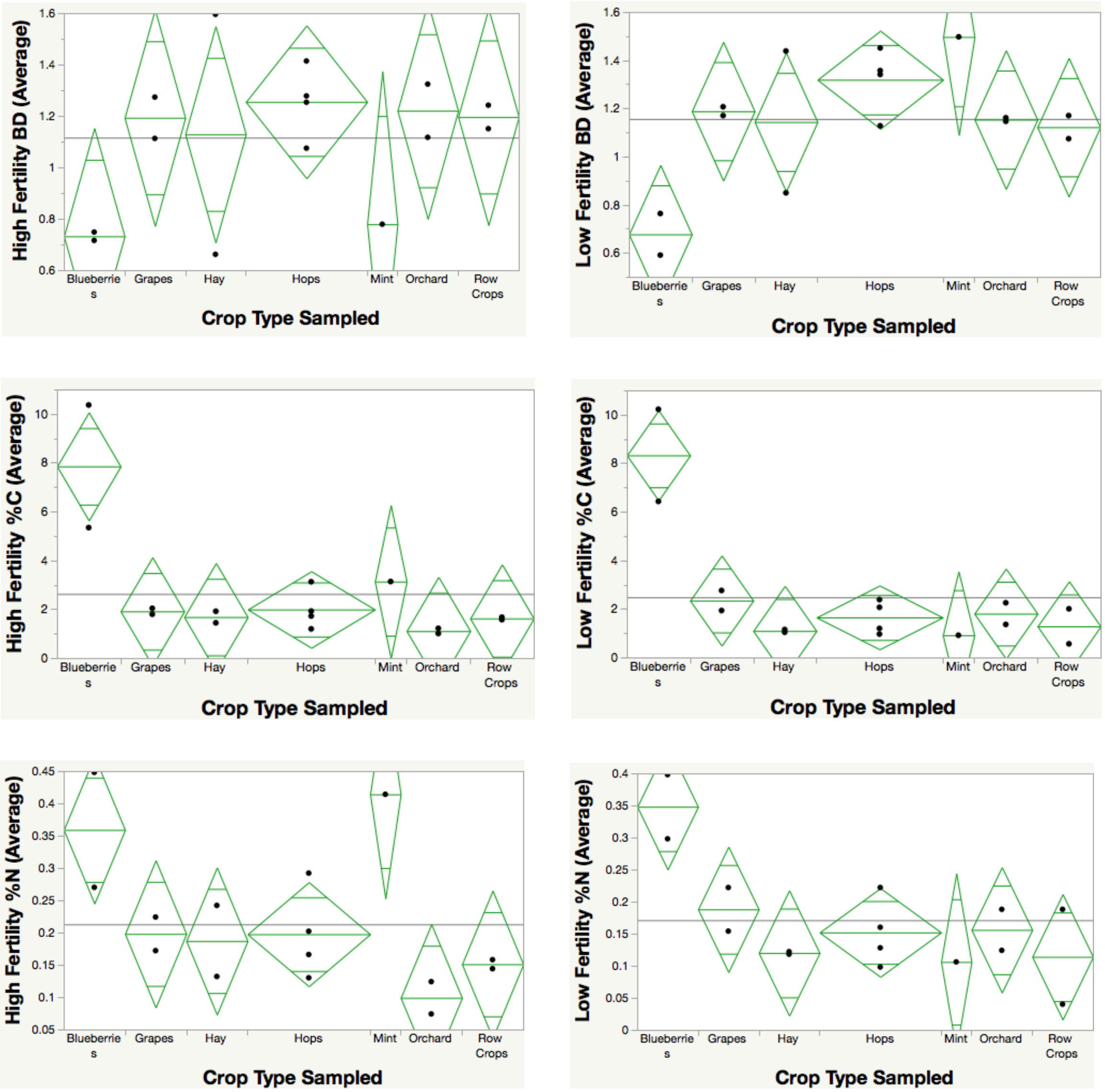

Figure 21: Multiple linear regressions (MLR) finding correlations between BD, %C, %N with the sampled crop type[30].

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[30] Of the six measurements collected, only high fertility BD showed no significant correlation with crop type

Crop type, a representation of management philosophy, had the most significant correlation with the three chosen indicators of soil health. As previously addressed, there were seven crop types where soil samples were collected: blueberries (2), grapes (2), hay (2), hops (4), mint (1), orchard (2) and row crops (2). Interestingly, for all 6 variables measured (HF and LF BD, %C, and %N), only HF BD did not yield a significant or noteworthy correlation (*p value* 0.34) for crop type. In other words, based on the different management techniques employed for each crop, the amount of organic matter (as expressed in BD, %C and %N) varies. This may also suggest that one can predict the value of higher or lower BD, %C and %N based on crop type.

Crop Type	Number	HF BD Mean (g/cm^3)	LF BD Mean (g/cm^3)
Blueberries	2	0.73	0.67
Grapes	2	1.19	1.18
Hay	2	1.12	1.43
Hops	4	1.25	1.31
Mint	1	0.77	1.49
Orchard	2	1.22	1.15
Row Crops	2	1.20	1.12

Table 3: Comparisons of high fertility and low fertility sites based on the mean bulk density (BD) for each crop type measured

When comparing means of high fertility and low fertility bulk density, one can see that much more variation exists within the low fertility (LF BD Mean) than the high fertility (HF BD Mean) (Table 3). For HF, blueberries and mint have the lowest BD mean (0.73 g/cm^3), while the other crops are within the range of 1.12 to 1.25 g/cm^3 (Table 3). The crop with the highest average BD for HF sites is hops (1.25 g/cm$^{3)}$. For LF sites, blueberries have an even lower BD mean than the HF sites (0.67 g/cm$^{3)}$ and mint has the highest mean (1.49 g/cm^3) (Table 3).

Crop Type	Number	HF %C Mean	LF %C Mean
Blueberries	2	7.85%	8.3%
Grapes	2	1.91%	2.34%
Hay	2	1.67%	1.09%
Hops	4	1.99%	1.65%
Mint	1	3.13%	0.91%
Orchard	2	1.11%	1.80%
Row Crops	2	1.62%	1.28%

Table 4: Comparisons of high fertility and low fertility sites based on the mean percent carbon (%C) for each crop type measured

It appears that the crops with the highest overall %C for HF sites are: blueberries, grapes, hops, and mint. For mean LF %C, the highest crops include: blueberries, grapes, orchard and hops (Table 4). The difference between HF and LF %C for the mint grower is the most significant; roughly 2.22% less C in the LF site than the HF site (Table 4). In addition, there are three crops with ‘inconsistent’ readings of High and Low Fertility: blueberries, orchard and grapes had lower %C for HF than for LF (Table 4).

Crop Type	Number	HF %N Mean	LF %N Mean
Blueberries	2	0.36%	0.35%
Grapes	2	0.20%	0.19%
Hay	2	0.19%	0.12%
Hops	4	0.20%	0.15%
Mint	1	0.41%	0.11%
Orchard	2	0.10%	0.16%
Row Crops	2	0.15%	0.11%

Table 5: Comparisons of high fertility and low fertility sites based on the mean percent nitrogen (%N) for each crop type measured

For %N, there is less variation between crops; the highest overall percentages include: blueberries, grapes, hay, hops, and mint (Table 5). Interestingly, the mint grower has the highest %N of any other crop for his HF site, and also the lowest for the LF site. Although not much difference can be discerned, the HF sites generally have higher %N than the LF sites, except for orchards (Table 5).

MLR proved to be a useful tool to determine the probability that soil health varied with crop type. While variation exists between crops and within high and low fertility sites, the crops with the lowest BD and highest %C and %N are by far blueberries; this indicates that blueberries have the best soil health based on the parameters tested. Other crops with better soil health based on the parameters measured include: grapes, hay, hops and mint. While this test offered useful insight concerning which crops had the best soil health, comparing these results using a paired t-test will provide more insight into the predictability of which crops yield the best soil health, which will be addressed later in the analysis.

Connections

Understanding the ways in which farmers interact with each other reveals how knowledge is generated and transferred within groups (Oreszczyn et al., 2010). For my study, farmers identified four different means of interaction: 1) through their local farm café, 2) with neighbors, or 3) other groups (Tilth Alliance or the South Yakima Conservation District, for example); in addition, 4) other participants felt disconnected from other farmers in their community or desired stronger relationships. Significant correlations emerged between the types of connections maintained by farmers with both HF %C ($R^2 = 0.82$ and p-value = 0.004) and LF %C ($R^2 = 0.89$ and p-value = 0.0005)[31].

Based on farmer responses, the MLR revealed that there may be correlations between the types of interactions maintained by the participants and the percentage of carbon measured at both high and low fertility sites. My initial hypothesis asserted that farmers who are well connected in their communities of practice (Oreszczyn et al., 2010)

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[31] Table 9, see Appendix, p. 345

will have better soil health results than other farmers. In order to test this hypothesis, I will conduct a simple linear regression, and an ANOVA test will analyze whether or not this hypothesis is correct, or if other factors contribute to the correlation between higher levels of %C and interactions with other farmers.

Certification

Some farmers explained that they are certified with one of the following quality control and environmental sustainability certifications: Salmon Safe, Global G.A.P, Organic and Grass Fed. A multiple linear regression considered the correlation between certification type and BD, %C and %N. Below is a table describing the correlations between the three variables and the different types of certification chosen by farmers.

According to Table 10, all measured indicators except for HF %N yielded significant correlations based on certification type (HF BD: $R^2 = 0.63$ and p-value = 0.03; LF BD: $R^2 = 0.63$ and p-value = 0.03; HF %C: $R^2 = 0.6$ and p-value = 0.04; LF %C: $R^2 = 0.66$ and p-value = 0.02; LF %N: $R^2 = 0.72$ and p-value = 0.008). As expressed in the graph above, the most significant correlations found from the MLR analysis were shown for Salmon Safe certified farmers; both Global GAP and Organic also yielded significant correlations. In order to further analyze these results, an ANOVA of each certification type will further address these potential correlations.

Dream farm

Much research shows that farmers make management decisions based on their aversion to risk (Boehm & Burton, 1997; Sulewski & Kloczko-Gajewska, 2014). For many farmers, implementing a new change in their system presents some financial or other form of risk, even if it may be beneficial for overall soil health and profits in the long-term. Short-term profits and learning curves have been shown to deter farmers from transforming their current practices (Boehm & Burton, 1997). In order to assess how specific constraints (labor, time, profit, etc.) impact management decisions, I asked farmers to imagine their system without these limitations. Interestingly, their responses showed correlation with some of the soil health parameters measured.

Farmers described 8 different changes they would make if they had no financial or practical constraints. These include: 1) farming for soil health, 2) improving overall nutrients and fertility, 3) not changing much in their system, 4) implementing better technology or precision agriculture, 5) using less mechanization, 6) asking for better legislation, 7) no chemical use, or 8) using more mechanization. The most significant parameter was %C, which is explained in further detail in the Table 11[32].

While farming for soil health or improving nutrients and fertility were not significant predictors of soil health, using no chemicals was the most significant correlation (HF %C p-value = 0.007; LF %C p-value = 0.003) (Table 11). Farmers that would not change much or would change their technology, either through the increased use of mechanization (HF %C p-value = 0.019; LF %C p-value = 0.021), less mechanization (HF %C p-value = 0.028; LF %C p-value = 0.025) or implementing precision agriculture (HF %C p-value = 0.021; LF %C p-value = 0.021), were also significant predictors of soil health for the parameters analyzed (Table 11). These results will be further analyzed in the following section using an ANOVA to determine whether or not these responses can be used as qualitative predictors of healthy soil for the farmers interviewed.

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[32] See Appendix, p. 346

By showing a relationship between two or more categorical independent variables with dependent variables through a linear analysis, MLR elucidates which variables are either significant or noteworthy for each soil health indicator tested. MLR also serves as another means to generate hypotheses based on categorical variable responses. Due to the small sample size of my study, it is difficult to make any concrete statements concerning which farmers or farm types universally have the best soil. Given the results from the MLR analysis, though, I believe it is advantageous to conduct a simple linear regression or paired t-test to compare two factors against each other based on a given soil health indicator.

Simple regression (ANOVA) and paired t-test

To test my initial hypotheses and those generated by the MLR method, I used an analysis of variance (ANOVA) to compare responses to categorical variables based on continuous indicators of soil health. I tested my hypothesis: that farmers with greater organic matter content would be older, raised in the Yakima Valley, come from farming families (at least 3 generations farming) and be well connected with other farmers (specifically through a local farm café). In addition, I compared categorical variables identified through the MLR screening process, and also evaluated responses using a paired t-test to identify noteworthy or significant correlations from ANOVA. While both noteworthy and significant correlations were found using ANOVA, most correlations were largely attributed to crop type, and therefore management philosophy.

Age

Initially, I predicted that due to greater experience, older farmers would have better soil health than younger farmers (Burton, 2014). To test this, I ran an ANOVA comparing the age of all 15 farmers with all 6 variables: HF and LF BD, %C and %N. Results demonstrated that age has almost no effect on soil health. As expressed in Table 12[33], the R^2 and p-values were collected to measure correlation between the given soil health variables and age. For all six indicators, there were no significant or noteworthy correlations ($R^2 < 0.15$; p-value > 0.19, average p-value = 0.53) (Table 12). This indicates that age, is not an indicator of increased levels of organic matter.

While Burton (2014) explained that age could be used as a representation of experience, others have found younger farmers to be more environmentally conscious in their management choices. In addition, many other factors, like education and the type of education received, inform one's management decisions (Brodt et al., 2006). While age can be used as an indicator of experience, one's familiarity with specific management practices may impede adoption of new conservation techniques; subsequently, generalized experience may not increase one's understanding of practices that increase organic matter content in the soil (Burton, 2014).

As discussed throughout this paper, the reliance of the expert to non-expert relay of information for many farmers who learned management techniques during the second half of the 20th century (the Productivist era), many may be more experienced with intensive tillage and the heavy application of synthetic fertilizers, all practices that have been shown to decrease organic matter content in the soil (Carolan, 2005; Burton, 2014).

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[33] See Appendix, p. 346

Nevertheless, other factors must be explored to understand what contributes to increased levels of organic matter for participants of this study.

Raised in Yakima and generations family farming

As previously discussed, Sense of Place theory, one’s ideological, physical and economic dependence on a specific location, may help inform an individual’s feelings of environmental stewardship to the land where they work, live, and may have inhabited for generations (Mullendore et al., 2015). In order to test this for my study, I proposed that farmers who were raised in the Yakima Valley were more likely to have higher levels or organic matter than other farmers.

An ANOVA was useful to compare the soil health indicators with two separate groups: farmers that were raised in Yakima, and others that weren’t; approximately half of the participants were born or raised in the valley. For most of the indicators of soil health, there were no significant correlations found ($R^2 < 0.10$; p-value > 0.4); this means that there was no correlation between most of the soil health indicators and whether or not the farmers were raised in Yakima. Interestingly, the only noteworthy reading was HF %N; while the R^2 was relatively low (0.18), the p-value was also much lower than the others (0.12). This suggests that %N measurements taken from the HF plots may be influenced by the place of origin for the participants.

In addition, other authors have found that one’s farming experience is largely informed not only by the amount of time one inhabits an area, but whether or not they were raised in a farming family (Goulet, 2013; Iniesta-Arandia et al., 2014). To test this, farmers that were raised in families with at least three prior generations of family farming were compared using an ANOVA. Seven farmers were at least third generation farmers;

however, no significant correlations were found between individuals born into farming families and higher levels of organic matter ($R^2 \leq 0.05$; p-value > 0.4). This suggests that the number of generations of farming within the participants' families were not correlated with the six variables measured for soil health.

Connections

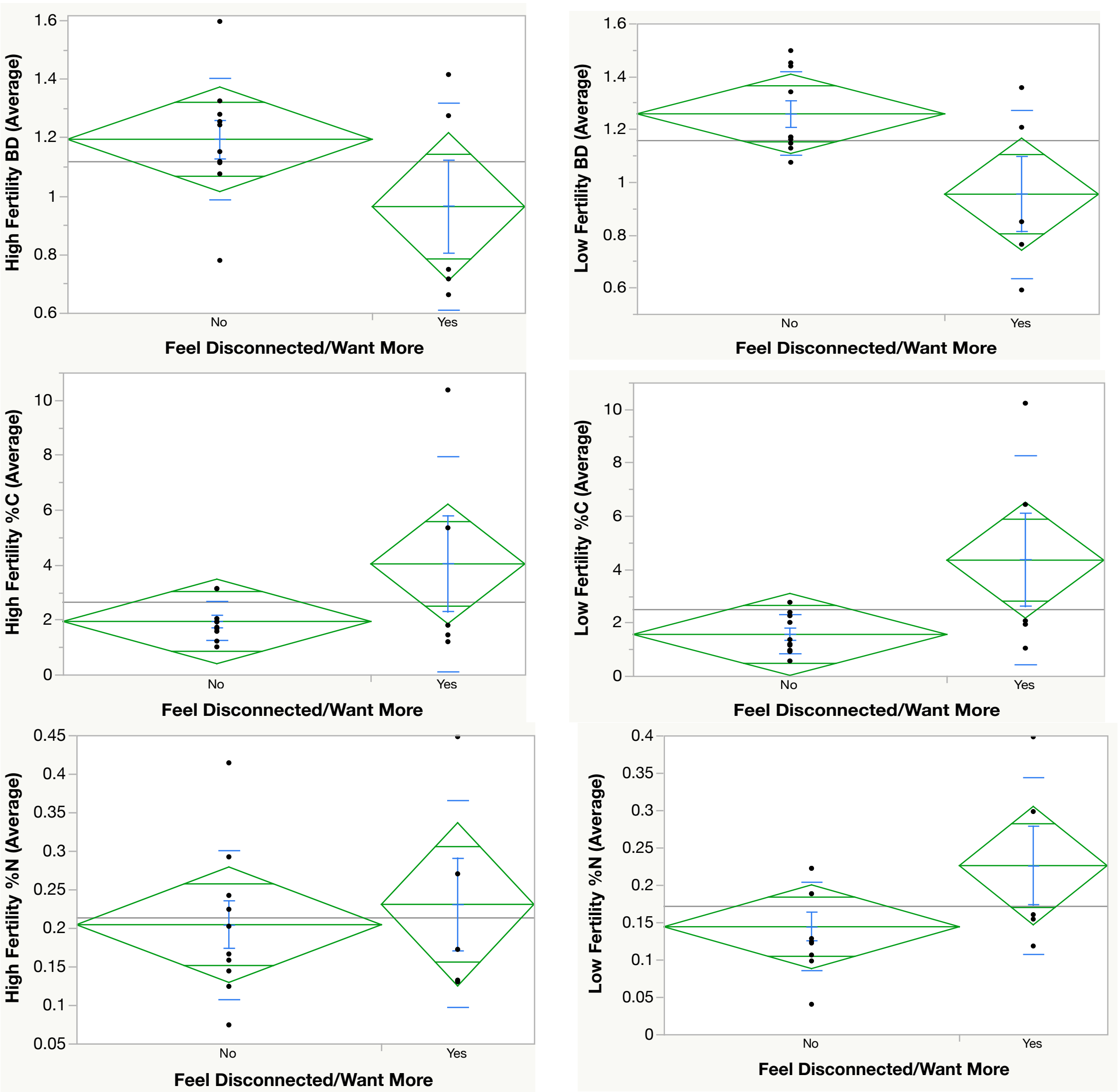

Figure 22: Feeling disconnected and organic matter content.

A paired t-test comparing all six measured variables with farmers that either indicated feeling disconnected and/or a desire for better relationships with other farmers or did not. All responses were noteworthy, and two (LF BD & %C) yielded significant correlations.

As previously discussed, four different categories were measured in terms of the types of connections upheld by farmers: involvement with local farm cafes, interactions solely with neighbors, feelings of isolation or a desire to create better relationships with other farmers, or involvement in other groups, like Tilth of Washington or the South Yakima Conservation District. As a categorical variable, I used an ANOVA test to compare responses for two variables on opposite ends of the 'connection spectrum': those well-involved in their local farm café, and those that felt isolated or wanted more connections. Six farmers interviewed expressed involvement or regular participation with their local farm café. Interestingly, there were no correlations found between farmers who were well connected with other individuals, specifically through the local farm café, and increased levels of organic matter ($R^2 < 0.1$; p-value ≥ 0.28) (Figure 22).

On the other hand, for the four farmers that felt disconnected or wanted more connections with other farmers, there were significant and noteworthy findings. As expressed in the figures above and Table 13[34], all but one variable was at least noteworthy, and two variables, LF BD and %C, were significant. This shows that some correlation can be found between increased organic matter content and farmers that felt disconnected or wanted more close connections with neighbors or other farmers (Figure 22).

What must be noted is that the farmers with the best soil health, two blueberry farmers, both felt disconnected or wanted better relationships with neighbors or other farmers. As expressed by one of the blueberry growers: "“There's a shortage of blueberry growers in our area, I'm one of the few. So, I don't get an opportunity to share

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[34] See Appendix, p. 346

a lot… when we grew apples here, everybody grows apples…it's a large community of apple growers, which is a plus, it's a very positive thing. I do miss that". This suggests that while there may be correlations between feelings of separation and disconnectedness and soil health, crop type and management style may also prove to be the explanatory variable for this correlation. In order to explore this point further, I suggest that a similar study be conducted in which both socio-economic factors contributing to SHK as well as organic matter content of the soil are measured for an exclusive cohort of blueberry growers. This will help inform whether crop type or feelings of disconnectedness have a greater influence over organic matter content in the soil.

These results show that for the most part, my hypothesis was untrue. For the most part, there were few if any significant or noteworthy correlations found between my selected variables, that older farmers, raised in Yakima, born into an established farming family and are well connected to other farmers would have better soil health than the other farmers. In the case of types of connections between farmers, the opposite was true; farmers that felt disconnected or wanted better relationships with others in their community had better soil health indicators than those involved in the farm café (Figure 3).

What must also be noted is that the two blueberry farmers, the individuals with the highest soil health indicators, both felt disconnected or wanted more involvement within their communities. This could suggest correlations outside of the qualitative variables measured from the interviews. It may also suggest that since few farmers in the area are blueberry growers, they may feel isolated or struggle to build meaningful relationships with other blueberry growers. Since blueberry cultivation employs practices that improve SOM accumulation and overall soil health, I suggest further analysis of blueberry growers in other more-established areas, and how their connections compare to their soil health.

Certification: Global GAP, Salmon Safe and Organic

Through hypothesis generation, MLR prompted further exploration into the correlation between the selected indicators of soil health and the types of certification practiced by farmers, specifically Global GAP, Salmon Safe and Organic. To further test these categorical variables, two-sample t-tests compared these three certification types with the six different soil health variables. Two of the larger hop farmers were certified Salmon Safe, three participants were Global GAP (the same two hop farmers and one blueberry grower) and seven growers were certified organic {one row and vegetable crop grower, one alfalfa and squash grower, one orchard and grape grower, two blueberry growers (one that is also Global GAP certified), and the same two hop growers}. While there were no significant or noteworthy correlations found between the soil health indicators and the salmon safe certified farmers ($R^2 \leq 0.07$; p-value ≥ 0.34), there were at least two significant or noteworthy findings for Global GAP and Organic certification.

For Global GAP, %C was the only noteworthy finding for all 6 indicators: HF %C ($R^2 = 0.19$; p-value = 0.10) showed somewhat stronger correlation than LF %C ($R^2 = 0.11$; p-value = 0.22). This suggests a better correlation between the percent of carbon (%C) for the high fertility sites than the low fertility sites, and more correlation between the influence of Global GAP certification practices on %C than %N and BD. What must also be noted is that the only difference between Salmon Safe certified participants and Global GAP certified participants is the blueberry grower with the best measurements of soil health. Yet again, crop type and associated management practices may be more influential than other qualitative variables.

More correlation could be found between soil health and Global GAP certified farmers than Salmon Safe certified farmers; this is due to the inclusion of the grower with the healthiest soil. In addition, both high and low fertility bulk density were clearly the most significant indicators of soil health for certified organic farmers (HF BD $R^2 = 0.24$, p-value = 0.06; LF BD $R^2 = 0.27$, p-value = 0.05)[35]. The significant correlation between certified organic farming and increased levels of bulk density may be justified by the fact that both blueberry growers are certified organic; however, with a more diversified quantity of crop types, a greater number of participants that are certified organic, there may be other factors contributing to the correlation between lower bulk density results and organic certification.

While no correlations could be found for Salmon Safe farmers and soil health, some were noteworthy for Global GAP, while others were significant for certified organic farmers. The only difference between Global GAP and Salmon Safe growers is that the blueberry farmer with the best soil health was Global GAP certified, and not Salmon Safe certified. It is possible that this farmers' high soil health results influenced the correlation between %C and Global Gap certification. With a more diverse sample size, certified organic farmers yielded both significant and noteworthy findings; it must be noted that both blueberry growers were also certified organic, which may influence the correlation between organic certification and increased soil health. It would be of value to compare different management requirements between Global GAP and Organic

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[35] See Table 14, Appendix, p. 347

certification within crops to see whether or not these requirements influence the specified soil health indicators.

Agricultural consultants

Farmers described a number of trusted sources that helped them improve their soil health. To identify any correlation between the six indicators of soil health and whether or not farmers used agricultural consultants, which was identified as a possible hypothesis during the MLR hypothesis generation step, an ANOVA measured the correlation between these indicators and whether or not it was a determinant of healthier soil. Significant correlations were found for HF %C ($R^2 = 0.28$; p-value = 0.04) and %N ($R^2 = 0.6$; p-value = 0.0007); with HF %N having the strongest correlation[36]. Based on these findings, one can guess that farmers within the study with a higher percent nitrogen and percent carbon in their high fertility sites will have worked with a private agricultural consultant.

According to Oreszczyn et al. (2010), webs of influencers, a wide network of public and private organizations, have the greater impact on the management decisions of farmers compared to more intimate Communities of Practice and more-loosely connected networks of practice. Based on these findings, it appears that the group of agricultural consultants may influence the carbon and nitrogen contents of sites deemed high fertility. In addition, Stuart et al. (2018) explored the role played by trust for farmers in internal groups (communities of practice, e.g.) and external groups (consultants, e.g.). The authors found that farmers valued nitrogen fertilizer recommendations from individuals within private sector external groups, like consultants, more so than recommendations

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[36] See Table 15, Appendix, p. 323

from the public sector (e.g. Land Grant university extension offices). Even so, they trusted recommendations from familiar individuals within both public and private sectors. For the participants in this study, recommendations provided by trusted agricultural consultants may impact the ways in which farmers are managing their land to increase levels of organic matter in their soil.

Dream farm description

As a measure of the impacts of risk aversion on farmers' management practices, the participants were asked to invent a dream farm without such limitations as profit, labor, or other extenuating circumstances. There were seven scenarios presented by farmers; without profit or labor constraints, farmers would: 1) farm for soil health, 2) improve nutrients and fertility, 3) implement technology and more precision agriculture, 4) either increase or decrease mechanization, 5) improve legislation, 6) use no chemicals, or 7) change very little.

The MLR hypothesis generation suggested possible correlations between farmers' dream farm description and increased quantities of SOM. Most farmers suggested 5 of these, which were analyzed through an ANOVA: 1) farm for soil health, 2) improve nutrients, 3) implement new technology, 4) use no chemicals and 5) change little within their current management regime. Interestingly, all five had at least one noteworthy or significant soil health indicator; of the five dream farm descriptors, no chemical use by far had the most significant soil health indicators. What must be noted is that both blueberry growers suggested no chemical use, which considerably influences these soil health indicators.

Improve nutrients and technology

Five farmers described scenarios in which they either improved the overall nutrient and fertility content of their soil or implemented new technology and precision agriculture on their farm. Interestingly, only two of these farmers described scenarios implementing both methods. For the farmers that suggested that they would improve nutrients and fertility, LF BD yielded somewhat significant ($R^2 = 0.25$ and p-value = 0.06) while LF %N was somewhat noteworthy ($R^2 = 0.12$ and p-value = 0.20). This suggests that farmers that would improve overall soil fertility and nutrients had better soil health readings for their low fertility sites in term of bulk density and percent nitrogen. This may suggest that farmers who would improve nutrient content of their soils are aware of their problem areas, and due to the shallow depth of soil sample collection (5-7 cm), are taking steps to improve these low fertility sites by adding organic matter.

For those that would implement precision agriculture or improve overall technology, only high fertility percent nitrogen was a noteworthy indicator ($R^2 = 0.14$ and p-value = 0.18); this may indicate that farmers that would implement new technology or precision agriculture would have better soil health for their high fertility sites in terms of percent nitrogen.

Farm for soil health and change little

Two other noteworthy or significant findings involved the farmers' ability to farm to improve overall soil health or change little in their operation. Three farmers (one row and vegetable crop farmer, one blueberry producer, and one orchard and grape farmer) specifically stated that they would implement practices that improved overall soil health, while four farmers (the same row and vegetable crop farmer, the same blueberry producer, one mint grower and one livestock and hay producer) would change little in their management practices. Interestingly, two participants identified both descriptions in their dream farm scenario

For farmers that would farm for soil health, there were noteworthy findings for HF %C and LF BD and %C ($0.13 \leq R^2 \geq 0.20$; $0.1 \leq$ p-value ≥ 0.19); however, there were no significant findings. This shows some predictive value between the soil health indicators and categorical variables as well as an increased chance that the relationship between these indicators and the farmers' management practices are true. For farmers that wouldn't change much, HF %C was noteworthy ($R^2 = 0.18$ and p-value = 0.11) and HF %N was significant ($R^2 = 0.36$ and p-value = 0.02). This suggests that higher nitrogen percentages can be predicted from high fertility sites than carbon percentages for farmers that would not change much of their current management regime.

Use fewer or no chemicals

Only two farmers suggested that they would use fewer or no chemicals in their operation and both were blueberry farmers. All six variables are either significant or highly significant indicators of soil health; both farmers indicating a preference to use less chemicals were both certified organic[37]. According to the NOP, synthetic chemicals are prohibited for use in organic agriculture; as such, their farming identity, which may be closely linked to their status as a certified organic grower, may influence this preference. One major point of contention, though is that both of these farmers are blueberry growers. As discussed throughout this section, these two individuals have the highest levels of organic matter due, and it is therefore difficult to discern whether their

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[37] See Table 16, Appendix, p. 347

farming identity or aversion to risk explain their high levels of organic matter. As previously addressed, it would be useful to conduct a similar study on an exclusive cohort of blueberry growers.

The dream farm description indicated both noteworthy and significant correlations between soil health indicators and interview responses; as a measure of risk aversion, farmer identity and farming philosophy, this question allowed farmers to consider how they would manage their land if socio-economic constraints were to disappear (Boehm & Burton, 1997). Some significant and noteworthy correlations were found for farmers that would improve overall soil fertility and nutrients or would implement precision agriculture and new technology.

While both significant and noteworthy results were observed for farmers that would change little in their current operation, there were only noteworthy correlations for farmers that would farm for soil health. By far the most significant correlation was observed within the group of farmers that would use no chemicals. What must be noted is that the most significant findings concerning the limited use of chemicals was described by both blueberry growers. This suggests yet again that farming philosophy, as expressed through chosen management practices, may be more influential than other factors measured concerning soil health knowledge and increased quantities of organic matter.

Chapter 5: Conclusion

Integrating soil indicators and soil health knowledge

The previous section has explored a number of ways to measure organic matter content, understand how farmers identify high and low fertility, and compare these results with responses concerning their soil health knowledge. My first hypothesis, that bulk density, percent carbon and percent nitrogen, were all effective measurements of organic matter content, was correct (Figure 1). Significant correlations could be found for all indicators measured; since organic matter is also an effective tool for expressing soil health, these parameters were extremely useful in analyzing the soil of all fifteen participants. I then compared high and low fertility sites as explained by farmers. Interestingly, no significant differences were found between high and low fertility sites for most farmers interviewed. Over half of the participants accurately identified high and low fertility sites; however, this does not suggest that these individuals have better SHK than the other farmers interviewed. A number of confounding variables could have accounted for error, and farmers may not have defined soil fertility in terms of organic matter content.

Next, I compared interview responses to the selected indicators of soil health; as a means to generate hypotheses, I conducted an MLR for 39 different categorical variables identified through the interview process. Possible correlations were identified, including: the types of connections described by farmers and their work with agricultural consultants (trust in internal and external groups), the types of certification they participate in (farming philosophy and identity) as well as their dream farm description (risk aversion, farming philosophy and farming identity).

The most significant finding using the MLR process concerned the crop types sampled. Based on the mean bulk density, percent carbon and percent nitrogen for both high and low fertility sites, blueberries were found to have the highest levels of organic matter for all three measurements. Conversely, annual row crops were found to have the lowest levels of organic matter for all three measurements (Figure 2). This suggests that correlations emerged for all three measurements of organic matter in both high and low fertility sites with the type of crop sampled. In other words, blueberries had the highest levels of organic matter, and therefore the healthiest soils. This indicates that farming philosophy may have the greatest influence on soil health of the seven other soil health knowledge indicators measured.

To further test my own hypotheses and the hypotheses generated using MLR, I conducted a simple ANOVA and paired t-tests of the potential correlations. Interestingly, none of my initially proposed hypothesis had noteworthy or significant correlations with increased organic matter content. While I proposed that farmers who were well-connected within their local agricultural communities would have better soil health than other farmers, I found the opposite to be true; farmers that felt disconnected or wanted stronger relationships were correlated to higher levels of organic matter. Interestingly, both blueberry growers indicated a feeling of disconnectedness or wanting stronger relationships, which may have confounded this finding; in order to test this, it would be valuable to conduct a similar analysis on an exclusive cohort of blueberry growers.

Of all other significant or noteworthy findings, crop type seemed to have the greatest impact on potential correlations. This was represented in the Global GAP certified and Salmon Safe certified farmers; significant correlations could be discerned between organic matter content and Global GAP certification, but not Salmon Safe, which is most likely due to the fact that no blueberry growers were certified Salmon Safe. With a larger sample size of farmers and a more complex diversity of crop types, organic certification was also found to have significant correlations with high and low fertility bulk density. For farmers that worked with crop consultants, significant correlations with high fertility sites concerning percent carbon and percent nitrogen were identified. Future research should consider how effective both organic certification and work with agricultural consultants influences the farming philosophy and management choices of farmers and land managers.

Finally, dream farm descriptions yielded some noteworthy and significant correlations. Most notably, all three parameters measured for both high and low fertility sites were significant for the two farmers that indicated that they would use less or no chemicals in their dream farm operation. Predictably, both of these individuals were blueberry growers, with the best overall organic matter levels and soil health.

In summary, my results show that farming philosophy, as expressed by selection of crop type, is the most influential factor in determining one's organic matter levels, and overall soil health. While other factors certainly contribute to a farmers' soil health knowledge, it is clear that blueberries have the greatest impact on organic matter accumulation for the top five to seven centimeters of the soil for all sites measured.

Insights from scientists, farmers and the soil itself

"A Conservationist is one who is humbly aware that with each stroke, he is writing his signature on the face of the land" – Aldo Leopold (1949)

The participants of this project represent a diverse array of farmers and land managers inhabiting Yakima county. They differ in their place of origin, personal and familial history, educational experience, involvement with external and internal groups, and management philosophy; however, they share a number of commonalities. Most notably, what unifies them is their sense of identity and their understanding that the success of their farms depends on the health of their soil.

While researchers have attempted to segregate farmers into either the Productivist or the Conservationist camps (Carolan, 2005; Sulemana & James, 2014; McGuire et al., 2015; Mills et al., 2018), the farmers interviewed in this study show that a simplified partitioning into two ideological camps does not account for the complex set of circumstances influencing a farmers' management decisions (Burton, 2014). It is therefore of utmost importance to recognize that each farmer, farm system, and farm community is unique. Furthermore, we must also understand that farmers view themselves as stewards of the land, and their intentions are not to create harm to the places they call home (Michel-Guillou & Moser, 2006).

As explained throughout this paper, there are a number of factors contributing to a farmer's soil health knowledge. While some factors may be more impactful than others, a complex interplay of demographic, educational, historical, social, ideological, philosophical and even existential circumstances inform a farmer's soil health knowledge and determine how they manage their land (Burton, 2014). This inquiry found that the most influential determinant of soil health, as represented through the presence of organic matter, was farming philosophy. The two farmers that grew blueberries had the highest levels of percent carbon, percent nitrogen and lowest bulk density in the top five to seven centimeters of the soil than any other crop type grown.

Therefore, my hypothesis that older farmers, born into farming families, raised in the Yakima Valley, and that regularly interacted with other farmers in their communities of practice, will have better soil health than other farmers, was incorrect. Of the seven factors measured (demography, history, education, community involvement, farmer identity, farming philosophy, and risk aversion) farming philosophy, as expressed through preferred crop and management practice, was the most influential determinant of increased levels of organic matter.

My final question concerned farmers' knowledge and familiarity with established indicators of soil health. Their understanding of biological, physical and chemical indicators varied with education type and duration, yet most were more familiar with soil physical structure and could easily identify management practices that either improved or degraded this parameter. This suggests that, as interactive and tacitly-based learners, farmers were more familiar with visibly recognizable indicators of soil health; regardless of education type and duration, physical indicators of soil health are more visibly identifiable than the other two parameters (McGarry, n.d.; Okali et al., 1994; Jensen et al., 2007; de Souza Mello Bicalho & dos Guimarães Peixoto, 2016; Sumane et al., 2017)

In addition, the three chosen indicators of soil health (bulk density, percent carbon and percent nitrogen) showed significant correlations for both high and low fertility sites; therefore, all three indicators can be used to measure organic matter content. As explained by a number of sources, organic matter is one of the most effective indicators of soil health and can serve as a useful tool for both farmers and scientists (Grigal et al., 1989; Lobry de Bruyn & Abbey, 2002; Tan et al., 2007; Sollins and Gregg, 2017). All 15 farmers interviewed identified organic matter as one of the most important measurements of soil health, indicating a solid point of connection between farmers and scientists (Lobry de Bruyn & Abbey, 2002).

This inquiry also examined the epistemological disconnect between farmers and scientists. I considered how the over-reliance on the expert to non-expert relay of information over the past century has greatly contributed to environmental degradation on local, regional, national and global scales (O'Boyle, 1983; Oosterlinck et al., 2002; Jensen et al., 2007; Ingram, 2008, Ingram et al., 2010; Biel, 2016; Bouma, 2018). In this regard, the value of both forms of knowledge should be recognized, and farmers and scientists should work cooperatively to prevent the historical trend of soil and environmental degradation (Sears, 1935; Wilson, 2001; Montgomery, 2007; Biel, 2016). The explicit basis of scientific inquiry, which conducts replicated lab and field trials in order to establish universally applicable rules and laws, must work in conjunction with the implicit, local ecological knowledge base of farmers and land managers that is acquired through trial-and-error and experience interacting within a site-specific region and context (Jensen et al., 2007; Hoffman et al., 2007; Ingram, 2008; Ingram et al., 2010).

In order to decrease soil erosion, minimize nutrient runoff in our waterways, and mitigate other negative environmental impacts caused by industrial agricultural practices, it is essential that farmers and scientists learn to work collaboratively to further their understanding of each other and the land in which humans inhabit (Doran, 2002).

Initiatives like Farmer Participatory Research (FPR) and other methods to bring farmers to the decision-making table should become the norm. In so doing, scientists can learn the most effective means to communicate new technology and information and can identify bottlenecks or non-traditional avenues to increase the dissemination of new knowledge (Eshuis & Stuiver, 2005; Mwaseba et al., 2009; Rogers et al., 2013; Bouma, 2018). In addition, scientists have much knowledge to gain from farmers and land managers; as experts of their given locality and region, farmers may have more of an awareness of the exact ecological processes taking place due to their preference towards experience and observation (Doran, 2002; Ingram, 2008; Ingram et al., 2010; Dawoe et al., 2012; Hauser et al., 2016).

By bringing farmers to the decision-making table in terms of the creation and dissemination of new information and technology, scientists can encourage farmers to recognize their own forms of knowledge as valid and indispensable (Bouma, 2018). Nevertheless, farmers must also learn to recognize weaknesses in their own management regimes, and they should be encouraged to create changes that minimize their environmental impact (Ingram et al., 2010). In order to facilitate this, socio-economic research should orient to help farmers transition to more sustainable management regimes while minimizing the economic impact they may experience when implementing new practices (Boehm & Burton, 1997; Mwaseba et al., 2009; Rogers et al., 2013).

Farmers and scientists have much valuable information to gain from each other; if they learn how to communicate and work cohesively, our chances at natural resource, ecological and environmental conservation increase greatly. In addition, effective communication can inform scientists of the socio-economic constraints experienced by farmers, and scientists can create tools that are easily adaptable for each farmer, farm system and farming community.

Recognizing the individuality of each agroecosystem allows researchers to comprehend the entire socio-economical, ecological and environmental frameworks of these complex communities. Considering farmers as part of their ecosystems and part of the framework of their locality will create lasting connections and increased efforts towards environmental sustainability. Remembering that farmers conceive of themselves as stewards of the land and do not see themselves as separate from the land they inhabit is an essential first step towards environmental and natural resource conservation. By recognizing the valuable role played by farmers in these complex agro-ecological systems, we can find ways to benefit the health and well-being of humans, flora, fauna, and the soil itself.

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Appendix

	Provisioning Services
1	Provides food, wood and other fibers
2	Provides raw materials
3	Supports human infrastructure and animals
	Regulating Services
4	Mitigates the impact of floods
5	Bio-filtration of both nutrients and contaminants
6	Sequesters carbon and aids in gas regulation
7	Recycling and waste detoxification
8	Aids in control of pests and diseases
	Cultural Services
9	Recreational pursuits
10	Human aesthetic appeal
11	Values of culture and heritage
12	Cultural identity

Table 6: Ecosystem services that emphasize soil function and quality

(as adapted from Bouma et al. 2015)

Correlation	R^2	p-value
High Fertility %C and %N	0.64	0.0004
High Fertility BD and %C	0.30	0.0325
High Fertility BD and %N	0.23	0.07
Low Fertility %C and %N	0.89	<0.0001
Low Fertility BD & %C	0.56	0.0014
Low Fertility BD & %N	0.45	0.0063

Table 7: ANOVA comparing selected indicators of soil health

Correlation	Adjusted R^2	*p value*
High Fertility Bulk Density	0.12	0.34
Low Fertility Bulk Density	0.53	0.05
High Fertility % Carbon	0.68	0.01
Low Fertility % Carbon	0.80	0.0021
High Fertility % Nitrogen	0.57	0.04
Low Fertility % Nitrogen	0.54	0.04

Table 8: ANOVA comparing selected indicators based on crop type

Type of Connection	Number	HF %C p-value	LF %C p-value
farm café/neighbors	7	.0064	.0002
just neighbors	4	.0009	.0002
feel disconnected/ want more	5	.0009	<.0001
other groups	4	.0003	.78
none described	1	.60	.0037

Table 9: MLR comparing the types of connections described by farmers, the number of farmers that selected each description and their p-value for both HF and LF %C

Certification	Number	HF BD p-value	LF BD p-value	HF %C p-value	LF %C p-value	HF %N p-value	HF %N p-value
Salmon Safe	3	0.027	0.016	0.013	0.003	0.119	0.0007
Global G.A.P	3	0.57	0.45	0.025	0.026	0.148	0.018
Organic	7	0.007	0.02	0.38	0.16	0.947	0.13
Grass Fed	1	0 (?)	0	0	0	0	0
None Described	7	0.08	0.38	0.31	0.528	0.672	0.5

Table 10: MLR comparing the types of certification maintained by farmers, the number of farmers that selected each description and their p-value for all HF and LF indicators measured.

Noteworthy or significant correlations were found, suggesting a more in-depth analysis of the results.

Dream Farm Description	Number of farmers choosing this	HF %C p-value	LF %C p-value
Farm for soil health	3	0.734	0.562
Improve nutrients/fertility	5	0.643	0.745
Not change much	4	0.016	0.033
Precision Ag/improve technology	5	0.021	0.021
Less mechanization	2	0.028	0.025
Better legislation	1	0.937	0.817
No chemicals	3	0.007	0.003
More mechanization	2	0.019	0.021
None described	1	0.031	0.041

Table 11: MLR comparing the farmers' dream farm description and the p-value for HF and LF %C.

For all highlighted responses, noteworthy or significant correlations were found. These include: not change much (HF & LF), precision agriculture (HF & LF), less mechanization (HF & LF), no chemicals (HF & LF), more mechanization (HF & LF) and none described (HF & LF)[38]

Variable	R^2	p-value
HF BD	.02	.58
LF BD	0.002	.86
HF %C	.08	.30
LF %C	.04	.50
HF %N	.13	.19
LF %N	.008	.75

Table 12: ANOVA comparing the age of respondents with indicators of soil health.

No significant or noteworthy results were found, indicating no correlation between age and levels or organic matter

Variable	R^2	p-value
HF BD	0.166	0.13
LF BD	0.33	0.03
HF %C	0.18	0.11
LF %C	0.28	0.04
HF %N	0.01	0.67
LF %N	0.20	0.09

Table 13: ANOVA Feeling Disconnected/Want More

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[38] Significant values highlighted in green

Variable	R^2	p-value
HF BD	0.24	0.06
LF BD	0.27	0.05
HF %C	0.12	0.20
LF %C	0.10	0.26
HF %N	0.02	0.61
LF %N	0.03	0.56

Table 14: ANOVA certification: organic

indicates a correlation between certified organic growers and better values for bulk density

Variable	R^2	p-value
HF %C	0.28	0.04
LF %C	0.15	0.15
HF %N	0.6	0.0007
LF %N	0.22	0.08

Table 15: ANOVA work with agricultural consultants

indicates a significant correlation between farmers that work with agricultural consultants and high fertility sites and the percent of carbon and nitrogen. Noteworthy correlations were also found for low fertility sites of the same measurements.

Variable	R^2	p-value
HF BD	0.32	0.03
LF BD	0.56	0.001
HF %C	0.78	<0.0001
LF %C	0.86	<0.0001
HF %N	0.31	0.03
LF %N	0.66	0.0002

Table 16: ANOVA dream farm description: Fewer or no chemicals

Areas highlighted in green have a highly significant probability of a relationship between farmers that would use fewer or no chemicals in their dream farm description